माधव प्रौद्योगिकी एवं विज्ञान संस्थान, ग्वालियर (म.प्र.), भारत
MADHAV INSTITUTE OF TECHNOLOGY & SCIENCE, GWALIOR (M.P.), INDIA
Deemed to be University
(Declared under Distinct Category by Ministry of Education, Government of India)
NAAC ACCREDITED WITH A++ GRADE

MULTIDISCIPLINARY INNOVATIONS IN TECHNOLOGY AND SCIENCE JOURNAL

MITS JOURNAL

Editor-in-Chief
Dr. Manjaree Pandit
Dean Academics & Professor
MITS | Gwalior | M.P. | India - 474005

Volume 01 || April 2024

MITS Journal Paper Submission

Dr. Manjaree Pandit
Editor-in-Chief, MITS JOURNAL
Dean Academics & Professor,
Department of Electrical Engineering,
MITS Gwalior

Message from Editor-in-Chief

Dear Esteemed Readers,

I am delighted to extend a warm welcome to the Multidisciplinary Innovations in Technology and Science Journal, hosted by Madhav Institute of Technology and Science. As the Chief Editor of this esteemed journal, it brings me great pleasure to introduce this compilation—a testament to the collective brilliance, dedication, and innovation of our global academic community.

Our journal serves as a beacon of interdisciplinary collaboration, where scholars from diverse fields converge to explore the frontiers of knowledge and chart new pathways for the future. Within the pages of this publication, you will discover a treasure trove of insights, discoveries, and perspectives spanning a myriad of disciplines, from artificial intelligence to sustainable engineering.

This journal transcends the traditional academic publication—it is a celebration of curiosity, creativity, and the relentless pursuit of excellence. It underscores the transformative power of collaboration as we unite to address the most pressing challenges facing our world today. I extend my deepest gratitude to all the contributors, reviewers, and editorial team members who have dedicated their time and expertise to make this journal a resounding success. Your passion, intellect, and commitment inspire us all to push the boundaries of what is possible and strive for greater heights of achievement.

As you delve into the pages of this journal, may you be inspired, challenged, and enlightened by the wealth of knowledge and innovation on display. Let us seize this opportunity to forge new connections, spark meaningful conversations, and collectively shape a brighter future for generations to come.

Warm regards

Dr. M.K. Gaur
Editor, MITS JOURNAL
Head & Professor,
Department of Mechanical Engineering,
MITS Gwalior

Message from Editor

Dear Esteemed Readers,

It is with great pleasure and enthusiasm that I extend my warmest greetings to you as the Editor of the Multidisciplinary Innovations in Technology and Science Journal, hosted by Madhav Institute of Technology and Science (MITS).

Our journal serves as a platform for scholars, researchers, and innovators to share their latest findings, breakthroughs, and insights across a diverse range of disciplines. From cutting-edge developments in technology to groundbreaking discoveries in science, each publication within our journal reflects the collective efforts and ingenuity of our esteemed contributors. As Editor, it is my privilege to witness the exchange of knowledge and ideas that takes place within the pages of our journal. I am continually inspired by the passion, dedication, and intellectual curiosity of our authors, whose work contributes to the advancement of society and the betterment of humankind.

Thank you for being part of our journey towards multidisciplinary innovation and scientific excellence. Together, let us continue to push the boundaries of knowledge and shape a brighter future for generations to come.

Warm regards,

ASSOCIATE EDITORS

Dr. Trilok Pratap Singh
Associate Editor, MITS JOURNAL
Assistant Professor,
Department of Management,
MITS Gwalior

Dr. Saurabh Kumar Rajput
Associate Editor, MITS JOURNAL
Assistant Professor,
Centre for Internet of Things,
MITS Gwalior

Dr. Nikhil Paliwal
Associate Editor, MITS JOURNAL
Assistant Professor,
Department of Electrical Engineering,
MITS Gwalior

STUDENT EDITORS

Rajkumar Prasad
Student Editor, MITS JOURNAL
Department of Electrical Engineering,
MITS Gwalior

Nandini Thakur
Student Editor, MITS JOURNAL
Department of Electrical Engineering,
MITS Gwalior

Abhinav Tiwari
Student Editor, MITS JOURNAL
Department of Electrical Engineering,
MITS Gwalior

Deepansh Kulshrestha
Student Editor, MITS JOURNAL
Department of Electrical Engineering,
MITS Gwalior

Harshit Tiwari
Student Editor, MITS JOURNAL
Center for Internet of Things,
MITS Gwalior

CONTENT

A Study on Analysis of Solar Dryer using Computational Fluid Dynamics (CFD)

M.K. Gaur[1*], Pushpendra Singh[1], Vikas Kumar Thakur[1]

[1]Department of Mechanical Engineering, Madhav Institute of Technology & Science, Gwalior-474005
*Corresponding Author: gmanojkumar@rediffmail.com

Abstract: Solar dryer emerges as best eco-friendly method for drying or space heating purpose. Various researches had undergone in past to make the dryer more efficient in terms of drying time and less heat loss to the ambient. But still the researches are carried out to make it more efficient and compact. The application of software makes this easier. CFD is used to study the fluid flow inside the dryer so that the fluid dynamics inside the dryer can be better understood. The temperature variation and variation in flow velocity can be easily analyzed using CFD. The software (CFD) easily simulates the free stream flow of fluid and the interaction of fluid with other surfaces within the defined boundary conditions. The paper presents the previous studies on CFD analysis of solar dryer and also the procedure that can be adopted to carry out the CFD analysis of any system. This helps the readers in easily implementing the CFD for analysis of their developed systems.

Keywords: CFD, solar dryer, greenhouse, simulation, software

1 Introduction

The world population rises from 6 billion to 7.7 billion in last 20 years [1] and expected to reach 9.7 billion in 2050 [2]. With increase in population the quantity of food required to feed the people also increases. To produce the required quantity of food is not possible as agricultural land will also decreases with increasing population. So drying is the only method is to conserve the food materials [3]. Solar dryers are developed to dry the products especially the agricultural produce so that it can be stored for long duration.

Solar dryers are basically of three types namely direct, indirect and mixed mode on the basis of the way the dryer receives the solar radiation [4]. All the dryers operate on two modes only that are either on active or passive mode [5]. Hybrid dryers are developed to operate the dryer in off sunshine period as they uses some thermal energy storage material if operating on single source or operates using more than one sources like solar with biomass, LPG etc. [6].

The performance of dryers are still tried to improve by various researchers. Various modifications have been applied to the solar dryer like making north wall opaque for reducing heat loss [7], attaching flat plate collector to preheat the air before supplying to greenhouse chamber [8], using thermal storage materials to store the excess heat that can be utilized during nocturnal or off sunshine period [9], application of various software like CFD, ANSYS, TRNSYS, MATLAB, FORTRAN etc. to simulate the behavior of drying, using soft computing techniques like fuzzy logic, neural network and others to optimize the required variable affecting the drying etc. [10]. Fig. 1 shows the some modifications carried out by researchers.

The paper presents the application of computational fluid dynamics on solar dryers so as to simulate the drying parameters basically the air flow rate and the temperature at several points. This helps in detecting the points where the losses are occurring and helps in improving the performance of dryer.

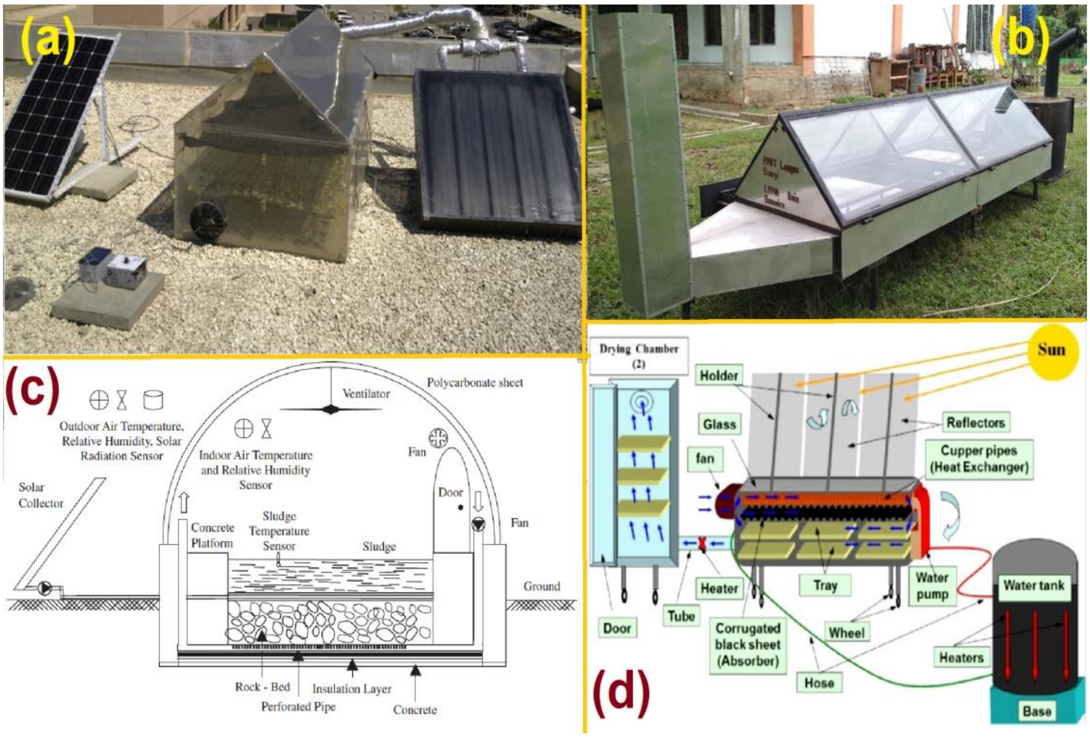


Fig. 1. Modification on Greenhouse to improve its performance [11]–[14]

2 CFD Analysis of Solar Dryer

CFD is the tool to carry out the analysis of fluid flowing inside the solar dryers. The pattern in which the temperature of fluid is varying inside the dryer can be determined and also the variation in air flow rate and velocity can be simulated [15]. The CFD analysis helps in predicting the variations in temperature and air flow rate of fluid in advance without performing the experiment. The results obtained from simulation can be used to minimize the heat loss occurring from the dryer by detecting the points where the temperature and air flow rate is not as per the requirement. The steps involved in carrying out the CFD analysis of any system are shown in Fig. 2 by means of flow chart. The simulation is carried out by using equations of energy, momentum and heat and mass transfer [16].

In solar dryers, CFD simulation of heat and mass transfer taking place inside drying chamber can be carried out by solving three dimensional mass momentum and energy equations. The solution of these governing equations are obtained by applying the boundary conditions and selecting the kind of flow taking place whether it is transient, laminar or turbulent flow. For incompressible flow, the partial differential equations of the governing equations are given by Eq. 1 to Eq.3. [17], [18]

Continuity Equation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \bar{u}) = 0 \tag{1}$$

Energy Equation

$$\frac{\partial (\rho E)}{\partial t} + \nabla \cdot \left(\bar{u}(\rho E + P)\right) = \nabla \cdot \left[\lambda_{eff} \nabla T - \sum_j H_j J_j + \left(\bar{\tau}_{eff} \bar{u}\right)\right] \tag{2}$$

Momentum Equation

$$\frac{\partial (\rho \bar{u})}{\partial t} + \nabla \cdot (\rho \bar{u} \bar{u}) = -\nabla P + \nabla\left(\bar{\tau}_{eff}\right) + \rho g \beta (\bar{T}_0 - \bar{T}) \tag{3}$$

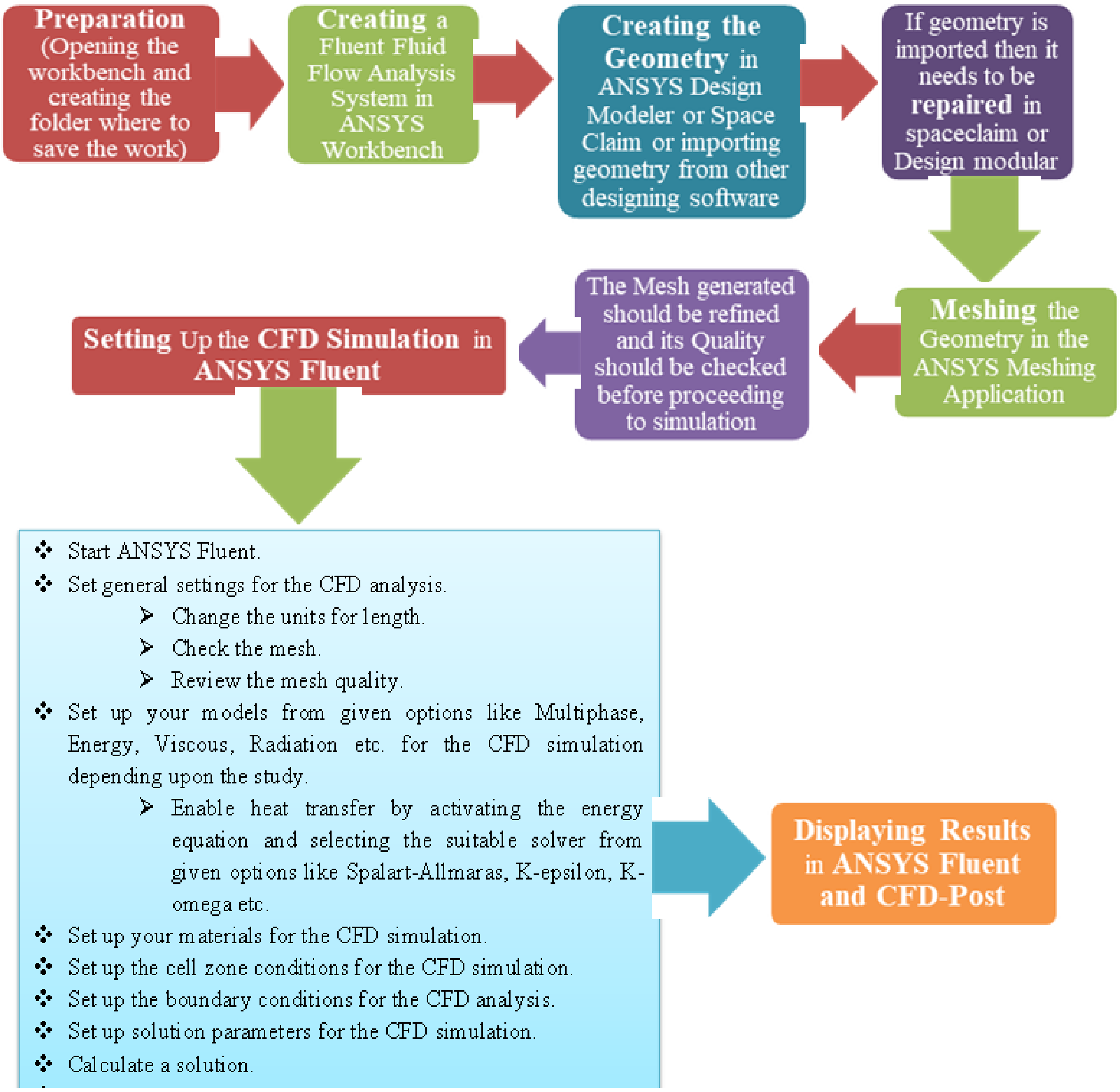


Fig. 2. Steps involved in CFD simulation of any system

Mathioulakis et al. carried out the simulation of industrial tray dryer for drying fruits. Simulation was carried out by considering three boundary conditions namely no-resistance, assuming wall shear stress and fixed mass inflow. CFD Fluent was used to optimize the drying process in each tray. The result obtained from CFD and experimentation showed the good correlation [19].

Bartzanas et al. studied the effect of vent provided for air circulation in a tunnel type greenhouse dryer. CFD Fluent V.5.3.18 software was used to determine the effect of ventilation through airflow and temperature distribution pattern. 3-D sonic anemometer was used to record the airflow variation and tracer gas method was used to record the ventilation flow rate. The average air velocity varies from 0.2 to 0.7 m/s inside the drying chamber. The CFD analysis helps in placing the ventilation holes for proper circulation of air [20].

Sonthikun et al. carried out the CFD analysis of biomass integrated hybrid dryer constructed for drying natural rubber sheets. CFD analysis gives slightly more value of temperature than experimental values due to non-consideration of moisture transport occurring inside dryer. The k-ϵ turbulent model was used to simulate the flow of air. The value of R2 was 0.98 which shows the closeness in experimental and predicted values. The path lines of air flow obtained through CFD analysis is shown by Fig. 3.

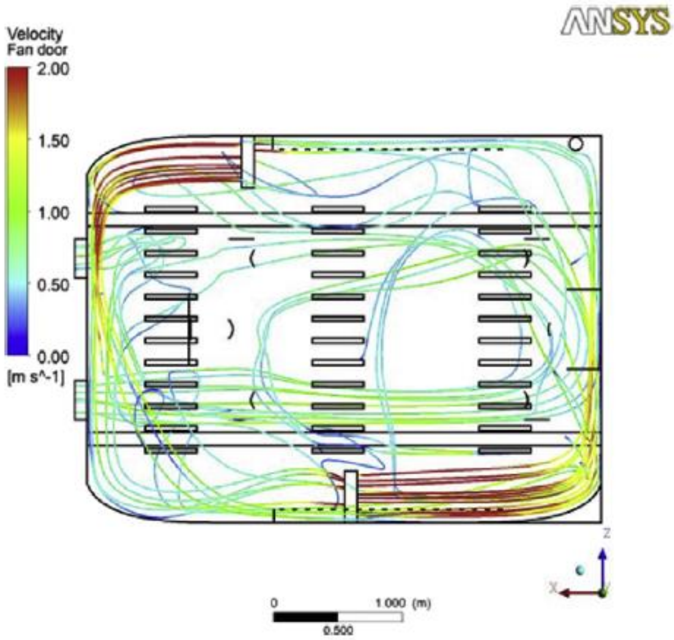


Fig. 3. Air flow rate distribution inside dryer [17]

Chen et al. used the CFD software for analyzing the photo-catalytic solar dryer. For analysis of fluid flowing inside the dryer, Reynolds-averaged equation of continuity and momentum was used. Turbulence intensity was considered 10% for inlet stream and at walls; no-slip boundary conditions were used. To achieve better result, the meshing of geometry was done using hexahedral shaped 600,000 cells. SIMPLE algorithm was used to solve the difference equation of pressure-velocity coupling of N-S equation [16].

Krawczyk and Badyda applied CFD analysis in greenhouse active dryer constructed for drying sludge. Unsteady state condition was used due to thermodynamic characteristic of sludge and conditions affecting the drying. As the CFD package is not able to give the good result with its predefined control parameters so the user defined functions (UDF) were developed using C language to adopt variable material properties, boundary conditions and initialization parameters. To get better result, the fine grid is suggested to use at the boundary[21].

Amjad et al. developed the batch type dryer for drying potatoes slices. The ANSYS-Fluent analysis was carried out to simulate air flow inside the dryer. The k-ϵ turbulence model was used along with steady state condition and considering air inlet velocity as 5m/s. The correlation coefficient between experimental and simulated result was 87.09%, which can be considered as good correlation [22].

Demissie P. et al. carried out the CFD analysis of indirect rack type solar dryer. ANSYS Fluent 18.1 was used to predict the variation in temperature and air flow rate. The mean value of air flow rate was predicted 0.14 m/s for the lower shelve while for other three selves it was 0.12 m/s and the maximum temperature inside the drying chamber was predicted as 320K. The maximum difference between the experimental and simulated temperature value was 4.3°C [23]. The temperature distribution inside the dryer using CFD analysis is shown by Fig. 4.

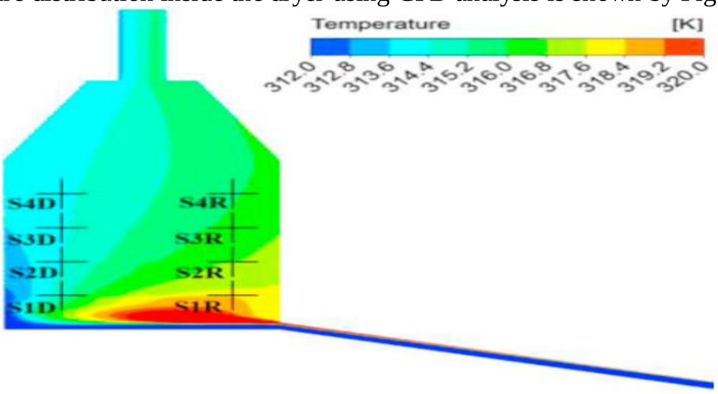


Fig. 4. Temperature distribution inside dryer [23]

3 Conclusions

The solar drying technique is the very oldest technique of drying crops. Due to certain limitations of drying in open sun, solar dryers were developed. Various modifications have been done till now to improve the efficiency of dryer so as to reduce the heat losses and reducing the drying time keeping the nutritious value unaffected. CFD analysis helps in predicting the points from where the heat losses are taking place. The CFD analysis also helps in locating the position of chimney or ventilation holes by air flow variation analysis. The important things that are necessary to be considered for getting good result are:

Generating mesh as fine as possible, keeping hardware limitation and analysis time in mind.

Finer mesh at boundaries gives better result at surface.

Mostly k-ϵ turbulent model is used by the researchers but other models are also available.

Developing UDF gives the more realistic result as it can consider the entire possible phenomenon occurring inside the dryer which is usually not provided in ANSYS Fluent package.

4 References

1. M. Roser, H. Ritchie, and E. Ortiz-Ospina, "World Population Growth," OurWorldInData.org, 2019. [Online]. Available: https://ourworldindata.org/world-population-growth.
2. M. Roser, "Future Population Growth," OurWorldInData.org, 2019. [Online]. Available: https://ourworldindata.org/future-population-growth.
3. A. Kumar and G. N. Tiwari, "Effect of mass on convective mass transfer coefficient during open sun and greenhouse drying of onion flakes," J. Food Eng., vol. 79, no. 4, pp. 1337–1350, 2007.
4. O. Prakash, A. Kumar, and Y. I. Sharaf-Eldeen, "Review on Indian Solar Drying Status," Curr. Sustain. Renew. Energy Reports, vol. 3, no. 3–4, pp. 113–120, 2016.
5. P. Singh, V. Shrivastava, and A. Kumar, "Recent developments in greenhouse solar drying: A review," Renew. Sustain. Energy Rev., 2017.
6. H. El Hage, A. Herez, M. Ramadan, H. Bazzi, and M. Khaled, "An investigation on solar drying: A review with economic and environmental assessment," Energy, vol. 157, pp. 815–829, 2018.
7. O. Prakash, A. Kumar, and V. Laguri, "Performance of modified greenhouse dryer with thermal energy storage," Energy Reports, vol. 2, pp. 155–162, 2016.
8. E. A. Mewa, M. W. Okoth, C. N. Kunyanga, and M. N. Rugiri, "Experimental evaluation of beef drying kinetics in a solar tunnel dryer," Renew. Energy, vol. 139, pp. 235–241, Aug. 2019.
9. G. Akmak and C. Yildiz, "The drying kinetics of seeded grape in solar dryer with PCM-based solar integrated collector," Food Bioprod. Process., vol. 89, no. 2, pp. 103–108, Apr. 2011.
10. O. Prakash, S. Ranjan, A. Kumar, and P. P. Tripathy, "Applications of Soft Computing in Solar Drying Systems," in Solar Drying Technology, O. Prakash and A. Kumar, Eds. Springer Nature Singapore Pte Ltd., 2017, pp. 419–438.
11. N. Kamil Salihoglu, V. Pinarli, and G. Salihoglu, "Solar drying in sludge management in Turkey," Renew. Energy, vol. 32, no. 10, pp. 1661–1675, 2007.
12. B. M. A. Amer, K. Gottschalk, and M. A. Hossain, "Integrated hybrid solar drying system and its drying kinetics of chamomile," Renew. Energy, vol. 121, pp. 539–547, Jun. 2018.
13. Hamdani, T. A. Rizal, and Z. Muhammad, "Fabrication and testing of hybrid solar-biomass dryer for drying fish," Case Stud. Therm. Eng., vol. 12, pp. 489–496, Sep. 2018.
14. M. A. Eltawil, M. M. Azam, and A. O. Alghannam, "Solar PV powered mixed-mode tunnel dryer for drying potato chips," Renew. Energy, vol. 116, pp. 594–605, 2018.
15. P. Singh Chauhan, A. Kumar, and P. Tekasakul, "Applications of software in solar drying systems: A review," Renew. Sustain. Energy Rev., vol. 51, pp. 1326–1337, Aug. 2015.
16. H. H. Chen, T. C. Huang, C. H. Tsai, and A. Mujumdar, "Development and performance analysis of a new solar energy-assisted photocatalytic dryer," Dry. Technol., vol. 26, no. 4, pp. 503–507, 2008.
17. S. Sonthikun, P. Chairat, K. Fardsin, P. Kirirat, A. Kumar, and P. Tekasakul, "Computational fluid dynamic analysis of innovative design of solar-biomass hybrid dryer: An experimental validation," Renew. Energy, vol. 92, pp. 185–191, Jul. 2016.
18. P. Tekasakul, R. Dejchanchaiwong, Y. Tirawanichakul, and S. Tirawanichakul, "Three-Dimensional Numerical Modeling of Heat and Moisture Transfer in Natural Rubber Sheet Drying Process," Dry. Technol., vol. 33, no. 9, pp. 1124–1137, 2015.
19. E. Mathioulakis, V. T. Karathanos, and V. . G. Belessiotis, "Simulation of Air Movement in a Dryer by Computational Fluid Dynamics : Application for the Drying of Fruits," J. Food Eng., vol. 36, pp. 183–200, 1998.
20. T. Bartzanas, T. Boulard, and C. Kittas, "Effect of vent arrangement on windward ventilation of a tunnel greenhouse," Biosyst. Eng., vol. 88, no. 4, pp. 479–490, 2004.
21. P. Krawczyk and K. Badyda, "Two-dimensional CFD modeling of the heat and mass transfer process during sewage sludge drying in a solar dryer," Arch. Thermodyn., vol. 32, no. 4, pp. 3–16, 2011.

22. W. Amjad, A. Munir, A. Esper, and O. Hensel, "Spatial homogeneity of drying in a batch type food dryer with diagonal air flow design," J. Food Eng., vol. 144, pp. 148–155, 2015.
23. P. Demissie, M. Hayelom, A. Kassaye, A. Hailesilassie, M. Gebrehiwot, and M. Vanierschot, "Design, development and CFD modeling of indirect solar food dryer," in Energy Procedia, 2019, vol. 158, pp. 1128–1134.

Advanced Energy Storage Technologies: Comparison, and Selection for Various Applications

Aniket Pippal [1], Rakesh Narvey [2], Himmat Singh [3]
[1, 2, 3] Department of Electrical Engineering, MITS, Gwalior

Abstract. The field of energy storage technologies has seen significant advancementsin response to the growing demand for efficient and sustainable energy solutions. This researchpaper offers a comprehensive overview and comparison of advanced energy storage technologies across mechanical, electrical, chemical, and thermal domains. We explore established technologies like Pumped Hydro Energy Storage (PHES), Compressed Air EnergyStorage (CAES), and Lithium-ion (Li-ion) batteries, as well as emerging technologies such as Super Capacitors and Sodium Sulfur batteries. Additionally, we highlight promising future storage technologies like Compressed CO_2, Nano Diamond batteries, and Metal-Air Batteries. We present a detailed comparison table evaluating these technologies based on key factors, including energy density, efficiency, cycle life, cost, environmental impact, and other significant considerations. Our research employs a weighted product model to select the most suitable energy storage technology for specific applications, offering valuable insights to decision-makers in choosing appropriate energy storage technologies for their intended use.

Keywords: advanced energy storage technologies, batteries, multi criteria decision making,selection methodology, weighted product model.

1 INTRODUCTION

The increasing global demand for clean and sustainable energy solutions, coupled with the urgent need to address climate change, has set ambitious goals for achieving carbon neutrality by 2050. To achieve this goal, a fundamental transformation of energy systems is required, with a strong emphasis on renewable energy sources and energy efficiency [1, 2]. As renewable energy generation expands rapidly, the integration of these intermittent sources into the grid becomes a crucial challenge.

Throughout history, the demand for energy has steadily grown as technological advancements and industrialization took place [3-6]. Non-renewable sources such as oil, petroleum, and natural gas were predominantly used to meet energy needs, but their finite nature and environmental impacts have necessitated a shift towards cleaner and renewable energy resources [2, 7]. The continuous growth of the global economy and energy consumptionhas led to increased CO_2 emissions, contributing to global warming, ocean acidification, smogpollution, ozone depletion, and changes in plant growth and nutrition levels [1].

Renewable energy sources like solar and wind power are less environmentally harmful and inexhaustible. However, their unpredictability and lack of control pose challenges [7]. These sources have significant potential to provide electricity in an environmentally friendly manner, but their intermittent and non-dispatchable nature inhibits their widespread adoption [1]. Therefore, one of the major challenges today is to match the available energy with the demand in terms of timing, location, and quantity.

Energy storage plays a crucial role in facilitating this adoption by ensuring a consistent and high-quality electricity supply from renewable energy systems. Furthermore, energy demand is not uniform throughout the day or year, but rather varies significantly within a day and across seasons due to individual needs and climatic effects. This necessitates energy storage. When electrical energy is produced in excess of demand, it must be stored; otherwise, it goes to waste and increases the cost per unit of electricity. Additionally, there are situations where electricity generation exceeds the total demand during off-peak hours, requiring the urgent storage of excess electricity. Energy storage helps maintain a balance between supply (generation) and demand (consumer use), prevents electrical fluctuations, reduces brownouts during peak demand, minimizes environmental pollution, and enhances the efficiency of the electric grid. It stabilizes grid power and improves the overall efficiency of the grid system. Energy storage is a vital mechanism for reliable electricity supply, increased security and economic value, and reduced carbon dioxide emissions [3].

Storing electricity is a complex task that requires specialized devices and mechanisms. Researchers and technologists are continuously improving and innovating in this area. However, selecting the appropriate storage technology remains a significant concern. Currently, considerable effort is being directed towards various battery technologies for energystorage. It is important to note that there is no perfect battery that suits every application. The selection of the right battery for a specific application involves weighing important battery metrics against each other [8]. For example, if an application requires a high-power output, theinternal cell resistance should be minimized, often achieved by increasing the electrode surfacearea in electrochemical batteries. However, this also results in increased inactive components such as current collectors and conductive aid, leading to a trade-off between energy density and power. When it comes to actual battery performance, it may be necessary to compromise certain design goals to achieve others.

This research paper aims to provide a comprehensive comparison and selection framework for energy storage technologies. It will evaluate a range of storage technologies, including mechanical, electrical, chemical, thermal, and electrochemical systems. Various factors such as energy density, efficiency, cycle life, cost, and environmental impact will be assessed to determine their suitability for different applications. Furthermore, the research willapply a weighted product model derived from operational research techniques to compare andselect the most suitable energy storage technologies for specific applications. By considering different weighting factors based on the goals and requirements of each application, the research aims to identify the optimal technology choice for maximizing performance and efficiency. The findings of this study will contribute to the advancement of energy storage technologies and provide valuable insights for policymakers, industry professionals, andresearchers working towards a sustainable and carbon-neutral energy future. By facilitating theadoption of suitable energy storage solutions, we can accelerate the transition towards a more resilient and environmentally friendly energy system.

2 OVERVIEW OF MAJOR ENERGY STORAGE TECHNOLOGIES

2.1 Mechanical Storage

Pumped Hydro Energy Storage (PHES).

Pumped hydro energy storage systems are the most widely used form of energy storage in power networks, serving various purposes including energy management, frequency regulation, and providing reserve capacity [9]. In the conventional setup of pumped hydroelectric systems, two water reservoirs are positioned at different elevations. The process involves the storage of energy by transferring water from a lower reservoir to a higher one, thereby capturing gravitational potential energy. Typically, surplus electricity, often obtained at a lower cost during off-peak periods, powers the pumps. When electricity demand surges, the accumulated water is released through turbines to generate electricity [6].

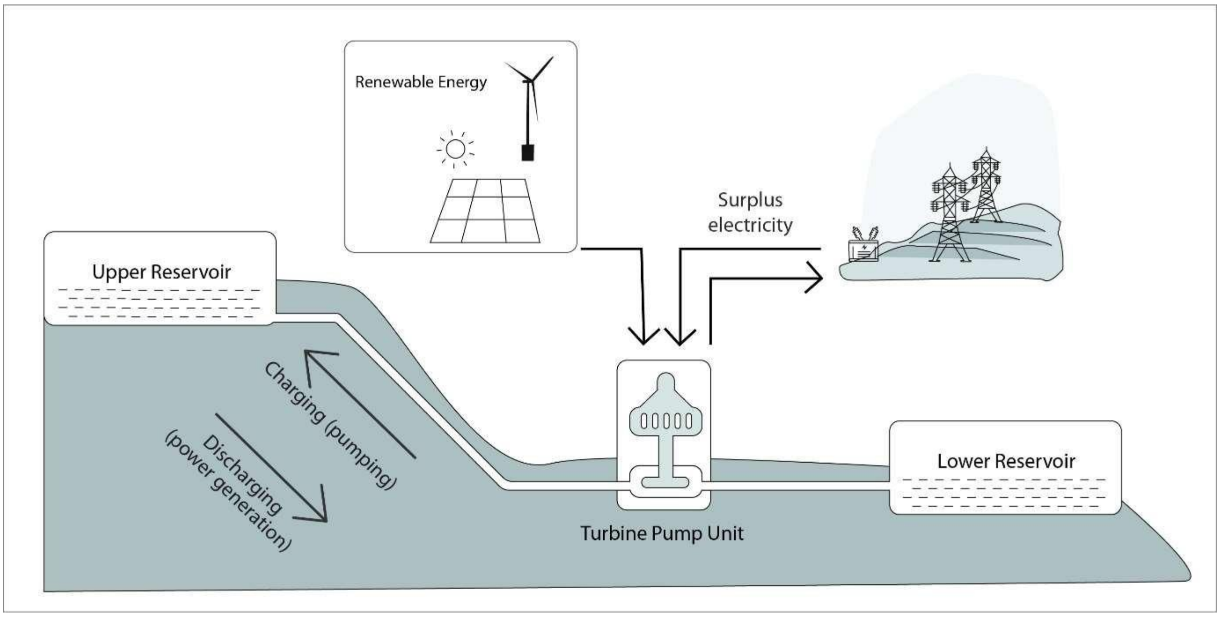


Fig. 5. Pumped Hydro Energy Storage System

The PHES system is an adaptation of conventional hydroelectric power plants with reversed functionality. Unlike conventional hydroelectric power plants, which use a single reservoir to store water and convert gravitational potential energy into electrical energy, PHESutilizes two vertically positioned reservoirs and a turbine/pumping station. Water from the upper reservoir is released through a generator turbine to generate electricity and is then stored in the lower reservoir. During periods of low demand, the water is pumped from the lower reservoir back to the upper reservoir using the turbine/pumping station. This stored water can be reused multiple times, increasing system efficiency [1].

The primary drawback of PHES is the need for specific site conditions, including suitable geographical height and water availability. Consequently, suitable sites are often foundin hilly or mountainous regions, which may also be areas of natural beauty, giving rise to potential social and ecological concerns. To address these issues, many proposed projects nowaim to avoid highly sensitive or scenic areas, with some considering "brownfield" locations such as disused mines.

Another variant of PHES involves seawater reservoirs. In this configuration, a hollow sphere submerged at significant depths serves as the lower reservoir, while the enclosing bodyof water acts as the upper reservoir [10]. Electricity is generated when water is allowed into the sphere through a reversible turbine integrated into the structure. This configuration offers advantages such as not requiring land area or large mechanical structures. Furthermore, in theevent of a reservoir collapse, the consequences would be limited to the loss of the reservoir itself. Additionally, evaporation from the upper reservoir has no impact on the energy conversion efficiency.

Compressed Air Energy Storage (CAES).

Compressed Air Energy Storage (CAES) is an energy storage technology that functions by compressing air, with the amount of stored energy dependent on variables including the storage container's volume, as well as the pressure and temperature conditions under which the air is stored. CAES was developed as an alternative to Pumped Hydro Energy Storage (PHES) to address challenges associated with the specific geological prerequisites of PHES and the resulting environmental concerns. CAES has gained prominence as a promising energy storage method due to its strong reliability, economic viability, and minimal environmental footprint.

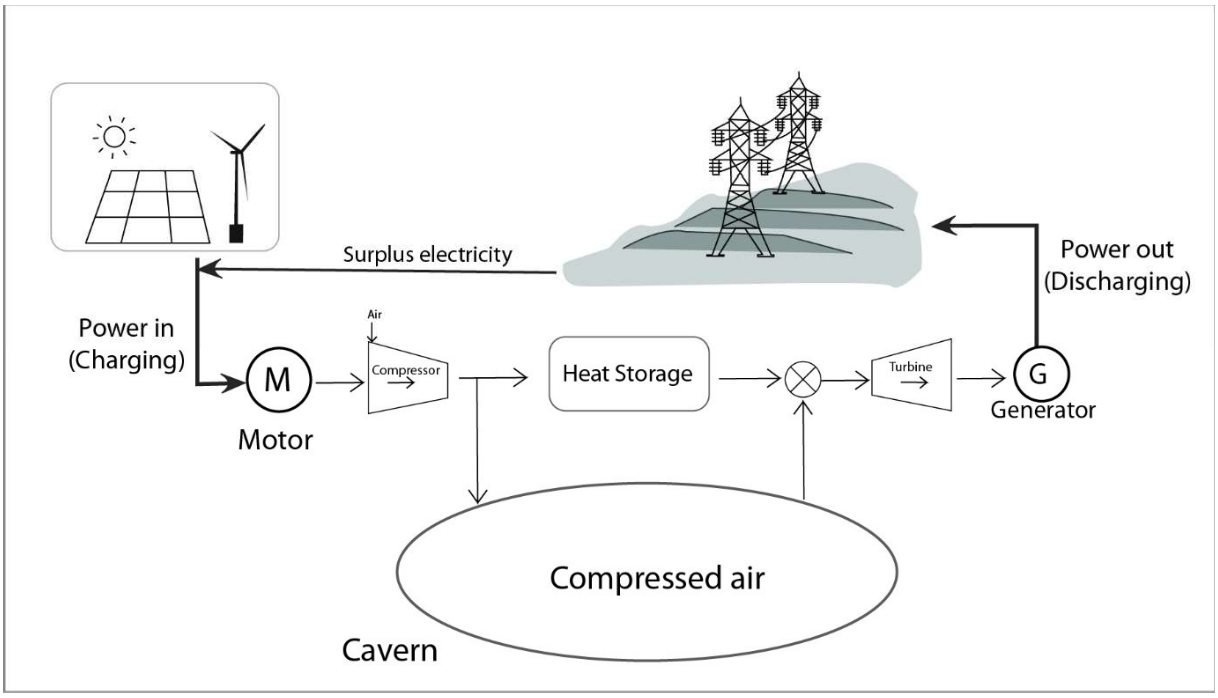


Fig. 6. Compressed Air Energy Storage System

A typical CAES system encompasses five key components: a motor for propelling a compressor, a multi-stage compressor for air compression, a storage container or cavity (which can take the form of underground caverns or porous reservoirs) for holding the compressed air, a turbine assembly comprising high and low-pressure turbines, and a generator for converting mechanical energy back into electrical energy for the grid.

During periods of reduced electricity demand, excess power is utilized to operate the motor, generating mechanical energy to drive the compressor. The compressor elevates the pressure of ambient air, which is subsequently stored in the subterranean cavern. When electricity demand surges, the compressed air from the cavern propels the pressure turbines. These turbines transform the compressed air's energy into mechanical energy, subsequently driving the generator to generate electricity [6]. Recent advancements in CAES involve the utilization of CO_2 gas as a substitute for air, presenting noteworthy advantages.

Flywheel Energy Storage (FES).

The Flywheel Energy Storage (FES) system is a mechanical energy storage device that accumulates energy in the form of rotational energy by harnessing the kinetic energy of a large rotating cylinder.

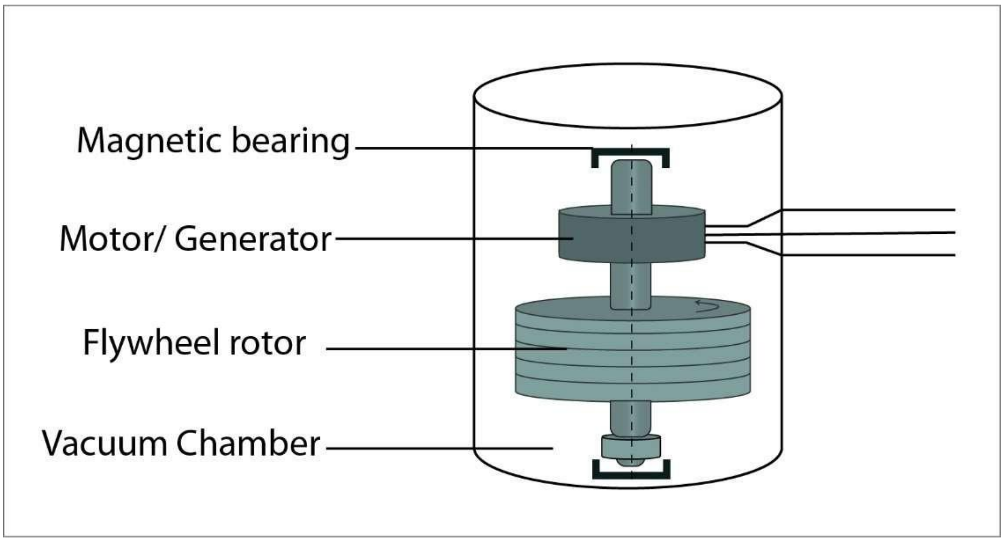


Fig. 7. Flywheel Energy Storage

A contemporary flywheel system comprises five fundamental components: a flywheel, magnetic bearings, an electrical motor/generator, a power conditioning unit, and a vacuum chamber. During the charging phase, the integrated reversible electrical machine operates as a motor. It draws electrical power from the grid to spin the flywheel system at high speeds, thus storing kinetic energy. When the system enters the discharging phase and the rotor slows down, the reversible machine functions as a generator. It converts the stored kinetic energy within the flywheel back into electrical energy. In this way, the FES system employs electricity to accelerate or decelerate the flywheel, facilitating the transfer of stored kinetic energy to or from the flywheel through the integrated motor/generator [6].

Flywheel energy storage offers benefits such as high energy and power density, extended cycle life, rapid response, and efficient energy conversion (90%–95%). It provides quick discharge for immediate energy supply. However, drawbacks include high self-dischargerates, limited storage capacity, and relatively high capital costs [3,7,11].

2.2 Electrical Storage

Super Capacitors.

Super capacitors, also referred to as electric double-layer capacitors (EDLC) comprise two conductor electrodes, an electrolyte, and a separator. They store energy by establishing an electrostatic field via a continuous direct current voltage applied between the two electrodes, which are divided by a slender insulator or dielectric material. The electrodes, commonly constructed from activated carbon, possess an extensive surface area, leading to increased energy density. A porous membrane separates the electrodes, enabling charged ions to move unimpeded while preventing direct contact [6].

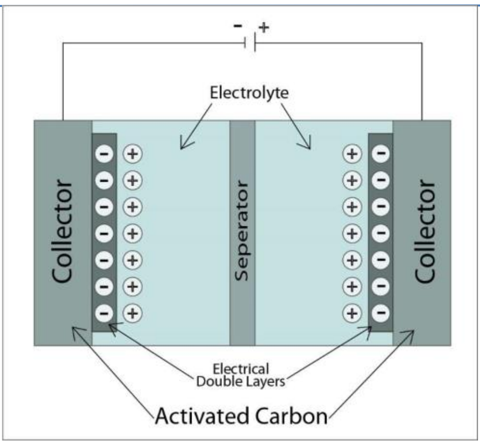


Fig. 8. Super Capacitor

Super capacitors possess structural characteristics that fall between batteries and capacitors. Similar to batteries, they consist of two electrodes separated by a porous medium and store energy within an electrostatic field. However, super capacitors exhibit significantly higher capacitance values, often in the range of thousands of farads, and have the capability tocharge and discharge rapidly due to their exceptionally low internal resistance [12]. They alsooffer advantages such as durability, reliability, maintenance-free operation, an extended lifespan, and the ability to operate effectively across a broad temperature range. The lifespan of super capacitors exceeds one million cycles without degradation, except for the chemicals used within capacitors, which degrade over time regardless of the cycle count. Moreover, supercapacitors demonstrate high efficiency, frequently exceeding 90%, and can discharge over durations ranging from seconds to hours.

Nevertheless, super capacitors are not well-suited for long-term energy storage due to their high self-discharge rate, relatively low energy density, and substantial initial investment requirements. However, they excel as uninterruptible power supplies (UPS) for addressing minor power disruptions. In the context of electric vehicles, super capacitors can serve as a buffer system for acceleration and regenerative braking, offering unique applications within this field [4].

Super magnetic energy storage (SMES).

Superconducting Magnetic Energy Storage (SMES) is an advanced energy storage technology that leverages the unique properties of superconductors to store and releaseelectricity efficiently. By using superconducting materials to create strong magnetic fields, SMES systems can store electrical energy as a magnetic field and later convert it back into electrical energy when needed.

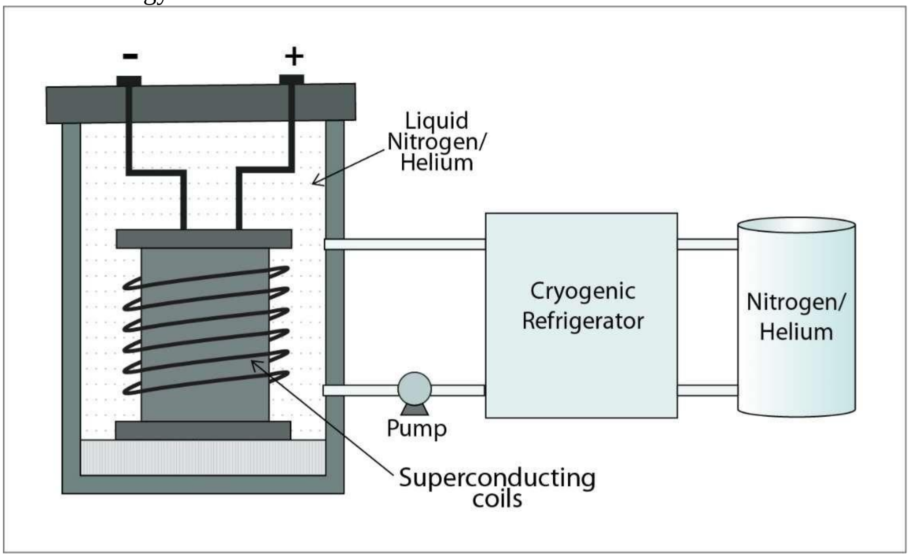


Fig. 9. Super Conducting Magnetic Energy Storage

In the SMES system, direct current (DC) is generated within superconducting coils constructed using niobium-titanium (NbTi) filaments, which exhibit no resistance to the flow of electric current. The absence of resistive losses in superconducting coils ensures that the SMES system achieves an overall efficiency exceeding 95%.

When compared to other storage systems, the SMES system boasts a high-power density and an exceptionally short response time, typically in the range of a few milliseconds.Furthermore, it offers extended cycling time and a longer lifespan, and through the implementation of distributed SMES (DSMES), it enables independent control of reactive andreal power.

Nevertheless, the SMES system is not without its inherent drawbacks. Its energy density, both volumetric and gravimetric, is relatively low. Additionally, the introduction of mechanical stress can lead to material fatigue, and the overall cost is a significant consideration.Despite these limitations, the SMES system exhibits remarkable potential in applications suchas load levelling, reduction of intermittency, and peak shaving due to its exceptional efficiency and minimal response time [1].

2.3 Chemical Storage.

Chemical storage systems harness the principles of endothermic and exothermic chemical reactions. Endothermic reactions require an input of energy to build high-energy chemical bonds, while exothermic reactions release energy, resulting in the formation of lower- energy products. By leveraging these reactions, energy storage systems can store electricity and heat within the bonds of chemical compounds, comprising atoms and molecules, which can be tapped into for future energy supply. Chemical energy storage (CES) systems encompass various technologies such as hydrogen storage, synthetic natural gas, and solar fuel storage.

While CES systems generally exhibit lower overall efficiency compared to pumped hydroelectric storage (PHS) and lithium-ion storage technologies, they offer greater cost efficiency and effectiveness compared to conventional batteries. These systems provide a viable means of storing energy on a large scale and for extended durations, enabling the reliablesupply of energy when needed.

2.3.1. Hydrogen energy storage system.

Hydrogen is widely recognized as an excellent energy carrier due to its cleanliness and carbon-free nature, making it a zero-emission chemical energy carrier. It can be produced through a process called electrolysis, using a hydrogen generation unit like an electrolyzer, which converts electrical energy into hydrogen.

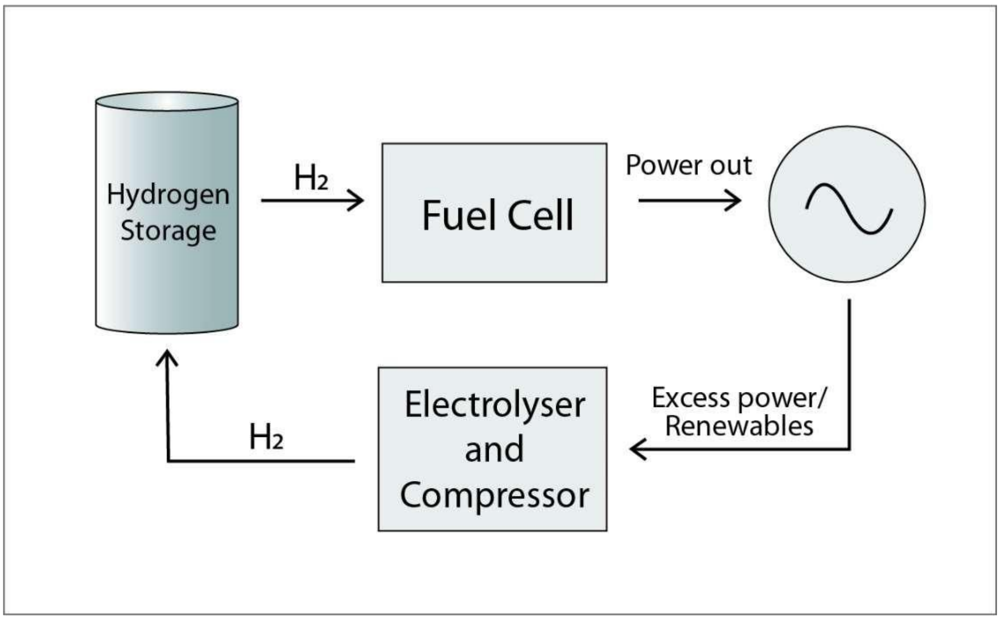


Fig. 10. Hydrogen Energy Storage System

In a standard hydrogen energy system, there are three primary components: a hydrogengeneration unit, such as an electrolyzer, responsible for converting electrical energy into hydrogen; a hydrogen storage system; and a hydrogen energy conversion unit, such as a fuel cell, which transforms the stored chemical energy in the hydrogen back into electrical energy.

During the charging process, when there is surplus power available, water is electrolyzed to produce hydrogen, which is then stored in a storage tank. During peak hours orwhen power availability is limited, the stored hydrogen is used to generate electricity through fuel cells. The electrolyzer utilizes electrolysis to break down water into hydrogen and oxygen.The oxygen is released into the atmosphere, while the hydrogen is safely stored in a storage tank [6].

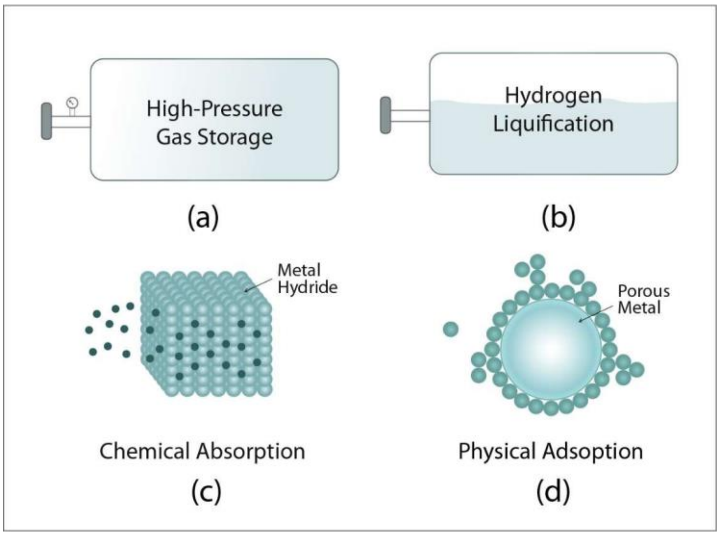


Fig. 11. Various Hydrogen Storage Techniques

Hydrogen needs to be either compressed into pressurized vessels or liquefied for storage. Additionally, nanotubes or solid metal hydrides can serve as storage units for hydrogenwith high density [13]. Recent research has focused on improving storage density through advancements in systems like Mg-Li-Al and Mg-Na-Al, which are used for solid-state hydrogen storage [6].

2.3.1.1. <u>Fuel Cell</u>

A fuel cell is a device that directly converts the chemical energy of a chemical reactioninto electrical energy, generating hydrogen and water as by-products. Its primary function is torestore the energy used in the production of hydrogen through the electrolysis of water. Fuel cells combine the best characteristics of engines and batteries. Under load conditions, they operate similar to batteries, while also resembling engines as long as fuel is available [1].

Fig. 12. Fuel Cell

A fuel cell consists of four key components: an anode, a cathode, an electrolyte, and an external circuit. At the anode, hydrogen is oxidized, splitting into protons (positively charged hydrogen ions) and electrons, which power the fuel cell. The positively charged hydrogen ions migrate through the electrolyte to the cathode. At the cathode, oxygen, hydrogen ions, and electrons combine, producing water and heat. During this process, the flow of electrons from the anode to the cathode through an external circuit leads to current flow and the production of electricity [6].

Fuel cells offer several advantages, including a long lifespan of approximately 15 years, high charging and discharging rates, and high energy density. Consequently, fuel cells are highly suitable for both small and large scale energy storage applications, such as peak shaving, load leveling, intermittency reduction, and demand-side management. They are also utilized indistributed power generation, where integration with the grid helps control voltage frequency and enhance power quality.

However, the widespread implementation of fuel cells faces challenges such as low round-trip efficiency, short life expectancy, and associated costs. Researchers are actively engaged in ongoing work to overcome these limitations and unlock the full potential of fuel cells [1].

2.4 Thermal Storage

Thermal storage systems play a vital role in capturing heat from diverse sources and storing it in insulated storage units for later utilization in industrial and residential applications.These systems serve as a bridge between the demand and supply of thermal energy, making them essential for the integration of renewable energy sources.

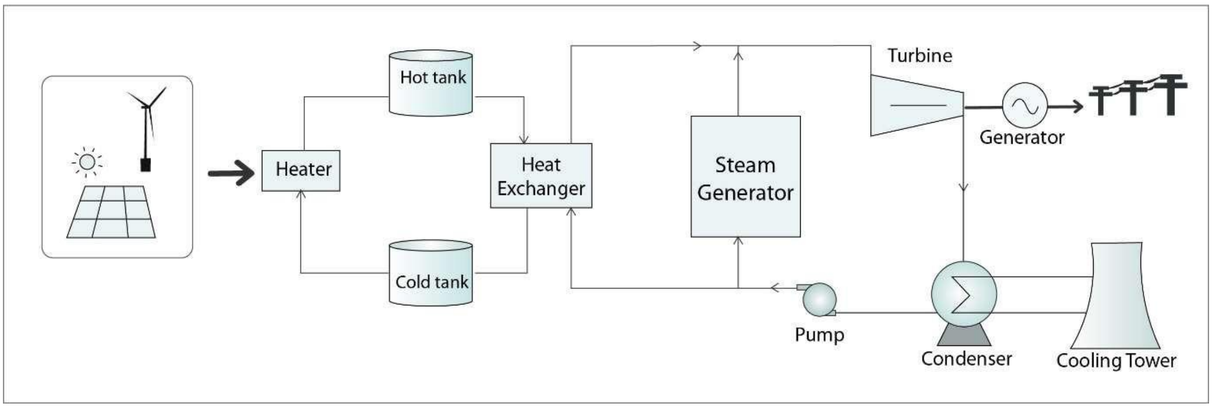


Fig. 13. Thermal Energy Storage System

Thermal storage can take three primary forms: sensible heat storage, latent heat storage,and thermo-chemical adsorption and absorption storage. The storage medium employed can beeither a liquid or a solid substance. In the context of thermal storage, energy is stored by alteringthe temperature of the storage medium. The capacity of a thermal storage system is determinedby the specific heat capacity and mass of the chosen medium [4].

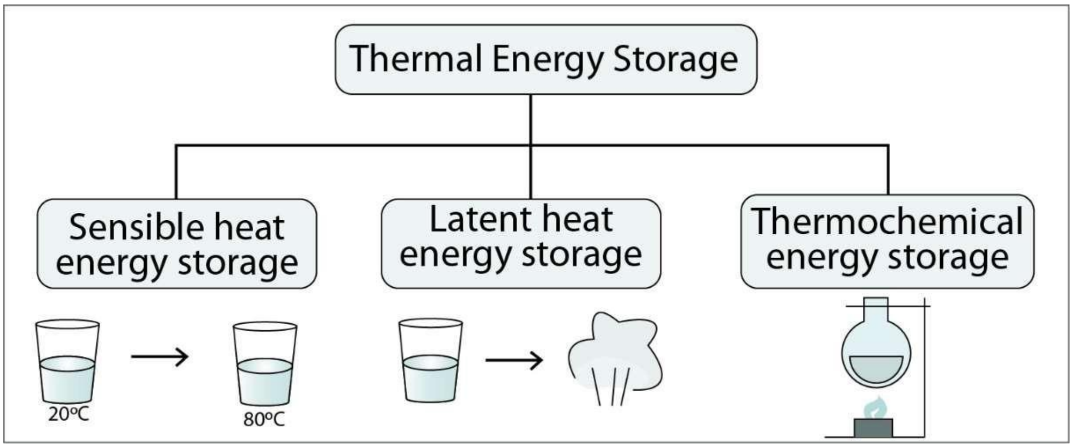


Fig. 14. Types of Thermal Energy Storage [6]

For latent heat storage, phase change materials (PCMs) are utilized as the storage medium. These PCMs can undergo a phase transition, such as melting or solidification, duringwhich they absorb or release significant amounts of energy. Organic PCMs, such as paraffin, and inorganic PCMs, such as salt hydrates, are commonly used options for such storage systems. Latent heat refers to the energy exchange that occurs during a phase transition, such as the melting of ice [4].

Thermochemical energy storage (TCES) is a method of storing thermal energy by utilizing chemical reactions. The fundamental principle of TCES involves starting with a chemical compound composed of two or more components. This compound is then broken down through the addition of heat, resulting in the separation of its constituent components. These components are stored separately until a demand for thermal energy arises. During periods of high demand, the components are combined again to reform the chemical compound,releasing heat in the process. The heat released from the reaction represents the stored energy capacity.

Unlike Sensible Heat Storage (SHS) and Latent Heat Storage (LHS), which are often limited in their duration due to heat losses, TCES offers the advantage of bridging longer periods between energy demand and supply. This characteristic makes TCES particularly well-suited for large-scale electricity generation, where the need for reliable and continuous powersupply is crucial [7]. By harnessing the potential of chemical reactions to store and release thermal energy, TCES provides a viable solution for managing energy fluctuations over extended periods. It enables the efficient utilization of excess energy during low-demand periods and allows for its subsequent retrieval when demand increases. TCES has the potentialto contribute significantly to the development of sustainable and resilient energy systems, particularly in the context of large-scale electricity generation.

2.5 Electrochemical Storage

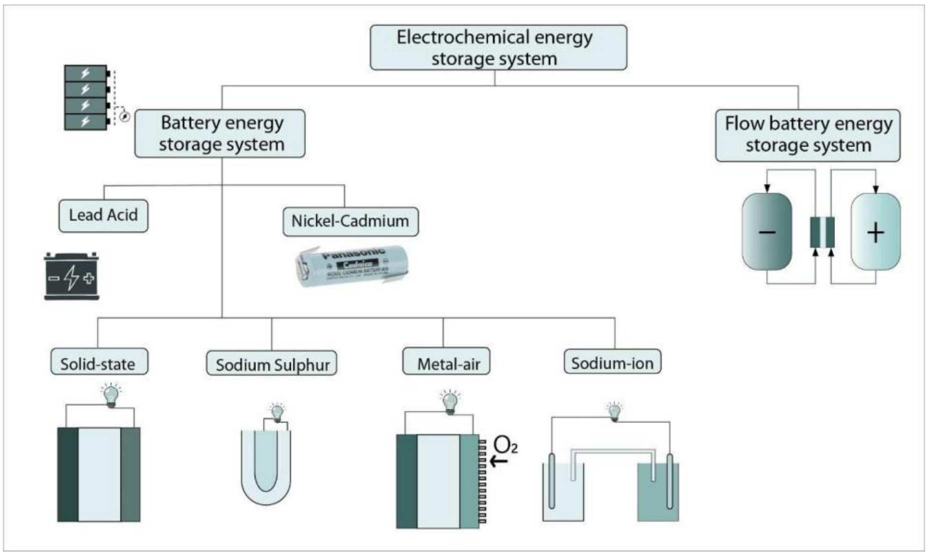
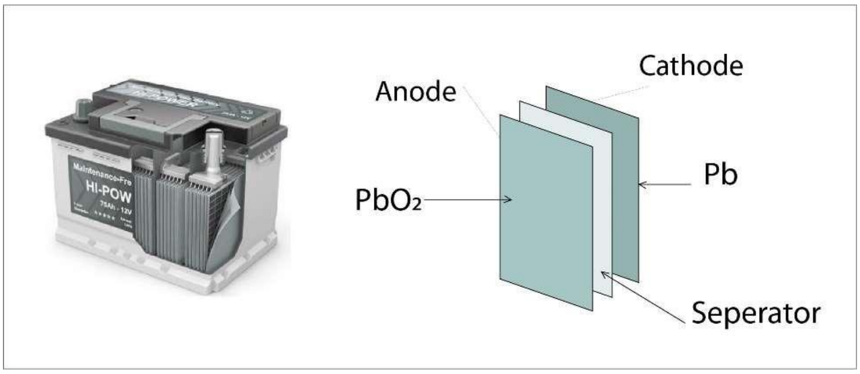


Fig. 15. Various Electrochemical Storage Systems [6]

Lead Acid Battery.

The lead acid battery stands as a pioneering breakthrough as the first practical rechargeable battery, with its revolutionary ability to charge through reverse current application [1]. Representing a mature and globally accepted technology, lead acid batteries have solidified



their reputation as a highly reliable energy storage solution.

Fig. 16. Lead Acid Battery

Constructed typically with lead oxide (PbO2) cathodes and lead (Pb) anodes immersed in electrolyte, lead acid batteries comprise interconnected cells. Commonly utilizing sulfuric acid (36%) and water (64%) as the electrolyte, these batteries facilitate energy storage through intricate chemical processes. During discharge, the lead in the negative plate dissolves into the electrolyte, releasing electrons that flow through the circuit to the positive plate. This results in a reduction of dissolved sulfuric acid in the electrolyte, eventually transforming it primarily into water. The discharge process leads to the plates becoming chemically similar, weakening the acid and a drop in voltage [1,14].

While their energy density may be surpassed by other batteries, lead acid batteries excelin delivering substantial currents, making them highly suitable for applications like car starting.In the electric vehicle realm, their affordability and widespread availability grant them significance as storage devices. However, the drawback lies in their weight, resulting in highercosts per distance travelled due to fewer life cycles. Lead-acid batteries find widespread application in various industries, including telecommunications, power systems, radio and television systems, solar energy, uninterruptible power supplies (UPS), electric vehicles,automobiles, forklifts, and emergency lighting systems [1].

Environmental concerns surrounding lead-acid batteries stem from the emission of toxic lead, a heavy metal with bioaccumulation impacts and potential health risks. Nonetheless,their ability to be recycled multiple times stands as a testament to their success, positioning them among the most effectively recycled consumer products.

Nickel Cadmium.

Nickel Cadmium (NiCd) batteries have long been a reliable choice in the realm of rechargeable energy storage. Their enduring popularity arises from their robustness, ability to handle high discharge currents, and exceptional cycle life of around 1500 cycles. NiCd batteries consist of a nickel oxide hydroxide cathode and a cadmium anode, immersed in an alkaline electrolyte. These batteries offer consistent performance across a wide range of temperatures and are capable of delivering steady power output.

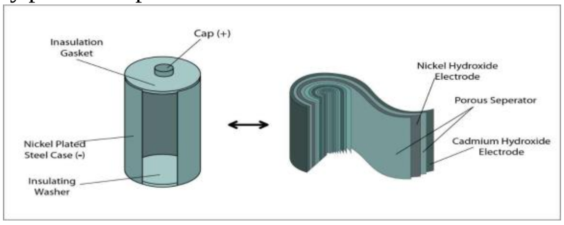


Fig. 17. Nickel Cadmium Battery

However, the use of toxic cadmium and lower energy density compared to newer technologies has led to their gradual displacement by more environmentally friendly options like lithium-ion batteries. Despite this, NiCd batteries still find applications in industries requiring high discharge rates, reliability, and resilience. These batteries were widely used in applications such as two-way radios, emergency medical equipment, professional video cameras, and power tools [1,15].

Nickel metal Halide.

Nickel Metal Hydride (NiMH) batteries have gained recognition as a versatile rechargeable energy storage solution. Their composition includes a hydrogen-absorbing alloy anode and a nickel-based cathode, paired with an alkaline electrolyte [1]. NiMH batteries offera higher energy density compared to NiCd batteries and have become popular alternatives dueto their reduced environmental impact and absence of toxic cadmium. With good cycle life and less susceptibility to memory effect, NiMH batteries find applications in various devices, including portable electronics and hybrid vehicles. However, the widespread adoption of lithium-ion batteries has gradually replaced NiMH batteries in many applications due to their superior energy density and performance.

Li-ion Battery.

The lithium-ion (Li-ion) battery is composed of a positive electrode (anode), a negative electrode (cathode), a separator, electrolyte, and two current collectors. The anode typically consists of lithiated metal oxide, such as LiCoO2, LiMO2, or LiNiO2, while the cathode is composed of graphitic carbon with a layered structure. The electrolyte is a solution of lithium salt, usually LiPF6, dissolved in organic carbonates.

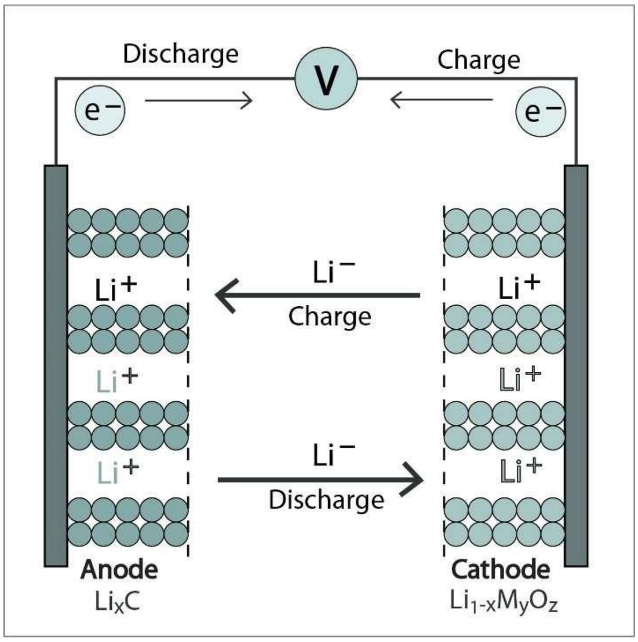


Fig. 18. Li-ion Battery

Current is generated when lithium ions migrate between the anode and cathode. During the charging cycle, lithium cations travel through the electrolyte to the carbon anode. They combine with external electrons and are deposited as lithium atoms within the carbon layers. This process is reversed during the discharge process.

Li-ion batteries have emerged as the preferred choice for numerous applications due totheir high energy density, increased capacity, improved performance, lightweight design, and cost-effectiveness. Additionally, they exhibit a low self-discharge rate of approximately 1.5%per month. Repeatedly charging Li-ion batteries after partial discharge does not negatively impact their maximum capacity, thereby minimizing any memory effect. Li-ion batteries also offer higher open-circuit voltage compared to aqueous batteries such as lead-acid, nickel-metalhydride, and nickel-cadmium. They can typically endure thousands of charge-discharge cycles.Currently, Li-ion batteries find extensive use in electronics and transportation industries, particularly in power grid applications and plug-in hybrid electric vehicles, due to their superiorcharge density compared to other rechargeable batteries [1,6].

Safety is a prominent concern in Li-ion batteries due to potential thermal instability inmetal oxide electrodes at high temperatures, leading to explosions from overcharging or overheating. Monitoring devices and voltage regulation circuits are integrated to prevent risks.Li-ion technology's evolution emphasizes safety enhancements and novel materials for electrodes and electrolytes. Additionally, environmental and health implications from lithium mining calls for ongoing monitoring and exploration of alternative materials.

Lithium polymer (Li-Po).

Li-polymer (Li-Po) batteries, belonging to the family of Li-ion batteries, share many similarities with conventional Li-ion batteries. However, the differentiating factor lies in the type of electrolyte utilized. Li-Po batteries employ a dry solid polymer electrolyte. The dry polymer electrolyte simplifies the fabrication process of Li-Po batteries. However, it also results in high internal resistance, limiting their suitability for high-current applications. To address this issue, modern Li-Po batteries incorporate a gelled electrolyte in addition to the drypolymer electrolyte. This combination overcomes the poor conductivity challenges and enables Li-Po batteries to excel in high-current applications with exceptionally high discharge rates. Li-Po batteries are known for their slim and lightweight design [1].

Sodium Sulfur.

Sodium sulfur (NaS) batteries have established themselves as a prominent technology in the current energy storage market. Offering a remarkable energy density ranging from 150 to 240W and a robust power output of 150 to 230W/kg, NaS batteries stand out as a formidable choice for various applications. These batteries exhibit a lifespan of up to 2500 cycles, indicating long-term reliability.

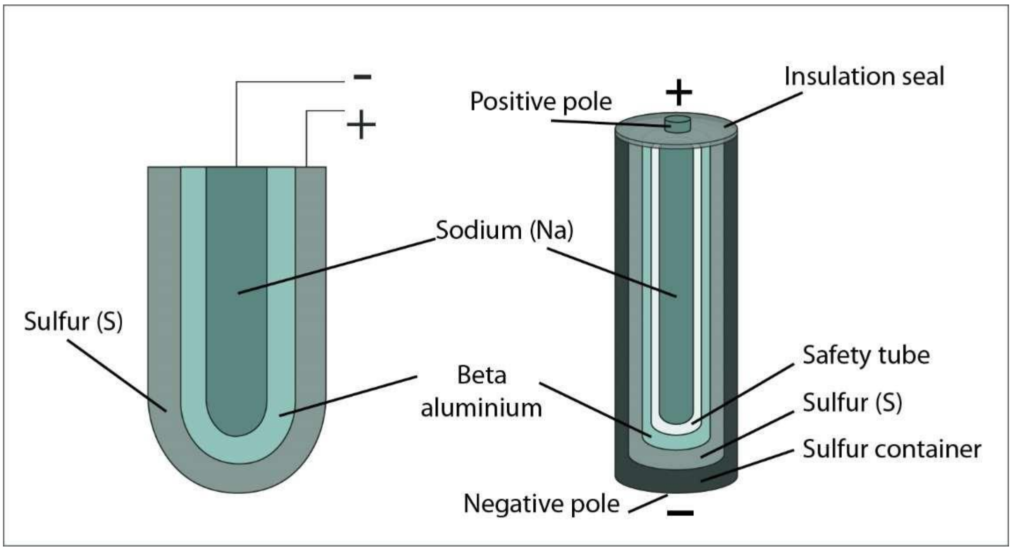


Fig. 19. Sodium Sulfur Battery

The composition of NaS batteries includes cost-effective materials, contributing to their attractiveness for widespread use. The distinctive design involves molten sulfur as the positive electrode and molten sodium as the negative electrode. Acting as both the electrolyte and separator, a solid beta alumina ceramic material segregates the active components. This allows selective passage of sodium ions from the positive to the negative electrode, facilitating recombination with sulfur to form sodium polysulfides. During discharge, sodium releases electrons and transitions into Na+ ions, generating a voltage of 2.0V. These electrochemical reactions are reversible, enabling the sodium polysulfides to release Na+ ions through the electrolyte, which later recombine to form elemental sodium.

Operating within a temperature range of 300 to 360°C is ideal for NaS batteries, wherevariations in temperature occur during charging and discharging, leading to fluctuations in electromotive force due to the charge-discharge cycles. A compelling advantage of NaS batteries is their exceptional DC conversion efficiency, reaching 85%, positioning them as strong contenders for future distribution systems centered on DC power. This feature renders NaS batteries promising candidates for various applications, including load leveling, peak shaving, renewable energy integration, emergency power, and power reliability [1,9,34].

Sodium Metal Halide.

Sodium metal halide (Na-MX) batteries, also known as ZEBRA batteries, share similarities with Na-S batteries as they utilize inorganic molten salt as the electrolyte. ZEBRA batteries exhibit a high tolerance to overcharging and discharging, along with a high energy density and long cycling life. Additionally, they operate within a wide temperature range (523- 623 K) and have low self-discharge rates and excellent pulse power capabilities. These batteries are maintenance-free and possess high mechanical strength, making them well-suited for stationary power quality and heavy-duty transportation applications. They are predominantly utilized in utility-scale energy storage systems. In Na-MX batteries, liquid sodium serves as the negative electrode, while a solid metal halide acts as the positive electrode. The electrodesare separated by a ceramic beta alumina separator. The electrolytes are immersed in asecondary electrolyte called sodium chloro-aluminate [1].

Redox Flow battery:

A flow battery is an advanced aqueous electrolytic battery that combines a hybrid of batteries and traditional fuel cells. Flow batteries are different from traditional batteries in that they contain two tanks filled with liquid electrolyte, one for the cathode and one for the anode. These tanks hold chemicals in different oxidation states. The cell stack, which is separated by an ion-selective membrane, is placed between the two tanks.

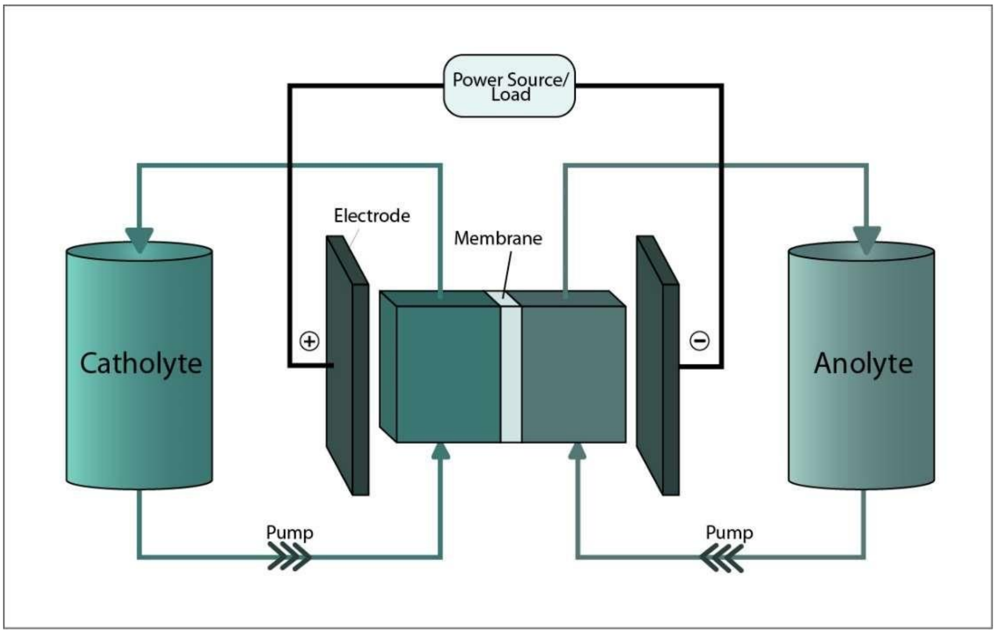


Fig. 20. Redox Flow Battery

When the battery is discharged, the chemical energy stored in it is converted into electrical energy through a process called reduction-oxidation (redox). As the battery charges, this process is reversed. The large size of the tanks and pumps make flow batteries more suitable for stationary applications, such as in homes or on a larger scale in power grids, due to their flexibility in design. One advantage of flow batteries is that they are easily scalable. If more power is needed, additional stacks can be added. If more storage capacity is required, additional electrolytes and storage tanks can be added.

Vanadium Redox Flow Battery.

Vanadium Redox Flow Batteries (VRFBs) are a promising energy storage technology known for their unique design and characteristics. These batteries utilize the redox reactions ofvanadium ions in different oxidation states (V^{2+} and V^{3+}) to store and release energy. The VRFB consists of two electrolyte tanks containing vanadium-based electrolyte solutions with different oxidation states. During charging and discharging, electrolytes flow through separatechambers, while an ion-selective membrane prevents mixing and enables ion exchange.

VRFBs offer advantages like long cycle life, high efficiency, and the ability to maintaina constant capacity over many charge-discharge cycles. Their scalability and low environmental impact due to the use of vanadium salts further enhance their appeal. However,challenges such as lower energy density compared to some other technologies and relatively larger system footprint remain areas of improvement [1,6].

Polysulphide Bromide Battery.

Polysulfide Bromide batteries, a type of redox flow battery, present an innovative approach to energy storage. These batteries employ a combination of polysulfide and bromine-based electrolytes that undergo redox reactions during charging and discharging processes. Polysulfide Bromide batteries consist of two tanks containing the respective electrolytes, whichare circulated through an electrochemical cell during operation. This design allows for energystorage and release without degradation of the active materials, contributing to their long cyclelife and durability. Polysulfide Bromide batteries offer advantages such as high energy density,scalability, and the potential for cost-effective energy storage solutions. They are still in the experimental stage and face challenges like electrode stability and efficiency optimization [9].

3 EMERGING AnD FUTURE ENERGY STORAGE TECHNOLOGIES

3.1 Gravity Battery

Gravity batteries, also known as gravity energy storage systems, are a new type of energy storage technology that uses the force of gravity to store and release energy. Unlike traditional batteries that use chemical reactions to store and release energy, gravity batteries rely on the interaction between a heavy object, often a weight or a piston, and gravity to store and release energy. The basic principle behind a gravity battery is to use gravity to lift a heavyobject to a higher elevation, where it is held in place by a locking mechanism. When energy isneeded, the heavy object is released, and as it falls, it turns a turbine or generator to produce electricity. The process is then reversed to recharge the battery by lifting the heavy object backto its original position using electricity from the grid or by using renewable sources.

One of the main advantages of gravity batteries is their long life cycle. They can last for decades, making them a more cost-effective option for long-term energy storage. Another advantage of gravity batteries is their high energy density. Because the stored energy is in the form of a heavy object, a small amount of space can store a large amount of energy. This makesgravity batteries a good option for applications where space is at a premium, such as in urban areas or on offshore platforms. Gravity batteries also have a very high efficiency, as they can convert up to 90% of the stored energy into electricity. This makes them a more efficient optionthan traditional batteries, which typically have an efficiency of around 70%.

Despite these advantages, there are also some limitations to gravity batteries. One of the main limitations is the cost of building and maintaining the storage systems, as they requirea significant amount of infrastructure and equipment. Additionally, the location for theinstallation of gravity battery must have a suitable topography for the movement of heavy object, which can limit the deployment of this technology [16,17].

3.2 Compressed CO2

Carbon dioxide (CO_2), a well-known contributor to global warming, has the potential to play a pivotal role in the development of an environmentally friendly battery system that canbe widely adopted worldwide. While renewable energy sources are crucial in combating climate change, their intermittent availability necessitates a cost-effective and long-lasting storage solution. Utilizing CO_2, despite its role in global warming, presents a unique opportunity.

Energy Dome, a research and development firm, is working on developing new and innovative ways to store and use compressed CO_2. The Energy Dome technology operates on a closed-loop thermodynamic system, where surplus renewable electricity is used to charge thesystem. CO_2 is drawn from a large dome-shaped gas holder and stored as a highly dense liquidat ambient temperature and pressure. During discharge, the stored heat is recovered and used to convert the liquid CO_2 back to vapor, generating electricity through a turbine. The CO_2 is then returned to the dome for the next charging cycle, completing the loop.

In comparison to other gas-based storage methods such as Compressed Air Energy Storage (CAES) and Liquid Air Energy Storage (LAES), the Energy Dome's CO_2 battery offershigher energy density, increased efficiency, and lower operational costs. CAES systems requirelarge spaces and have lower energy density, limiting scalability. LAES systems can store moreenergy but suffer from lower efficiency due to cryogenic-cooling and warming processes. By storing CO_2 at ambient temperature, the Energy Dome system minimizes operational costs andenergy penalties. With its simple design and two-step process of compression and evaporation,the Energy Dome achieves high round-trip efficiency of 75-80%. In conclusion, compressed CO_2 storage presents a promising alternative to conventional compressed air storage, offering enhanced efficiency, cost-effectiveness, and sustainability. The advancements made by EnergyDome in this field are noteworthy and are expected to have a significant impact on the energystorage industry [18,19].

3.3 Nano diamond battery

Nano diamond batteries are a new type of energy storage technology that harnesses theunique properties of diamond to store and release energy. The technology is based on the fact that diamond is an exceptional conductor of both electricity and heat, and it has a very high thermal conductivity.

NDB (Nano Diamond Battery), is a company that is pioneering the development of a revolutionary energy storage technology known as the nano diamond battery. The company iscreating these batteries by converting carbon-14, a radioactive isotope found in natural diamond, into a stable form of carbon. They plan to use nuclear waste as the source of carbon-14, which means the availability of this isotope shouldn't be a problem. Using nuclear waste asa source of carbon-14 for nano diamond batteries can help reduce the cost of producing these batteries, as well as help address the issue of nuclear waste management. NDB produces electricity similar to that of a solar cell, but instead of sunlight, it uses radiation from radioactivedecay. The main components of a NDB battery are: isotope, transducer, and storage unit. The isotope decays and releases radiation, which is then converted into power by the transducer. The excess energy is stored by the storage unit for future use during inactivity.

One of the main advantages of nano diamond batteries is their extremely long life cycle.The half-life of carbon-14 is 5,730 years, which means that these batteries can last for thousands of years without needing to be replaced. Another advantage of nano diamond batteries is their safety characteristics. Unlike traditional batteries that use chemicals and can be dangerous if they overheat or are punctured, nano diamond batteries are completely safe. The diamond lattice is a solid-state material, and it does not catch fire or explode. The carbon-14 isotope is sealed inside the diamond lattice and is not exposed to the environment. The levelof radiation emitted by the carbon-14 isotope is very low, much lower than the natural background radiation that we are exposed to on a daily basis. The long life cycle of nano diamond batteries makes them an ideal power source for space exploration missions or medicaldevices such as pacemakers, that are expected to last for decades or even centuries [20,21,36].

3.4 Aluminium-based batteries

Aluminium-based batteries are a promising new technology in the field of energy storage. These batteries offer a number of advantages over traditional lithium-ion batteries, including higher energy density, faster charging times, and lower cost. Aluminium has a high charge capacity, which means that these batteries can store more energy in a smaller space thantraditional lithium-ion batteries. This makes them an ideal choice for portable electronic devices and electric vehicles, where space is at a premium. These batteries can be charged much faster than traditional lithium-ion batteries, which means that they can be used more frequently without needing to be recharged. This makes them a great choice for applications such as electric vehicles or portable electronic devices. Aluminium is a more abundant and lessexpensive material than lithium, which makes it more cost-effective to produce aluminium-based batteries.

Despite these advantages, there are still some challenges to be overcome beforealuminium-based batteries can be widely adopted. One of the main challenges is finding a suitable electrolyte that can withstand the high voltage and high current needed for aluminium-based batteries. Researchers are currently working on developing new electrolytes that can meet these requirements. Another challenge is the safety of aluminium-based batteries. Aluminium can react with water to produce hydrogen gas, which can be dangerous if not properly ventilated. Researchers are working on developing safe and reliable designs for aluminium-based batteries to address this issue.

There are several types of aluminium-based batteries that are currently available or under development. These include: Aluminium-Graphite batteries, Aluminium-Carbon Nanotube batteries, Aluminium-Polysulfide batteries, Aluminium-Ion batteries and Aluminium-Air batteries [22,23,24].

3.5 Metal-Air Batteries

Metal-air batteries are a type of battery that utilizes a metal anode and an air cathode to generate electricity through the reaction of the metal anode with oxygen from the air. This process can be reversed for recharging the battery. The choice of electrolyte depends on the specific battery design and can be either an alkaline aqueous solution, a neutral aqueous solution of a salt, or a non-aqueous solution of a base metal salt. The positive electrode of a metal-air battery contains oxygen from the surrounding air, taking advantage of its strong oxidizing properties, lightweight nature, and abundant availability. This allows for a larger capacity as most of the battery interior can be used for the negative electrode material. For thenegative electrode material to be suitable in a metal-air battery, it needs to fulfill certain criteria.It should have a strong reducing power, a low molecular weight, high density, and a large valence change to provide a high battery voltage and capacity. Promising candidates for the negative electrode include lithium, aluminium, magnesium, zinc, and iron.

Zinc-air batteries are seen as a promising technology for replacing lead-acid batteries in various applications, such as electric vehicles, due to their higher energy density and longerlifespan. They also have potential for use in grid-scale energy storage. Another example is lithium-air batteries, which have the potential to store even more energy than zinc-air batteries.

Despite their advantages, metal-air batteries have limitations that need to be overcomebefore they can be widely adopted. The corrosion of the metal anode limits the battery's lifespan, and they often have poor cycle life and low recharging efficiency. Lithium-air batteries face safety risks due to lithium's reactivity to air and humidity. These challenges needto be addressed to enable the widespread use of metal-air batteries as a replacement for existing technologies [25,26,35].

3.6 Organic polymer batteries

Organic polymer batteries are a type of battery technology that uses organic polymers as the electrodes and electrolytes. They have been under development for several decades andhave several potential advantages over traditional lithium-ion batteries, including the ability toproduce large-scale and low-cost batteries, high flexibility, and safety. One of the main advantages of organic polymer batteries is that they can be made using low-cost and readily available materials. This is because the active materials in organic polymer batteries, such as polymers and small molecules, can be synthesized in large quantities using relatively simple and inexpensive chemical synthesis methods. Additionally, organic polymer batteries are highly flexible, which means that they can be bent and folded without affecting their performance. This allows for the creation of new form factors for battery-powered devices and systems. Organic polymer batteries also have high safety, as they do not typically pose a risk of thermal runaway.

However, there are still some challenges that need to be addressed before organic polymer batteries can be widely adopted. One of the main challenges is their relatively low energy density compared to lithium-ion batteries. This means that they need larger capacity tostore the same amount of energy. Additionally, their cycle life is also lower than lithium-ion batteries and their charging process is not as efficient [27].

3.7 Zinc–bromine non-flow batteries

Gelion, a research and development firm, has developed a unique type of zinc-brominebattery called the Endure, which is different from traditional redox-flow batteries (RFBs). Instead of using the typical RFB design of pumps and tanks, the Endure uses a similar plate format and casing to a lead-acid battery. It replaces lead and sulfuric acid with a bromide- positive plate and a zinc-negative plate, with a layer of gel acting as the electrode in the middle. Using gel-based electrolytes, the Endure eliminates pumps and tanks for a compact design. This plate configuration also eradicates the need for specialized maintenance, auxiliarypower sources, and backup systems. The chemical process inside, however, remains constant.When the battery is charged, zinc ions migrate to the negative electrode, accept electrons, andthen reduce to zinc. Bromide ions migrate to the positive electrode, where they lose electrons and oxidise to bromine. The opposite occurs upon discha

COMPARISON OF STORAGE TECHNOLOGIES [1,4,6,11,12,30]

Table 1.

Technology	Energy Density (Wh/L)	Power Density (W/L)	Specific Energy (Wh/Kg)	Specific Power (W/Kg)	Energy Capital Cost ($/KWh)	Response Time	Discharge Time	Self-Discharge (%) per day	Round Trip Efficiency (%)	Life Cycles	Environmental Impact
Lead Acid	25-90	10-700	30-50	75-300	200-400	150ms-sec	s-10h	0.1–0.3%	70–80	2000	Medium: Toxic remains
Li-ion	200-500	1300-10,000	30-300	150-350	600-2500	150ms-sec	15 min-8 h	0.1–0.3%	85-95	4500	Very Low: Toxic residues
Ni-Cd	60-150	75-700	10-80	50-300	800-1500	150ms-sec	s-8h	0.2–0.6%	60–80	3000	Very Low: Toxic residues
Sodium sulfur	150-345	50-180	150-250	150-260	300-500	150ms-sec	s-7h	~20%	75-85	2500	Very Low: Toxic residues
Vanadium Redox Flow (VRF)	10-70	30-60	10-75	30-60	150-1000	1s -10s	sec-10h	1-1.5	65-75	12,000+	Low: Toxic remains
Pumped Hydro Storage (PHES)	0.5-1.5	0.1-0.2	0.5-1.5	0.1-0.2	5-100	1 min-10 min	1 - 24h+	0.005-0.03	70–85	>100,000	High: Destruction oftrees and green land for reservoirs
Flywheel	20-80	5000	5-130	400-1600	1000-5000	<4 ms	ms-15 min	100%	90-95	> 100,000	Very Low
Compressed Air Energy Storage (CAES)	3-6	0.1-0.2	30-60	1-2	2-50	1 min-15 min	1 - 24h+	1-2	40-60	>13,000	Medium: Emissions from combustion of natural gas
Super-capacitors	10-30	100,000+	2.5-15	500-5000	300-2000	<5 ms	1ms-1h	20–40%	85-97	>100,000	Medium
Superconducting Magnetic Energy Storage (SMES)	0.2-2.5	1000-4000	0.5-10	500-2000	1000-10,000	<5 ms	1 ms-1h	10–15%	95-98	>100,000	Low: Strong magnetic fields

- Flow batteries like the Endure offer distinct advantages, particularly regarding depth ofdischarge and safety. They can be fully discharged without harm, whereas some lithium-ion batteries suffer degradation below 20%. Flow batteries avoid lithium-ion safety concerns by using non-flammable elements and water-based electrolytes, with bromine acting as a natural fire retardant. Vanadium flow batteries (VFBs) share low fire risk and unique benefits, but facecost and toxicity challenges. Zinc-bromine batteries offer affordability and eco-friendliness, though with lower energy density. They compete well in round-trip efficiency (85-90%) and boast a wide temperature range, eliminating air conditioning needs. The Endure battery's tank-free design, long lifespan (5,000 cycles), and recyclability further enhance its appeal as an energy storage solution.
- However, zinc-bromine batteries could potentially face the challenge of zinc dendrite formation, which can damage the battery. Gelion has addressed this issue by using a porous membrane that blocks the growth of dendrites. Zinc-bromine batteries are best suited for providing electricity to homes, solar or wind farms, or remote areas, but may not be practical for mobile or portable use due to their bulkiness [5,28,29,34].

- **Energy density**: The energy stored per unit volume of the storage material, measured in kWh/L.
- **Power density:** The power output per unit volume of the storage material, measured in kW/L.
- **Specific energy:** The energy stored per unit mass of the storage material, measured in kWh/kg.
- **Specific power**: The power output per unit mass of the storage material, measured in kW/kg.
- Energy capital cost: The capital investment required to produce a unit of energy, measured in $/kWh. Higher energy capacity typically results in lower cost per unit energy.
- **Response time:** The time it takes for an energy storage system (ESS) to begindischarging energy to a load after receiving a command or a signal.
- **Discharge time (at rated power):** The time required for an energy storage system to fully discharge its stored energy at its rated power output.
- **Daily self-discharge:** The amount of energy lost by a storage system due to self- discharge during non-use periods, typically expressed as a fraction of the total storage capacity.
- **Round-trip efficiency:** The ratio of energy put into an energy storage system during charging to the energy retrieved from it during discharging, expressed as a percentage. It represents the efficiency of the storage system in storing and retrieving energy.
- **Life cycles:** The number of complete charging and discharging cycles that an energy storage system can perform throughout its lifetime. It indicates the durability and longevity ofthe storage system.
- **Environmental Impact:** It refers to the effects that the storage system has on the environment, which can include emissions, waste, land use, and other factors. These impacts can include air and water pollution, deforestation, and habitat destruction, as well as the releaseof greenhouse gases and other pollutants into the air.

4 SELECTION METHODOLOGY

With the increasing demand for energy storage solutions and the emergence of new battery technologies, decision-makers face the challenge of evaluating and selecting the most suitable option among a range of alternatives. Multi-criteria decision making (MCDM) can be employed as a systematic approach to address the complexity of battery selection. By considering multiple parameters such as energy density, power density, cost, environmental impact, lifespan, safety, and availability, a comprehensive evaluation of battery alternatives can be conducted.

The first step in the MCDM process involves clearly defining the problem and identifying the specific parameters relevant to the application. Each parameter or criterion is assigned a weight (w) to reflect its relative importance, which is determined based on the preferences and priorities of the decision-maker. Subsequently, battery alternatives are evaluated against these parameters using a weighted scoring system to obtain a performance score, which is then used to rank the battery technologies [31,32].

The weighted product model (WPM)

The weighted product model (WPM) is a decision-making method that will be utilized in this research for battery selection. The WPM is similar to the weighted sum model (WSM) but differs in its calculation approach, as it involves multiplication rather than addition. One notable advantage of the WPM is its dimensionless analysis, which eliminates the reliance on units of measurement. This feature allows the WPM to be applied to decision-making problems with varying dimensions. Additionally, the method allows for the use of relative values instead of actual values, enhancing flexibility in the evaluation process.

Let, a_i {for i = 1, 2, 3, ..., m} be a (finite) set of storage technology alternatives,
c_j {for j = 1, 2, 3, ..., n} be a (finite) set of parameters or criteria

In order to evaluate the battery technologies, the parameters can be categorized as either non-beneficial or beneficial. To ensure fair comparison, the quantified values of non-beneficial parameters are normalized using the ratio of the minimum value to the actual value {$Min(a_i)/a_i$}, while the beneficial parameters are normalized using the ratio of the actual value to the maximum value {$a_i/Max(a_i)$} for each parameter (c_j). Let's call this value X_{ij} for both the cases. This normalization process yields a set of normalized performance values. Upon analysing the parameters, it is observed that all parameters fall under the category of beneficial, indicating that higher parameter values correspond to better battery technology performance [31,33].

Next, following the weighted product model (WPM), weights are assigned to each parameter based on their relative importance. These weights reflect the significance of each parameter in achieving the desired performance. The values of all parameters are then multiplied together, raised to the power of their respective weights, to obtain the performance value of each battery technology. This calculation is represented by the expression:

$$\square_i^{WPM} = \prod_{j=1}^{n} \square_{ij}^{w_j}$$

where, $\square_i^{WPM}$ is the overall performance score

X_{ij} is the normalized performance value of the j^{th} parameter of i^{th} battery.

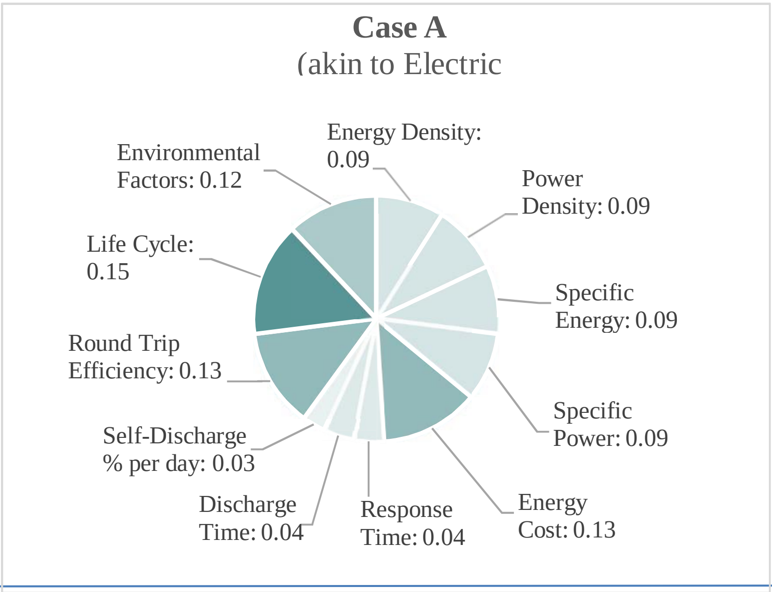
w_j is the weight of the j^{th} parameter for specific application.

Weights determination (w_j)

The determination of weights in the weighted product model is based on the specific requirements and priorities of the given application. These weights reflect the significance of each parameter in achieving the desired performance. The sum of all weights must be 1.

Let's say for a specific application A (akin to Electric Vehicles), the allocation of weightage percentages for the different parameters are:

1. Energy Density: 0.09
2. Power Density: 0.09
3. Specific Energy: 0.09
4. Specific Power: 0.09
5. Energy Cost: 0.13
6. Response Time: 0.04
7. Discharge Time: 0.04
8. Self-Discharge % /day: 0.03
9. Round Trip Efficiency: 0.13
10. Life Cycle: 0.15



11. Environmental Factors: 0.12

Similarly, for another application **B** (akin to Frequency Regulation):

1. Energy Density: 0.08
2. Power Density: 0.08
3. Specific Energy: 0.07
4. Specific Power: 0.07
5. Energy Cost: 0.12
6. Response Time: 0.15
7. Discharge Time: 0.05
8. Self-Discharge % /day: 0.04
9. Round Trip Efficiency: 0.15
10. Life Cycle: 0.14
11. Environmental Factors: 0.05

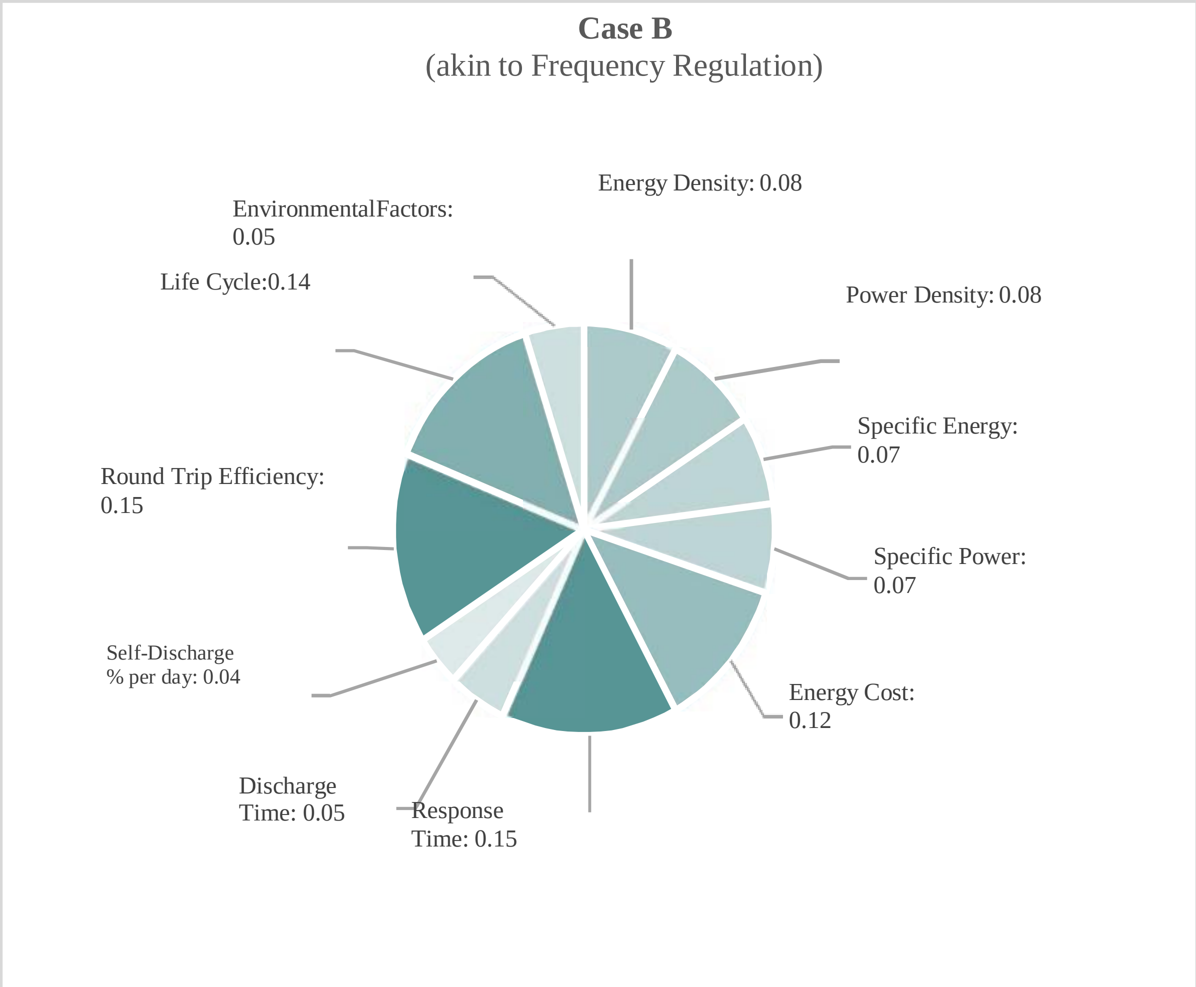


Table 2. SIMPLIFIED PERFORMANCE VALUES

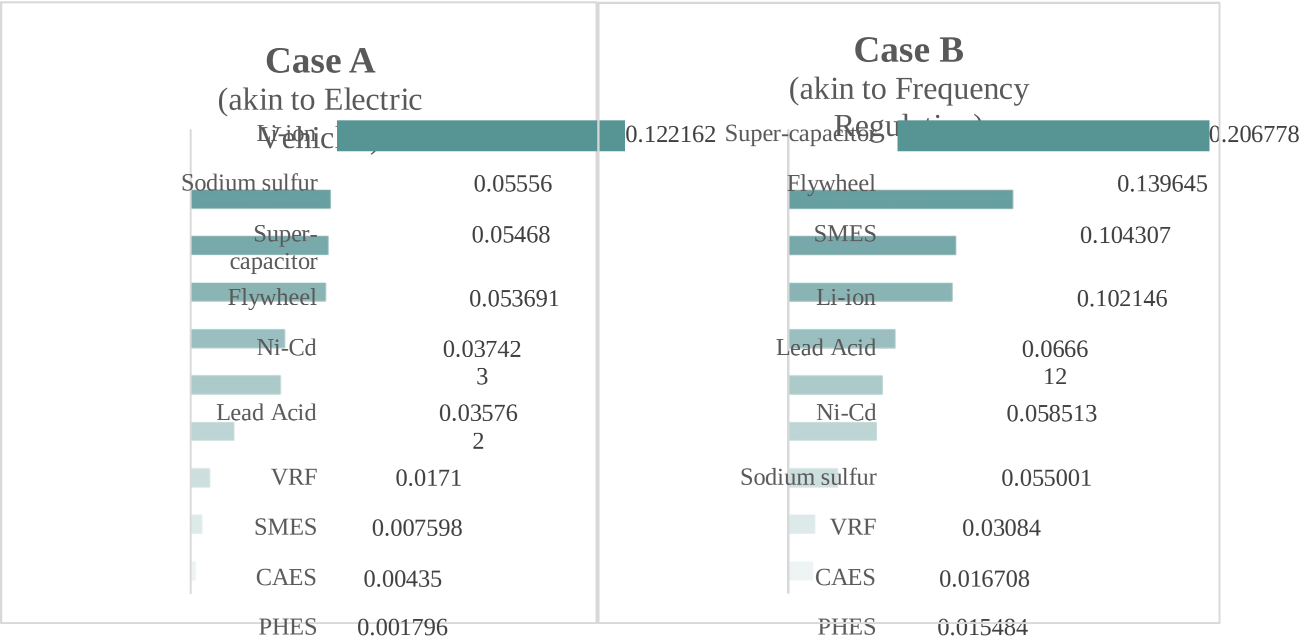
Technology	Ene-rgy Den-sity (Wh/L)	Power Density (W/L)	Specific Energy (Wh/Kg)	Specific Power (W/Kg)	Energy Capital Cost ($/KWh)	Response Time (ms)	Discharge Time	Self-Discharge(%) per day	Round Trip Efficiency (%)	Life Cycles	Environmental Impact
Lead Acid	90	700	50	300	200	150ms	10h	0.1	80	2000	3
Li-ion	500	10000	300	350	600	150ms	8 h	0.1	95	4500	1
Ni-Cd	150	700	80	300	800	150ms	8h	0.2	80	3000	1
Sodium sulfur	345	180	250	260	300	150ms	7h	20	85	2500	1
VRF	70	60	75	60	150	1sec	10h	1	75	12000	2
PHES	1.5	0.2	1.5	0.2	5	1 min	24h	0.005	85	100000	4
Flywheel	80	5000	130	1600	1000	4 ms	15 min	100	95	100000	1
CAES	6	0.2	60	2	2	1 min	24h	1	60	13000	3
Super-capacitors	30	100000	15	5000	300	5 ms	1h	20	97	100000	3
SMES	2.5	4000	10	2000	1000	5 ms	1h	10	98	100000	2

- For our calculations, we simplify values by considering the best-case scenario, where we take the maximum value forbeneficial parameters and the minimum value for non-beneficial parameters

Fig. 21. Table 3. NORMALIZED **PERFORMANCE VALUES (Xij)**

Technology	**Energy Density**	**Power Density**	**Specific Energy**	**Specific Power**	**Energy Capital Cost**	**Response Time**	**Discharge Time**	**Self - Discharge**	**Round Trip Efficiency**	**Life Cycles**	**Environmental Impact**
Lead Acid	0.18	0.007	0.16667	0.06	0.01	0.02667	0.41667	0.05	0.816327	0.02	0.75
Li-ion	1	0.1	1	0.07	0.00333	0.02667	0.33333	0.05	0.969388	0.045	0.25
Ni-Cd	0.3	0.007	0.26667	0.06	0.0025	0.02667	0.33333	0.025	0.816327	0.03	0.25
Sodium sulfur	0.69	0.0018	0.83333	0.052	0.00667	0.02667	0.29167	0.00025	0.867347	0.025	0.25
VRF	0.14	0.0006	0.25	0.012	0.01333	0.004	0.41667	0.005	0.765306	0.01	0.5
PHES	0.003	0.000002	0.005	0.00004	0.4	6.6667	1	1	0.867347	1	1
Flywheel	0.16	0.05	0.43333	0.32	0.002	1	0.0104167	0.00005	0.969388	1	0.25
CAES	0.012	0.000002	0.2	0.0004	1	6.6667	1	0.005	0.612245	0.13	0.75
Super-capacitors	0.06	1	0.05	1	0.00667	0.8	0.0416667	0.00025	0.989796	1	0.75
SMES	0.005	0.04	0.03333	0.4	0.002	0.8	0.0416667	0.0005	1	1	0.5

Final performance scores A_i^{WPM} and ranks:



Higher performance scores indicate better suitability of a storage technology for a specific application.

5 CONCLUSION

In this study, we conducted a comprehensive review of advanced energy storage technologies and batteries, exploring their characteristics, advantages, and limitations. We also discussed emerging technologies that are currently in the research phase, highlighting their potential to shape the future of energy storage.

To facilitate the selection process, we developed a comparison table that considered more than 10 different factors crucial for energy storage technology evaluation. The comparison table served as a valuable tool for assessing and comparing various battery technologies. It's worth noting that while our comparison table provides general values, real- world decision-makers should exercise caution and select values with meticulous consideration, ensuring they align with the unique context and goals of their specific application. Decision-makers should be aware that certain energy storage technologies may notbe suitable for specific applications, such as PHES or CAES being impractical for mobile phone batteries due to size and infrastructure constraints.

Furthermore, we employed the weighted product model of multi criteria decision making (MCDM) to determine the most suitable energy storage technology for two distinct applications. By assigning different weights to the evaluation factors based on the objectives of each application, we successfully identified Li-ion batteries as the optimal choice for applications like EVs and super capacitors as the preferred technology for applications like frequency regulation. The widespread use of Li-ion in the automotive industry further supports their effectiveness in this application. In contrast, super capacitors showcased their superiorityby offering rapid response times, and long operational lifespans. These attributes make them particularly suitable for applications where frequent charge and discharge cycles are essential to stabilize grid frequency.

It's important to note that selecting the most suitable energy storage technology for a specific application relies heavily on the unique objectives, constraints, and operational contextof the system. The assigned weights for evaluation factors can be adjusted to accommodate varying priorities across different applications, and ongoing research and technological advancements may introduce additional factors for consideration in the decision-making process.

In conclusion, our research provides valuable insights into the selection of advanced energy storage technologies and batteries for different applications. The comparison table andthe weighted product model serve as effective tools to assist decision-makers in choosing the most appropriate technology based on their specific requirements. It is crucial to recognize thatenergy storage technologies are not one-size-fits-all; they vary significantly in size, infrastructure needs, and application suitability. Decision-makers must carefully consider thesevariant-specific values to make informed choices that align with their unique contexts and goals.

As energy storage technologies continue to advance, it is essential to remain attentive to ongoing research and development efforts that may introduce even more efficient and tailored solutions for various applications. Ultimately, the continued exploration and utilizationof advanced storage technologies, along with the recognition of variant-specific values, will contribute to the widespread adoption of sustainable and efficient energy systems.

6 FUTURE SCOPE

In future research, we aim to consider a wider range of factors, including variant-specific values, explore the latest technological advancements, and seek synergies among various storage technologies. These efforts will foster ongoing improvements in energy storage systems, enabling more efficient and versatile use across diverse applications.

7 REFERENCES

23. Hossain E, Faruque HMR, Sunny MdSH, Mohammad N, Nawar N. A Comprehensive Review on Energy Storage Systems: Types, Comparison, Current Scenario, Applications,Barriers, and Potential Solutions, Policies, and Future Prospects. *Energies*. 2020;13(14):3651. doi:10.3390/en13143651
24. Ling C. A review of the recent progress in battery informatics. *Npj Computational Materials*. 2022;8(1). doi:10.1038/s41524-022-00713-x
25. Shaqsi ASA, Sopian K, Al-Hinai A. Review of energy storage services, applications, limitations, and benefits. *Energy Reports*. 2020;6:288-306. doi:10.1016/j.egyr.2020.07.028
26. Chakraborty MR, Dawn S, Saha PK, Basu JK, Ustun TS. A Comparative Review on Energy Storage Systems and Their Application in Deregulated Systems. *Batteries*. 2022;8(9):124. doi:10.3390/batteries8090124
27. May, G., Davidson, A. J., & Monahov, B. (2018). Lead batteries for utility energy storage:A review. *Journal of Energy Storage*, *15*, 145–157. https://doi.org/10.1016/j.est.2017.11.008
28. Mitali J, Dhinakaran S, Mohamad AA. Energy storage systems: a review. *KeAi Publishing*. 2022;1(3):166-216. doi:10.1016/j.enss.2022.07.002
29. Johanna Gustavsson. Energy Storage Technology Comparison - A knowledge guide to simplify selection of energy storage technology. https://www.diva-portal.org/smash/get/diva2:953046/FULLTEXT01.pdf
30. Challa V. Selecting the Right Battery for Your Application: Important Battery Metrics. https://www.ansys.com/en-in/blog/important-battery-metrics
31. Fast Response Energy Storage Devices Technology Descriptions and Overview. *scottmadden.com*. https://www.scottmadden.com/content/uploads/userFiles/misc/80279278a617721d1711623bff4f6616.pdf
32. Vilanova, M. R. N., Flores, A. T., & Balestieri, J. a. P. (2020). Pumped hydro storage plants: a review. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, *42*(8). https://doi.org/10.1007/s40430-020-02505-0
33. Luo X, Wang J, Dooner MS, Clarke J. Overview of current development in electrical energy storage technologies and the application potential in power system operation.
34. *Applied Energy*. 2015;137:511-536. doi:10.1016/j.apenergy.2014.09.081
35. Krishan, O., & Suhag, S. (2018). An updated review of energy storage systems: Classification and applications in distributed generation power systems incorporating renewable energy resources. *International Journal of Energy Research*, *43*(12), 6171– 6210. https://doi.org/10.1002/er.4285
36. Lee SY, Lee JH, Kim YH, Kim JM, Lee KJ, Park SJ. Recent Progress Using Solid-State Materials for Hydrogen Storage: A Short Review. *Processes*. 2022;10(2):304. doi:10.3390/pr10020304
37. Kp, Lakshmi & .B, Pruthvija. (2020). Review on Battery Technology and its Challenges.
38. *International Journal of Scientific and Engineering Research*. 11. 1706

39. Lipu MSH, Mamun AA, Ansari S, et al. Battery Management, Key Technologies, Methods, Issues, and Future Trends of Electric Vehicles: A Pathway toward Achieving Sustainable Development Goals. *Batteries*. 2022;8(9):119. doi:10.3390/batteries8090119
40. Fyke AD. The Fall and Rise of Gravity Storage Technologies. *Joule*. 2019;3(3):625-630. doi:10.1016/j.joule.2019.01.012
41. D. K. Chaturvedi, S. Yadav, T. Srivastava and T. Kumari, "Electricity storage system: AGravity Battery," 2020 Fourth World Conference on Smart Trends in Systems, Security and Sustainability (WorldS4), London, UK, 2020, pp. 412-416, doi: 10.1109/WorldS450073.2020.9210321
42. Liu, S., Wu, S., Hu, Y., & Li, H. (2019). Comparative analysis of air and CO2 as workingfluids for compressed and liquefied gas energy storage technologies. *Energy Conversion and Management*, *181*, 608–620. https://doi.org/10.1016/j.enconman.2018.12.031
43. Energy Dome. *CO2 battery | Energy Dome*. https://energydome.com/co2-battery/
44. Diamond_battery_FAQs_Nov_2016. University of Bristol. https://www.bristol.ac.uk/media-library/sites/cabot-institute-2018/documents/Diamond_battery_FAQs_Nov_2016.pdf
45. Arkenlight – Brilliant Power for Very Useful Things. https://www.arkenlight.co.uk
46. Elia, G. A., Marquardt, K., Hoeppner, K., Fantini, S., Lin, R., Knipping, E., Peters, W., Drillet, J., Passerini, S., & Hahn, R. W. (2016). An overview and future perspectives of aluminum batteries. *Advanced Materials*, *28*(35), 7564–7579. https://doi.org/10.1002/adma.201601357
47. Mori, R. (2020). Recent developments for Aluminum–Air batteries. *Electrochemical Energy Reviews*, *3*(2), 344–369. https://doi.org/10.1007/s41918-020-00065-4
48. Elia, G. A., Kravchyk, K. V., Kovalenko, M. V., Chacón, J., Holland, A., & Wills, R. (2021). An overview and prospective on Al and Al-ion battery technologies. *Journal of Power Sources*, *481*, 228870. https://doi.org/10.1016/j.jpowsour.2020.228870
49. Wang, C., Yu, Y., Niu, J., Liu, Y., Bridges, D., Liu, X., Pooran, J., Zhang, Y., & Hu, A. (2019). Recent progress of Metal–Air Batteries—A mini Review. Applied Sciences, 9(14), 2787. https://doi.org/10.3390/app9142787
50. Arai H, Hayashi M. SECONDARY BATTERIES – METAL-AIR SYSTEMS | Overview (Secondary and Primary). In: *Elsevier EBooks*. ; 2009:347-355. doi:10.1016/b978- 044452745-5.00099-x
51. Goujon N, Casado N, Patil N, Marcilla R, Mecerreyes D. Organic batteries based on justredox polymers. *Progress in Polymer Science*. 2021;122:101449. doi:10.1016/j.progpolymsci.2021.101449
52. Chen H, Cong TN, Yang W, Tan C, Li Y, Ding Y. Progress in electrical energy storage system: A critical review. *Progress in Natural Science: Materials International*. 2009;19(3):291-312. doi:10.1016/j.pnsc.2008.07.014
53. *Gelion's EndureTM battery - Gelion - inspired energy*. (2021, August 3). Gelion -
54. Inspired Energy. https://gelion.com/gelion-endure-battery
55. Georgious R, Refaat R, Garcia JA, Daoud A. Review on Energy Storage Systems in Microgrids. *Electronics*. 2021;10(17):2134. doi:10.3390/electronics10172134
56. M. K. Loganathan, C. Ming Tan, B. Mishra, T. A. M. Msagati and L. W. Snyman, "Review and selection of advanced battery technologies for post 2020 era electricvehicles," 2019 IEEE Transportation Electrification Conference (ITEC-India), Bengaluru, India, 2019, pp. 1-5, doi: 10.1109/ITEC-India48457.2019.ITECINDIA2019-254
57. Shimin VV, Shah VA, Lokhande MM. *Electric Vehicle Batteries: A Selection Based on PROMETHEE Method*.; 2016. doi:10.1109/poweri.2016.8077224

58. Triantaphyllou E, Shu B, Sanchez SN, Ray TG. Multi-criteria decision making: An operations research approach. *ResearchGate*. February 1998.
59. https://www.researchgate.net/publication/284107964_Multi-criteria_decision_making_An_operations_research_approach
60. Cho J, Jeong S, Kim YS. Commercial and research battery technologies for electrical energy storage applications. *Progress in Energy and Combustion Science*. 2015;48:84- 101. doi:10.1016/j.pecs.2015.01.002
61. Ma J, Li Y, Grundish NS, et al. The 2021 battery technology roadmap. *Journal of PhysicsD*. 2021;54(18):183001. doi:10.1088/1361-6463/abd353
62. Prabakaran V. Future of Battery Technologies. *ResearchGate*. January 2021.
63. https://www.researchgate.net/publication/348631115_Future_of_Battery_Technologies.

AIR POLLUTION DETECTION & MONITORING USING INTERNET OF THINGS(IOT)

Deepansh Kulshrestha[1] ,Avishi Asati[2],Srashti Vyas [3],Sneha Sharma[4]

Department of Electrical Engineering
MITS, Gwalior, MP, India
deepansh84500@gmail.com1 avishi.asati@gmail.com2,
srashtivyas559@gmail.com3, ekiyairadiran@gmail.com4,

Aashi Singh Bhadouria[5]

Assistant Professor
Madhav Institute of Technology and Science, Gwalior, M.P., India.
aashisingh910@gmail.com5

Abstract: The term "internet of things" is used to describe a worldwide system of connected, self-aware devices that may gather data about their surroundings and share it with other networks (IOT). Since more people are breathing in polluted air due to growing rates of car usage, industrialization, and urbanisation, it poses a serious threat to public health. To combat this, a cutting-edge Internet of Things (IoT)-based air pollution monitoring system has been developed. This system is able to identify and quantify dangerous gases and compounds such carbon dioxide, nicotine, alcohol, benzene, nh3, and no2. Sensors connected to an esp32 microcontroller collect data on the surrounding environment and send it to the cloud in real time using the MQTT protocol. Accessible from anywhere with an Internet connection, the data is shown on both a website and an LCD. This system has the potential to provide employees real-time information about the source and location of any pollution. By providing precise data on air quality and issuing alerts when pollution levels reach over acceptable limits, an IoT-based air pollution monitoring system has the potential to decrease threats to public health.

Keywords: Internet of Things (IoT), Smart Devices, Air Pollution, Air Quality Sensors, Microcontroller, MQTT protocol, cloud platform, webpage, remote monitoring, alert, real-time data.

1 Introduction

One of the most promising applications of the Internet of Things (IoT), which is changing the way people interact with technology, is in the field of air quality monitoring. Air pollution is the most pressing problem, because it has consequences for both the natural world and for human health. Rising populations, industrial activities, and transportation contribute significantly to air pollution worldwide. To better monitor air quality in real time and alert nearby workers and residents when pollution levels rise over safe thresholds, an Internet of Things (IoT)-based system is proposed. A microcontroller named ESP32 controls the device's temperature, humidity, and air quality sensors. The MQTT standard paves the way for information to be saved in the cloud. A web interface and an LCD screen provide remote monitoring capabilities. Nicotine, alcohol, benzene, NH3, and NO2 are just some of the compounds that the system might potentially identify. In theory, the monitoring system's findings may be useful in a variety of contexts. Possible benefits include more precise localization of polluted areas, tracking of the effectiveness of pollution-reduction programmes, and simpler access to reliable data on air quality Analyzing monitoring data allows us to calculate the daily air pollution level, allowing us to take the appropriate measures. The Internet of Things-based air pollution monitoring system is a viable alternative for businesses that must maintain tabs on pollution levels for purposes of employee safety because of its dependability and cheap cost. The technology might be used to protect not just commercial buildings, but also residential areas, parks, and other public areas. It's likely that Internet of Things-based air pollution monitoring devices hold the key to figuring out how to solve the massive issue of air pollution and its devastating impact on the ecosystem and human health. The ability of these technologies to identify dangerous substances in real time and provide relevant data has the potential to improve air quality and protect human health. It's important to get the word out about them and take steps to make them more affordable and accessible to the general population.

2 Objective

Air quality data are collected and analysed as part of air pollution detection and monitoring to determine where and how much pollution is present. Our mission is to improve air quality and preserve human health by sharing accurate and timely information with politicians, environmental groups, and the general public. By keeping tabs on where pollution levels are highest, we can cut down on emissions from vehicles and companies. To further minimise pollution and encourage the use of eco-friendly technology, this data might also be used to draught laws and direct the creation of regulations. The identification and frequent monitoring of air pollution is crucial to achieving the goals of sustainable development, public health, and climate change mitigation.

3 Literature survey

N. S., Vuayalakshmi (2016) [1] Standard AQI values and more information are available here. Anywhere between 0 and 100 ppm is safe for human habitation. The dangerous threshold is reached if the ppm level rises over 100. When the concentration rises over 200 parts per million, it poses a significant risk to human health.

Anand Jayakumar and Yesyand, **Praviss**. (**2021) [2]** The DHT11 sensor module can detect both the temperature and humidity of its surroundings. The MQ-135 gas sensor is used to evaluate air quality. Oxygen-rich air, alcohol, carbon dioxide, Page hydrogen, and methane are just some of the gases and liquids that may be utilised to alter it. In this study, the quality of the surrounding air serves as a standard.

Amir Chetri and Heniel (2018) [3] It has been shown that Node MCU exhibits dominant behaviour. This study demonstrates how useful a scripting language C++ may be for programmers. Because of its built-in Wi-Fi module, it's easy to incorporate IoT into preexisting software. The coding for this project is done in the Arduino IDE. The cloud service is provided by Thing Speak. There is a free version, but it adds 15 seconds to the time it takes to upload a file to the cloud.

Jesif Ahmed (2018) [4] Due to the power drive, the sensors' output voltage levels vary and display unpredictable behaviour even when both are switched ON; this is because the project employs two sensors, each of which incorporates internal heater components and hence consumes more power (P=V*I). Since the Node MCU can only power one sensor at a time, we needed to find a different way to power them.

4 System requirements

Hardware Components - LEDs that emit green, yellow, and red light, AC-DC adapters, resistors, and sensor modules like the Node MCU V3, the DHT11, and the MQ-135.

Technology: ThinkSpeak Cloud and the Arduino Software Development Kit

A. **Node MCU V3 -** The Node MCU V3 development board runs on open-source software and is based on the ESP8266. The built-in USB connector simplifies the process of creating and debugging IoT apps. It contains GPIO (general-purpose input/output) pins for easy connection to various gadgets and sensors..

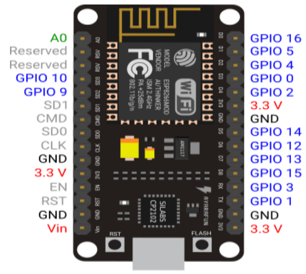


Fig. 22. Node MCU V3

B. DHT11 Sensor Module -The DHT11 is a digitally output voltage-based temperature and humidity sensor. A thermistor and a capacitive humidity sensor are used to examine the surrounding air. The Vcc pin must be connected to 5V DC and ground (GND), as shown in Fig. 2. It is easier to interpret the sensor's output voltage when using the Data pin in digital mode. Comparing Dry and Wet Conditions The humidity sensing capacitor is shown in Figure 2; it comprises of two electrodes and a dielectric substrate that may trap moisture between them. Humidity has an effect on the value of capacitance. The IC tracks the resistance and translates the data into a digital format as it fluctuates. A thermistor with a negative temperature coefficient is used to measure temperatures using the DHT11 sensor. The resistance of this thermistor drops as its temperature increases. The sensor's semiconductor ceramics or polymer construction enables it to measure resistance changes across a broad dynamic range..

Fig. 23. . DHT11 Sensor Module

MQ-135 Gas sensor Module- Ammonia, nitrogen oxides, sulphor dioxide, benzene, smoke, and carbon dioxide are just some of the gases that may be detected by the MQ-135 gas sensor module. The idea is based on the observation that the resistance changes when the target gas is present. The module's analogue output corresponds to the observed concentration of gas. Among the various applications it has found are in security systems, air quality monitoring, and pollution management.

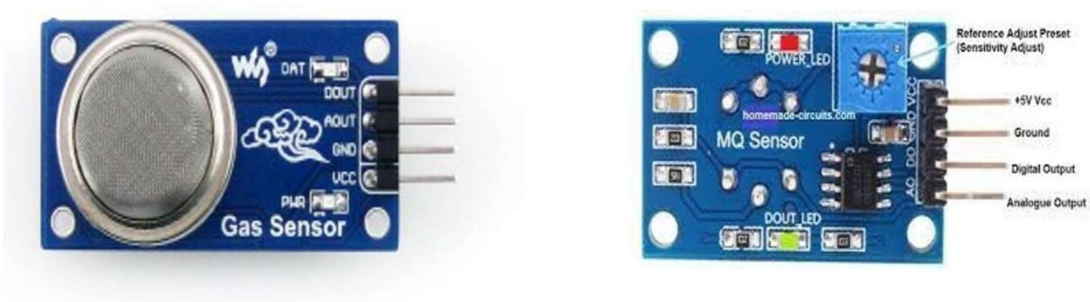


Fig. 24. MQ-135 Gas sensor Module

C. Veroboard- Veroboard (KS100) is a kind of PCB used for electrical circuit prototyping. Connections may be made by trimming the copper strips that separate the rows of copper pads. Because of how easily it can be tailored to meet a variety of aesthetic needs, it is often used for quick jobs.

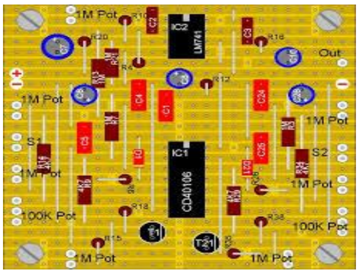


Fig. 25. Veroboard

D. Breadboard- A breadboard is a tool used to prototype electrical circuits without solder. The board's slotted shape makes it easy to connect the different electrical pieces by providing a snug fit for the component leads. Breadboards are useful for quick development and testing of circuits since they do not need soldering or other permanent connections..

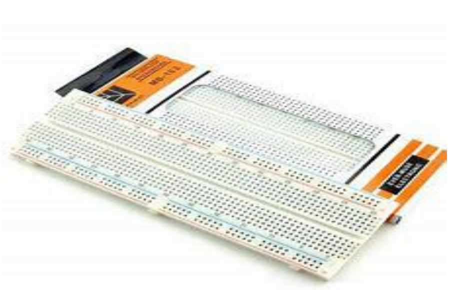


Fig. 26. :Breadboard

E. AC-DC Adapters –A breadboard, a solderless tool, is used to prototype electrical circuits. The electrical components may be connected quickly and easily by simply inserting the component leads into the appropriate holes on the board. Because they don't need solder or other permanent connections, breadboards are ideal for quickly prototyping and testing circuits..

Fig. 27. : AC-DC Adapters

F. LED emitting green, yellow and red colors Green, yellow, and red LEDs are often used as status indicators in electronics, with each colour serving a somewhat different purpose. In many cases, a green light indicates that everything is running well, whereas a yellow light serves as a warning or indicates that there may be a problem. Indicators of electricity and traffic utilise these hues often as visual status indicators.

Fig. 28. : LED light

G. Resistor – In an electrical circuit, a resistor limits how much current can pass. Its major function is to protect electrical components from being damaged by electrical current. The ohm is a universal unit of resistance measurement. Electrical circuits often use voltage dividers, current limits, and signal conditioners..

Fig. 29. : Resistor

I. Arduino IDE - This open-source software may be used to programme the Arduino board. For building and uploading programmers to the board, it provides a user interface. The IDE supports a simplified version of C++ and includes a library of pre-written scripts for commonly performed tasks. A serial monitor is also provided, which may be used to investigate data sent by the board and troubleshoot the code.

J.Thing Speak Cloud – With the help of the open-source, cost-free application Thing Speak, gadgets may communicate with one another online. Developers used Ruby to construct it. It offers an application programming interface (API) that mobile devices and social networking sites may utilise to access, retrieve, and record data more easily. Thing Speak was made available by io Bridge in 2010 to assist with IoT applications. Customers may analyse and display data by using Thing Speak integrated within MathWorks' C++ without purchasing a separate copy of C++.

Fig. 30. Thing Speak Cloud

5 Working Procedure

Sensor data is read by the system's central controller, a Node MCU, and then displayed through LEDs. The MQ-135 is a part-per-million air quality sensor, while the DHT11 is a meteorological station. LEDs indicate the current security status and data is sent to the Thing Speak server. After the MQ-135 is calibrated for 24 minutes, the DHT11 is heated for 10 minutes. When the complete working code for the Node MCU is available, the hardware circuit may be constructed from the necessary components.

6 Hardware Model

The DHT11 and MQ-135 gas sensor modules are calibrated and warmed up with the help of the hardware model. After powering the Node MCU with 12V DC for 20 minutes, the DHT11 sensor is preheated by connecting its Vcc and Gnd pins to the VU and Gnd pins of the Node MCU, respectively. Connect the MQ-135 gas sensor module's Vcc, Gnd, and analogue DATA wires to Node MCU's VU, GND, and A0 pins, then run Node MCU on 12V DC for a day to bring it up to temperature and calibrate it. Both modules have their Vcc pins connected to the 5V adaptor on the Veroboard, and their LED indication cathodes connected to the Node MCU's D2, D3, and D4 pins, as well as the MQ-135's analogue DATA line's A0 pin, the DHT11's DATA pin, and the Node MCU's Gnd pin. An AC-DC converter supplies the required 9V DC, and the Node MCU is pre-loaded with the necessary instructions..

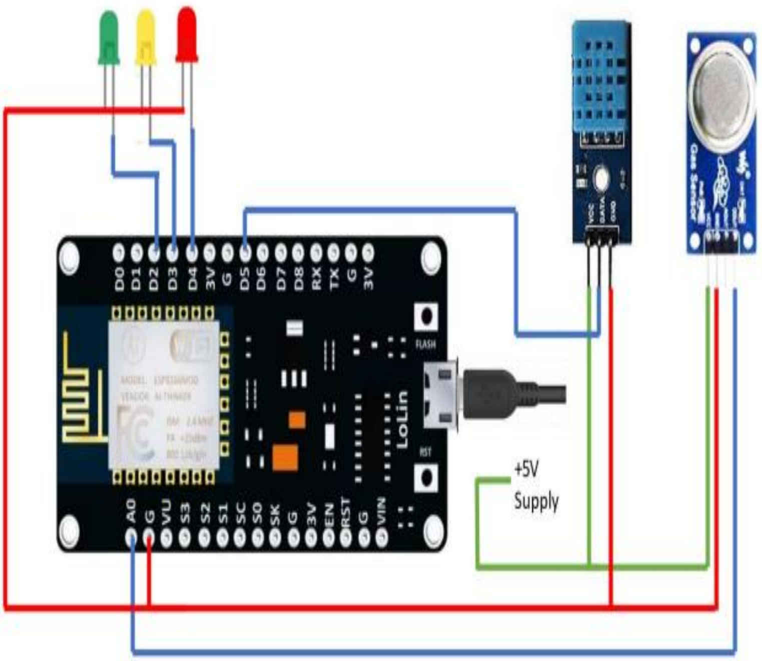


Fig. 31. : Hardware Model

7 SOFTWARE IMPLEMENTATION

Algorithms

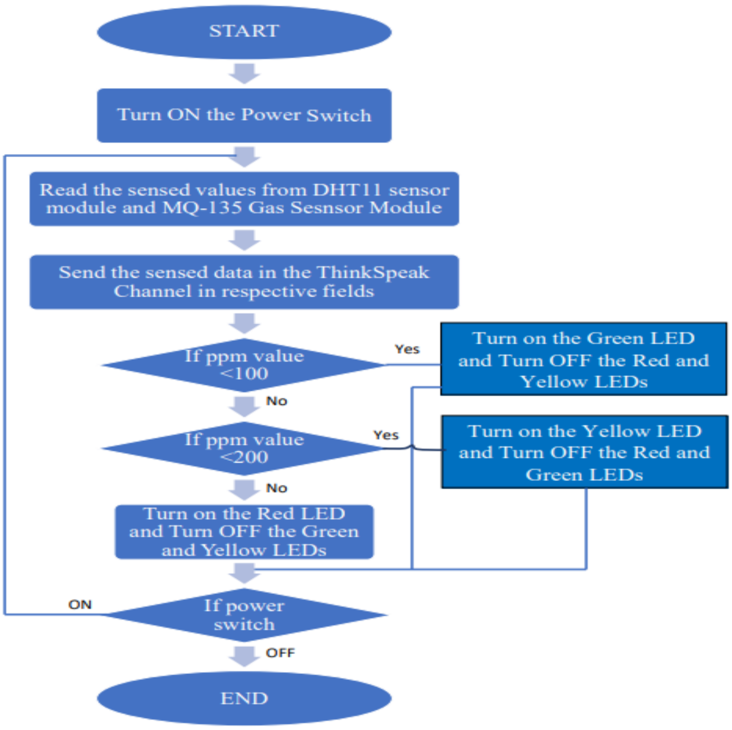


Fig. 32. Flow Chart of Software Implementation

8 Calibration of MQ-135 Gas Sensor Module

Calibration theory states that exposing the sensor to a clean air environment is crucial. Develop a formula to reduce the sensor's voltage reading to microvolts (parts per million). The following conclusion may be drawn from these data points: In theory, the most important step is to calibrate the sensor in ambient air. Determine a percentage value (ppm) for the sensor's voltage measurement (parts per million). With these figures, we may learn:

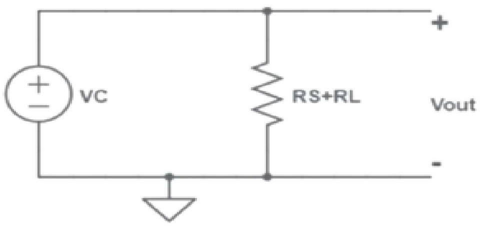


Fig. 33. : Calibration of MQ-135 Gas Sensor Module

From Ohm's Law, at a constant temperature, we can derive I as follows:

$$I = V/R \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

From Fig 11, eqn. 1 is equivalent to

$$I = Vc/RS + RL \ldots\ldots\ldots\ldots\ldots (2)$$

From Fig 10, we can obtain the output voltage at the load resistor using the value obtained for I and Ohm's Law at a constant temperature

$$V = I \, x \, R \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$VRL = [VC / (RS + RL)] \, x \, RL \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$VRL = [(VC * RL)/(RS + RL) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

So now we solve for RS:

$$VRL \, x \, (RS + RL) = VC \, x \, RL \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$(VRL \, x \, RS) + (VRL \, x \, RL) = VC \, x \, RL. \ldots\ldots\ldots\ldots (7)$$

$$VRL \, x \, RS = (VC * RL) - (VRL * RL) \ldots\ldots\ldots (8)$$

$$RS = \{(VC * RL - (VRL * RL)\} / VRL \ldots\ldots\ldots\ldots (9)$$

$$RS = \{(VC * RL) VRL\} - RL \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

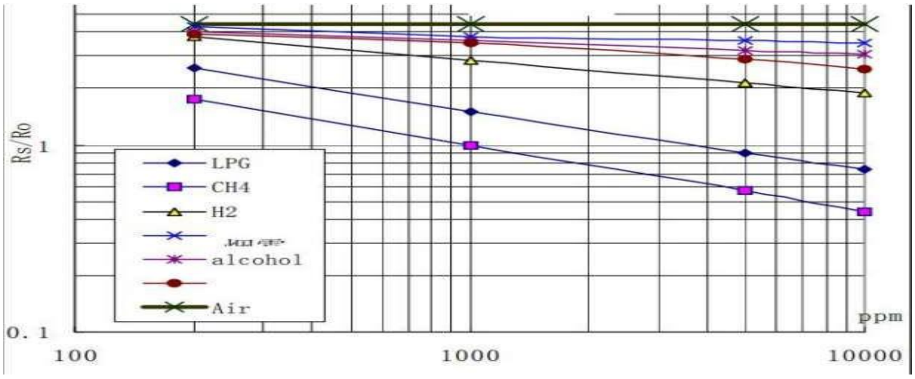


Fig. 34. Graph representing ratio vs ppm variations

Eqn. 9 helps us to find the internal sensor resistance for fresh air.

From the graph shown in fig 11. we can see that the resistance ratio in fresh air is a constant:

$$RS / R0 = 3.6 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Fig. 11 The result of Equation (Eq.) 3.6 is shown in the datasheet. The RS measurement taken in free space is used as a baseline from which R0 is determined. The average analogue reading from the sensor will be converted into a voltage digitally. The RS formula will then be used to determine R0. Assume for the moment that all lines are straight. Because of this linear connection, the formula for both the ratio and the concentration may be combined into a single expression. This allows you to determine the concentration of a gas at any ratio, regardless of whether or not that ratio is shown on the graph. We'll utilise the line equation, but this time using logarithms instead of degrees. Using the data in Figure 11, we attempt to get the following values.

$$y = mx + b \ldots\ldots\ldots\ldots\ldots\ldots (11) For \; a \; log - log \; scale,$$

the formula looks like this:

$$log10y = m * log10x + b \ldots\ldots\ldots\ldots\ldots (12)$$

Let's find the slope. To do so, we need to choose 2 points from the graph. In our case, we chose the points (200,2.6) and (10000,0.75). The formula to calculate slope m(here) is the following:

$$m = \{logy - log(y0)\} / \{ logx - log(x0)\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (13)$$

If we apply the logarithmic quotient rule, we get the following: Now we substitute the values for x, x0, y, and $y0 \colon m = log(0.75/2.6) / log(10000/200) \ldots\ldots\ldots\ldots\ldots\ldots.. (14)$

$$m = -0.318 \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (15)$$

We can compute the y-intercept now that we know m. In order to achieve this, we must choose one point from the graph (once again from the CO2 line). As for us, we went with (5000,0.9)

$$log(y) = m * log(x) + b \ldots\ldots\ldots\ldots\ldots\ldots.. (16)$$

$$b = log(0.9) - (-0.318) * log(5000) \ldots\ldots\ldots\ldots.. (17)$$

$$b = 1.13 \ldots\ldots\ldots\ldots\ldots.. \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

Now that we have m and b, we can find the gas concentration for any ratio with the following formula:

$$log(x) = \{log(y) - b\} / m \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (19)$$

However, in order to get the real value of the gas concentration according to the log-log plot we need to find the inverse log of x:

$$x = 10 \wedge [\{log(y) - b] / m \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (20)$$

We will be able to convert the sensor output numbers into PPM using equations 9 and 20. (Parts per Million). Now, we created the code and properly connected the Node MCU after flashing it.

9 SOFTWARE CODE for Calibration of MQ135 Sensor

```
#include <iostream>

using namespace std;

void setup() {
Serial.begin(9600);
pinMode(A0, INPUT);
}

void loop() {
float sensor_volt;
float RS_air;
float R0;
float sensorValue = 0.0;
    Serial.print("Sensor Reading = ");
Serial.println(analogRead(A0));

for (int x = 0; x < 500; x++) {
    sensorValue = sensorValue + analogRead(A0);
}

sensorValue = sensorValue / 500.0;
sensor_volt = sensorValue * (5.0 / 1023.0);
RS_air = ((5.0 * 1.0) / sensor_volt) - 1.0;
R0 = RS_air / 3.7;

Serial.print("R0 = ");
Serial.println(R0);
delay(1000);
```

```
#include <ESP8266WiFi.h>
#include <DHT.h>
#include <ThingSpeak.h>

DHT dht(D5, DHT11);
#define LED_GREEN D2
#define LED_YELLOW D3
#define LED_RED D4
#define MQ_135 A0

int ppm=0;
float m = -0.3376;
float b = 0.7165;
float R0 = 3.12;

WiFiClient client;
long myChannelNumber = 123456;
const char myWriteAPIKey[] = "API_Key";

void setup() {
Serial.begin(9600);
pinMode(LED_GREEN,OUTPUT);
pinMode(LED_YELLOW,OUTPUT);
pinMode(LED_RED,OUTPUT);
pinMode(MQ_135, INPUT);

WiFi.begin("WiFi_Name", "WiFi_Password");
while(WiFi.status() != WL_CONNECTED) {
delay(200);
Serial.print(".");
}
Serial.println();
Serial.println("NodeMCU is connected!");
Serial.println(WiFi.localIP());

dht.begin();
ThingSpeak.begin(client);
}
```

```
void loop() {
float sensor_volt;
float RS_gas;
float ratio;
int sensorValue;
float h;
float t;
float ppm_log;
float ppm;

h = dht.readHumidity();
delay(4000);
t = dht.readTemperature();
delay(4000);
sensorValue = analogRead(gas_sensor);
sensor_volt = sensorValue*(5.0/1023.0);
RS_gas = ((5.0*1.0)/sensor_volt)-1.0;
ratio = RS_gas/R0;
ppm_log = (log10(ratio)-b)/m;
ppm = pow(10, ppm_log);

Serial.println("Temperature: " + (String) t);
Serial.println("Humidity: " + (String) h);
Serial.println("Our desired PPM = "+ (String) ppm);

ThingSpeak.writeField(myChannelNumber, 1, t, myWriteAPIKey);
delay(20000);
ThingSpeak.writeField(myChannelNumber, 2, h, myWriteAPIKey);
delay(20000);
ThingSpeak.writeField(myChannelNumber, 3, ppm, myWriteAPIKey);
delay(20000);
```

```
if(ppm<=100) {
digitalWrite(LED_GREEN,HIGH);
digitalWrite(LED_YELLOW,LOW);
digitalWrite(LED_RED,LOW);
}
else if(ppm<=200) {
digitalWrite(LED_GREEN,LOW);
digitalWrite(LED_YELLOW,HIGH);
digitalWrite(LED_RED,LOW);
}
else {
digitalWrite(LED_GREEN,LOW);
digitalWrite(LED_YELLOW,LOW);
digitalWrite(LED_RED,HIGH);
}
delay(2000);
}
```

10 Results

The MQ135 sensor measures temperature, humidity, and air quality for the project. When the data was compared to that from a mobile weather app, it was found to be inaccurate by a total of 0.06 degrees, 2.0 percent, and 0.03 ppm for temperature, humidity, and air quality, respectively. The system's accurate readings of ambient temperature and humidity provide evidence of this.

Table 4. representing MQ135 sensor to detect the temperature, humidity, and air quality

Expt. No.	Temperature (in celsius)			Humidity (in %)			Air Quality (in ppm)		
	Project Reading	**App Reading**	**Error**	**Project Reading**	**App Reading**	**Error**	**Project Reading**	**App Reading**	**Error**
1	31.2	33	1.2	70	65	5	8.61	8.5	0.11
2	33.3	32	1.3	70	65	5	42.25	42	0.25
3	33.8	32	1.8	74	70	4	52.3	53	-0.7
4	34.2	33	1.2	74	69	5	4.26	4.34	-0.08
5	22.6	22	0.6	59	57	2	0.67	0.7	-0.03

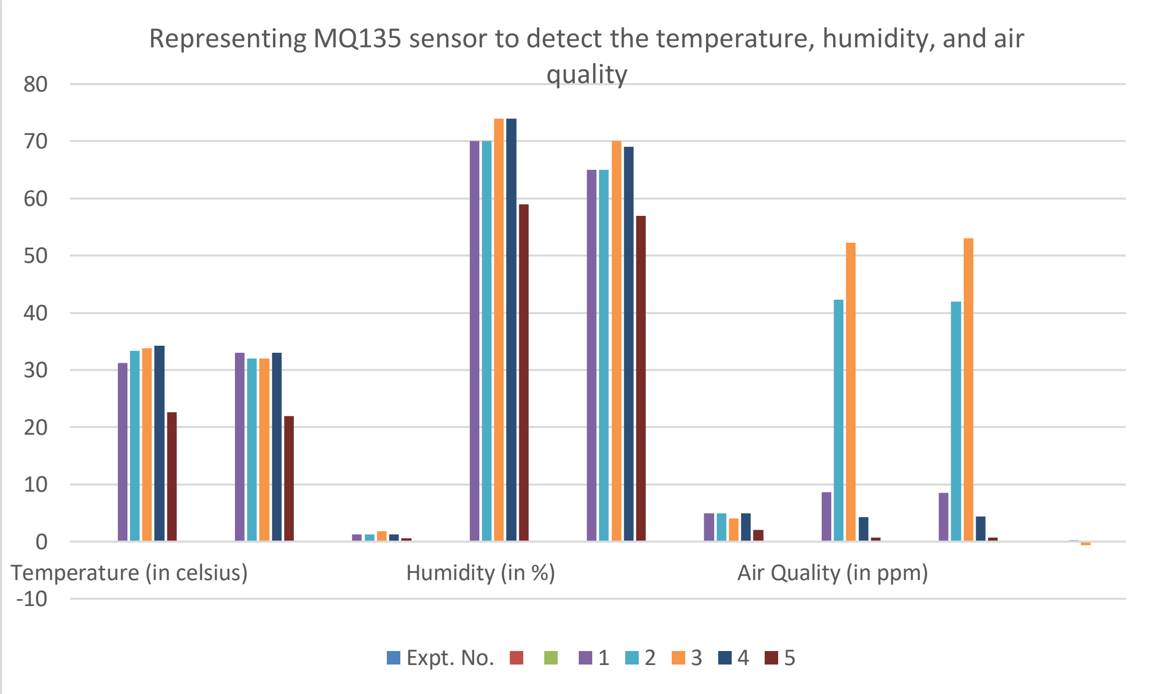


Fig. 35. Representing MQ135 sensor to detect the temperature, humidity, and air quality

11 CONCLUSION

The current temperature, humidity, and Air Quality Index are just some of the metrics that this IoT gadget monitors and displays (AQI). The system uses a MQ135 sensor to detect and measure airborne pollutants such as smoke, CO, CO2, NH4, and others in parts per million (ppm). The instrument provides very accurate readings of both temperature and relative humidity (in Celsius). LED lights on the gadget display the air quality around the setup, with Google data providing further confirmation. By including gas sensors for various pollutants, the system would be able to track the ppm concentrations of each pollutant separately. The sensor does a great job monitoring the local environment for things like temperature, humidity, and air quality, but it needs a constant internet connection to upload its findings to the Thing Speak cloud. In sum, the system offers a reliable and low-cost means of monitoring environmental factors including temperature, humidity, and air quality.

12 REFERENCES

64. Kumar, N. S., Vuayalakshmi, B., Prarthana, R. J., & Shankar, A. (2016, November). IOT based smart garbage alert system using Arduino UNO. In 2016 IEEE Region 10 Conference (TENCON) (pp. 1028-1034). IEEE.
65. Arumugham, Anand Jayakumar & Yesyand, Praviss & Prashanth, Venkstesh. (2021). IoT Based Air Pollution Monitoring System.
66. Ahmed, Jesif & Kalita, Udit & Kashyap, Heniel & Chetri, Amir. (2018). Centralized Air Pollution Detection and Monitoring: A Review. 2. 49-54.
67. WHO, Global Environmental Change, World Health Organization, Geneva, Switzerland, 2005.
68. Air Resource Management Centre, Vehicle-related air pollutants and public health, Ministry of Environment and Natural Resources, Sri Lanka, May 2003, pp. 611.
69. Kim, K. H., Kabir, E., & Kabir, S. (2015). A review on the human health impact of airborne particulate matter. Environment international, 74, 136-143.
70. Kaur, S., & Singh, P. (2020). Internet of things based air quality monitoring system. Materials Today: Proceedings, 33, 1806-1811.
71. Zhang, Y., & Chen, Q. (2020). An IoT-based air quality monitoring system for smart cities. IEEE Access, 8, 197152-197161.

72. Patel, A. R., & Patel, N. (2021). IoT-based air quality monitoring system using low-cost sensors. In 2021 11th International Conference on Cloud Computing, Data Science & Engineering (Confluence) (pp. 595-599). IEEE.
73. Akhtar, I., & Sardar, S. (2020). An IoT based air quality monitoring system using low-cost sensors. Journal of Physics: Conference Series,
74. Wijaya, I. K., Astuti, P., & Kusumadewi, S. (2020). An air pollution monitoring system based on IoT for urban areas. Journal of Physics: Conference Series, 1460(1), 012066.
75. Jain, S., Nigam, R., & Singh, S. (2020). A review on air quality monitoring using IoT. Journal of Ambient Intelligence and Humanized Computing, 11(11), 5105-5118.
76. Wu, H., Zhu, J., Liu, Y., & Lu, Y. (2021). An IoT-enabled air quality monitoring system with a wireless sensor network. Sustainability, 13(3), 1205.
77. Chen, S., Zhao, J., & Ren, Z. (2020). Design and implementation of air pollution monitoring system based on IoT. In 2020 IEEE International Conference on Information and Automation (ICIA) (pp. 1859-1864). IEEE.

Exploring the Motivation factors for Migrant Entrepreneurship in the Indian Economy

Trilok Singh

Department of Management
MITS, Gwalior, MP, India

trilokpratapsinghchauhan@mitsgwalior.in

Abstract: Over the last decade, migrant entrepreneurship has increased dramatically, with social integration problems, violence, exclusion, intolerance, and prejudice still clouding their contribution to Indian society. This article aims to provide an empiric explanation of the momentum of migrant businesses in the Indian economy. A 19-point survey of 480 migrant entrepreneurs in major Indian cities was conducted. Key exploratory factor analyzes and then confirmatory factor analyses were used to explore common factors that could clarify perceived variables' underlying views. Results revealed that five factors that motivate migrated entrepreneurship are family survival needs, community support, market conditions, individual identity, and business operational know-how. This work gave valid and reliable scale measurement that measures motivations responsible for migrant Entrepreneurship and confirms that migrated entrepreneurs do associate particular motivation dimensions during their migration. This study's results provide valuable insights and the real reason for Indian migrant entrepreneurs and have implications for government policies and owners.

Keywords: Migrant entrepreneur; Motivation; Economic growth; Entrepreneurialism; Migration; Globalization.

1 Introduction

Human civilization was followed by migration. Historically, as in the case of slavery, movement may have been forced or associated with colonization. However, rapid industrialization and urbanization in developing countries led to major international waves in the late 19th and early 20th centuries (Thapan, 2005). While people migrate to improve their lives and health, the migration cycle is nevertheless characterized by barriers that affect not only systemic and even cultural constraints but also the emotional and psychological distress of migrants (Mishra and Misra, 2017).

Migration is one of the critical factors affecting demographic changes. This affects the growth, composition, and distribution of the population. 'Migration' is interdisciplinary. Demographers, economists, sociologists, and academics investigated the causes and consequences of migration for humans, families, cultures, and regions (Roy and Tumbe, 2019). The movement has a direct impact on the social, political, and economic lives of citizens. Given the migration process's inherent complexity, not all migrants can be examined within the same theoretical framework (Reja and Das, 2019). Migration is defined as a transition to another migration region, which usually crosses administrative boundaries during a certain migration period, including changes in residence (UN,1993).

Tumbe (2014) states that migration has consistently been overlooked in the broad range of Indian labor market and economic history research under the assumption of 'low' spatial mobility. Gender roles are crucial to the maintenance of migration flows dominated by men and remittance economies. A male-dominated movement can be a significant household strategy. It can also enhance women's autonomy in many ways, but in the long term, women are likely to resist dramatically increased freedom if they only marry primary economic activity. If lessons can be learned from the Great Indian Migration Wave, not only should public policy support migrant workers and their ambitions, but they also create conditions for more gender-balanced migration.

Migration statistics began to be collected during the 1872 Census but were only quite specific until 1961. The changes made in 1961 lasted until 2001; a more comprehensive format was adopted in the 2011 Census. The Indian Census describes a migrant as a permanent resident, A mandatory minimum stay for the destination of six months. This is not a temporary transfer. The census deals with migration present residence (state of destination) and place of origin (Origin status) and includes different stay durations. Indian movement is of two types: birth migration and last migration from your home. If a person is identified in a census other than his / her birthplace, this will be considered migrants in the hometown. One individual is deemed to be the last migrant if she/he had earlier been living outside her / his place of mention.

Before the 20th century, economic migration was driven by men, semi-permanents, and refugees, much like the Great Indian Wave of Migration. However, these migrations have taken place in various areas, such as the Northwest Indian Subcontinent and some coastal regions. Indian business historian Claude Markowitz explains the unique selectivity of migration in Punjab, Rajasthan, Gujarat, and Sindh. In the 20th century, capital migration to the Great Indian Wave of Migration contributed to the international development of Indian enterprises. Mining, gold, and Indian multinationals also saw the second half of the 20th century (Tumbe, 2019). There is no human population that is completely immobile. Migration is as ancient as human culture is. Regional borders have played a significant role in the identification of movement in early history. Migration was then limited to a certain extent due to a lack of transport. However, migration is now responding to technological advances, industrialization, urbanization, and convenient transportation (Reja and Das, 2019). Migration has become natural in modern times. It has become part of global urbanization and industrialization due to the growth of transport and connectivity. For most nations, people's rapid movements from villages to cities, from cities to towns, have followed industrialization and economic development. The Constitution of India offers fundamental freedom to live in every part of the world. Therefore, migrants don't need to register at origin or destination (Keshri & Bhagat 2012).

Tumbe (2012) has shown that the magnitude of remittance-based migration in regions with 20% of the Indian population in the 20th century is persistently high. These magnitudes decreased from the early 20th century's heights in areas such as Bihar and the East Coast and increased over the century in some other regions. Most significantly, some of India's wealthiest districts have seen an increase in migration, indicating that underdevelopment is not the primary cause of migration. In explaining migration's persistence, we highlight the importance of the social networks and deeply rooted migration cultures affected by factors in the source region.

Since the beginning of the 20th century, Indian censuses have collected data on migration from birthplaces. However, data on migration of last residence and residence at the list location have also been collected since 1971. As a result, migration from 1971 to migration should be measured from the previous decades (Kapur 2014). It is essential to study migration trends to understand changes in the movement of people around the world. It is a highly unpredictable aspect of population development that is most likely to have a political and cultural impact on the economy (Breman, 1994; Haberfeld, 1999). Proper knowledge of migration dynamics will help predict the potential redistribution of the population. In terms of birth, death, and internal migration, these forecasts' reliability and accuracy are highly dependent on considering all the transient variables under which the population is most accurate (Chakravarty, 1997). Increased understanding and analysis of migration trends and patterns should be emphasized during periods when economic and industrial growth has increased in various parts of the world, and population movements have increased. Several studies have shown that the amount of cross-state migration in India is small. They have confirmed that about one-third of the Indian population is reported outside their birthplace, demonstrating the importance of movement as a significant demographic process in India (Beck, 1985). Migration is a cycle of balance that reduces regional inequalities at different growth stages and is as old as human society. The rate of national movement has decreased since 1991. However, the figures from the 2001 census show a setback in this pattern. In the 1990s, rising migration rates are often seen as a symptom of the new economic policy's unleashed power. It was a political and economic transition in India following the LPG policy of 1991. New ethnic populations are on the rise as the Indian economy restructures, while some immigrant groups become business owners, and initial steps have been taken by immigrant entrepreneurship. Since 1991, India's rise in new ethnic groups and recent immigration reforms, immigrant entrepreneurship has become a significant contemporary issue (Kundu and Gupta, 2002). Many immigrants have moved to small businesses and their families, and many have moved to broader ethnic enclave markets (Hassan and Daspattanayak, 2007; Chand 2010).

India's focus on demographic migration research is relatively low as most researchers pay attention to economic, political, and public health phenomenon (Bhagat and Keshri, 2020). This is partly due to the dramatic decline in interest in migration research, particularly internal migration, since the early 1990s, with demographic analysis shifting towards reproductive health. However, demographers seriously ignore the abundance of data from Indian migration censuses, which prefer data from projects sponsored by external agencies. Therefore, it is possible to identify very few recent demographic studies on the causes and effects of internal migration in India (Bhagat, 2008).

However, no study has been conducted that includes all variables to address migrant entrepreneurship's motivation in the Indian economy. None of the previous papers used a factor analysis approach. This paper empirically sets out the motives behind India's migrant entrepreneurship. This paper consists of five sections. Following this introduction, Section 2 provides a literature review for the promotion of entrepreneurship. The third section contains data and analytical findings. Section four summarizes the results and integrates them into the existing framework and few closing remarks at the end.

2 Literature Review

The idea of entrepreneurship is not recent: it became apparent in economics and sociology at the beginning of the 18th century (Lee and Black 2017). There is a lot of literature, and therefore there are specific principles for entrepreneurship. Butler (2001) defines entrepreneurs as perceiving opportunities and risking opening up new markets, designing and improving new products and processes in the face of uncertainty. The combination of new forms of value creation and entrepreneurship is also defined as adopting critical aspects of risk-taking, innovation, and proactively entrepreneurship is increasingly involved in international business, ethnic enterprises, and transnational enterprises (Dana, 1993).

Migrants include those who have immigrated but exclude members of ethnic minority groups who have spent several centuries living in a state that has reached the early stages of the business cycle (Sahin et al., 2007). Several studies support migration-business connections, while businesses have had a significant impact on migrants' economic and social integration. Entrepreneurship is, therefore, the strategy chosen for workers to remain active in several situations; to move away from unemployment; to use their skills and resources; to increase their income, and even to create jobs for members of families or ethnic groups entering the host country (Collins 2008). Chapple et al. (1994) argue that self-employed workers are an extension of the ethnic community to ensure that the group members are healthy and functioning.

Many researchers have studied other characteristics or habits that may be related to business. The overwhelming majority of these features belong to both migrants and non-immigrants. Clark and Drinkwater (2010) found that successful competitive individuals are more likely to engage in practices or services that are personally responsible. Khadria (2006) argued that providing opportunities for start-ups, technology, economic development, society, and organizations impacts entrepreneurship. According to Chand and Ghorbani (2011), the high unemployment rate among indigenous peoples also offers ample opportunities for small entrepreneurs. Market conditions in these areas encourage immigrants to start a business. Four criteria have been established for the success of small ethnic companies in the open market: (1) under-served or discontinued markets; (2) low-level economies; (3) fragmented and unpredictable demand markets; and (4) markets supported by large mass-marketing organizations are one area in which immigrant companies can grow (Varma and Varma, 2009).

Goods, services, and jobs are growing worldwide in an increasingly global economy. Therefore, the focus was on understanding people's business behavior across international, economic, and cultural boundaries (Levent et al. 2003). Entrepreneurship is an effective form of economic activity and a useful springboard for migrants' socio-economic development throughout ethnic minority literature (Clark and Drinkwater 2010). However, the difficulties in understanding this practice also lie in the differences between ethnic groups, generations, business sectors, and the development of business in the various theories behind immigrant entrepreneurship (Blackburn and Ram 2006).

To achieve social and economic integration, rising wealth inequalities create jobs, markets, technology, and innovation; the migrant sector is becoming increasingly important (Fairlie and Lofstrom 2015). However, existing literature supports the view that employment and exports, increased social capital, increased consumer choice, and development in specific sectors play an essential role in migrant business economics (Rath 2002; Light and Gold 2000). However, the social and cultural orientations of immigrant enterprises face several challenges.

Several studies have supported the idea of a positive relationship between migration and trade that is best for skilled migrants. They are the most professional migrants in the country of residence and the state of origin with the expertise and resources. Migrant global knowledge and connections help reduce the cost of bilateral trade. Much is the result of the increased cultural awareness and anonymity of the ethnic network (Azmat and Samaratunge 2009). Numerous immigrant-controlled social networks help connect buyers and sellers around the world. Migrants will, therefore, act as intermediaries to change (Azmat 2010).

Also, indirect effects on migration are closely linked to trade. Migrants provide potential investors with useful information on the future success of the host economy. High performance, scale, reliability, and way of working. Migrants are also workers, as FDI requires knowledge arbitration, and foreign market experience would reduce the risk (Tung et al. 2011). We are providing useful resources for hosting economies and improving multiplier impacts and depleting economies. Innovation, cost savings, access to new markets, and incentives for social business learning can be driven (Checchi et al., 2007).

New globalized technologies and business strategies increasingly depend on growth and development. The fact that these structures are significantly different in terms of economic development (Deshingkar, 2017). Returning migrants may have significant adverse effects on growth and the direct impact of the importation of additional resources. As we build new companies, we will add scale, profitability, expertise, and market efficiency (Shukla and Cantwell 2018). The development of new technologies and best practices could also promote technological change and growth (Jiang et al. 2016; Keshri & Bhagat, 2012).

Several recent studies analyzed migrants as workers in their own countries (Kapur 2010). Overall, previous research also explored the reasons for choosing the impact of migrant workers. Migration is often not a random process but usually happens in areas previously occupied by family members or new migrants from similar ethnic groups (Singh et al., 2018). Internal migration is a critical element of economic growth and development, providing job transfer opportunities across sectors and regions. Growth, economic development, and other creative alternatives involve more efficient delivery. Labor is a crucial contribution because it is the main advantage of most people in developing states, particularly young people. Jobs can be reallocated, in particular across sectors, employees, and geographical regions. Therefore, it is no surprise that any episode of productive development and growth is followed by significant labor transactions, particularly from rural to urban. Migrant links were vital for trade facilitation in the early twentieth century, crucial for investment finance in the latter half of the century, and are still valued for investment in the service sector (Tumbe, 2017). Migration and the resulting funds result in higher incomes, increasing poverty, improving health and education, and sustainable growth. These innovations could have cost immigrants and their families a great deal in standard terms (Ratha et al., 2009).

Analyzing migration trends is essential to understand the changes taking place within the country in the movement of people (McGee, 1998; Singh, 1998; Srivastava and Sasikumar, 2003). People are most economically, politically, and culturally unpredictable and vulnerable (Singh, 1998; Srivastava and Lusome, 2006). Several studies have shown that the number of inter-state migrations in India is low. At the same time, about one-third of the Indian population is reported outside their birthplace, indicating the importance of movement as a significant Indian population (Nair and Narain, 1985; Premi, 1990; Singh, 1998). The prevalent caste system, new marriage patterns, the importance of family life, the plurality of Indian languages and cultures, the lack of education, and the commercial farming have repeatedly argued that the Indian population is virtually immobile (Rajan and Mishra, 2012). Sarkar (1978) noted that the majority of migration from rural to urban areas in developing countries, such as India and Bangladesh, was due to various socio-economic factors. Research by Lakshmanaswamy (1990) shows that the literature on rural development favors urban migration and growth. Vartak et al., (2019) state that movement has long been a critical factor in the global transformation of agricultural societies. The framework for migration-growth is of vital importance.

Rural migration describes people's movement between their communities and urban areas, who typically pursue better living conditions (Solanki, 2002; Breman, 1994; Haberfeld, 1999). India has a large number of landless workers and an equal number of partially rural workers. Many people's livelihoods depend on internal mobility, especially in rural areas, providing a steady stream of migrant workers to cities. An extensive sample survey was conducted in Bihar, Kerala, and Uttar Pradesh by Oberay, Prasad, and Sardana (1989). People are also known to move from low-wage to higher-wage areas, a fair way of making money and rising living standards. Since migration originates primarily from weak states, migrants' characteristics have to be studied over the century (Parameswaranaik and Jha, 2018). While spatial migration features shed some light on migration patterns, it is difficult to determine whether migration causes problems or developments. To understand the link between entrepreneurship and migration, it is therefore essential to examine migrants' economic characteristics in terms of debt and the type of employment involved (Bhagat, 2016).

2.1 States with the highest number of migrants

According to Mishra and Misra (2017), Indian migration is primarily between rural and rural areas (47.4%), followed by urban (22.6%), rural and urban (22.1%), and urban (7.9%). The census ranges from 21.8 to 22.1 percent for rural to urban migration between 2001 and 2011 and from 15.2 to 22.6 percent for urban migration. Biswas (2014) reported 45.36 crore migrants, some 37 percent of Indians. The studies described above and several others were based on data from the 2011 census. India is a village nation where most of the population still relies on farming. Global and international mobility are among the main characteristics of the people in today's world. This has contributed to an increase in demand in urban areas and is growing steadily every year. Indian urbanization rates rose from 27.81% in 2001 to 31.16% in 2011, according to the 2011 census. Urban transitions are essential for demographic transformation. As India has shown, the different rates of demographic change between rural and urban areas will influence the pace of urbanization. The extra speed of demographic change around the city will change the population growth rate between cities (Tumbe, 2016). Urbanization in India is the result of a population boom caused by poverty and rural-urban migration. The Hindi speaking belt is the primary route for migrants. According to the census, 50% of India's total migrants are from Uttar Pradesh, Bihar, Rajasthan, and Madhya Pradesh (Chandrasekhar and Sharma, 2015).

Uttar Pradesh and Bihar have a relatively high number of migrants, while metro stations such as Delhi and Mumbai are more than one-third (Sharma, 2017). On the other hand, there were 50% of migrants from Maharashtra, Punjab, Gujarat, Uttar Pradesh, and Haryana. Such proportions outweigh its share of India's total population. Ironically, on both sides, Uttar Pradesh is ranked, it includes people leaving it for livelihoods, and people are looking for livelihoods (Viswanathan and Kumar, 2015).

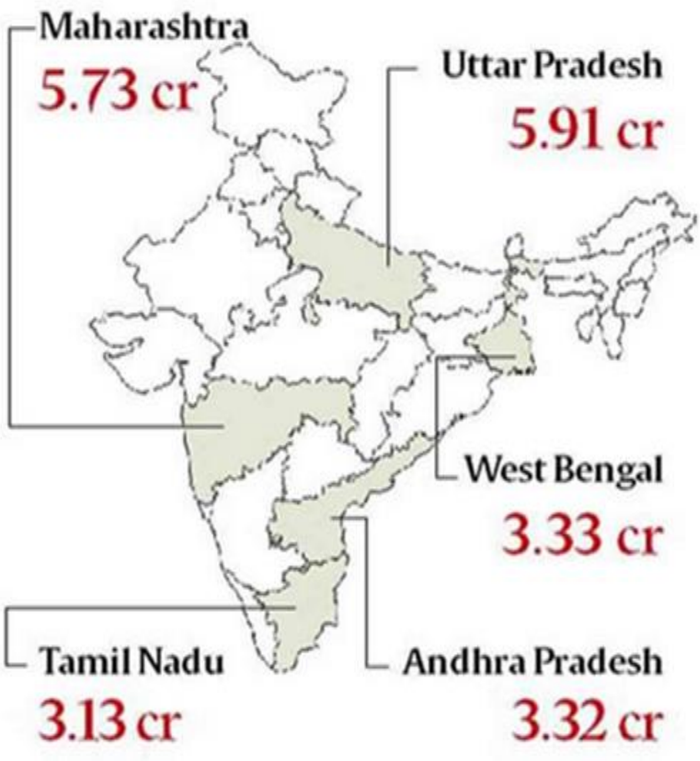


Fig. 36. State with the highest number of migrants

Source Census 2001, 2011

2.2 Inter-state migrations in India

Migrants traveling to other destinations in their own countries increased their growth rates around 2001 and 2011 compared to those traveling abroad. So-called inter-state migrants increased by 55% between the 1991 and 2001 censuses. It was only 33% between the 2001-2011 censuses.

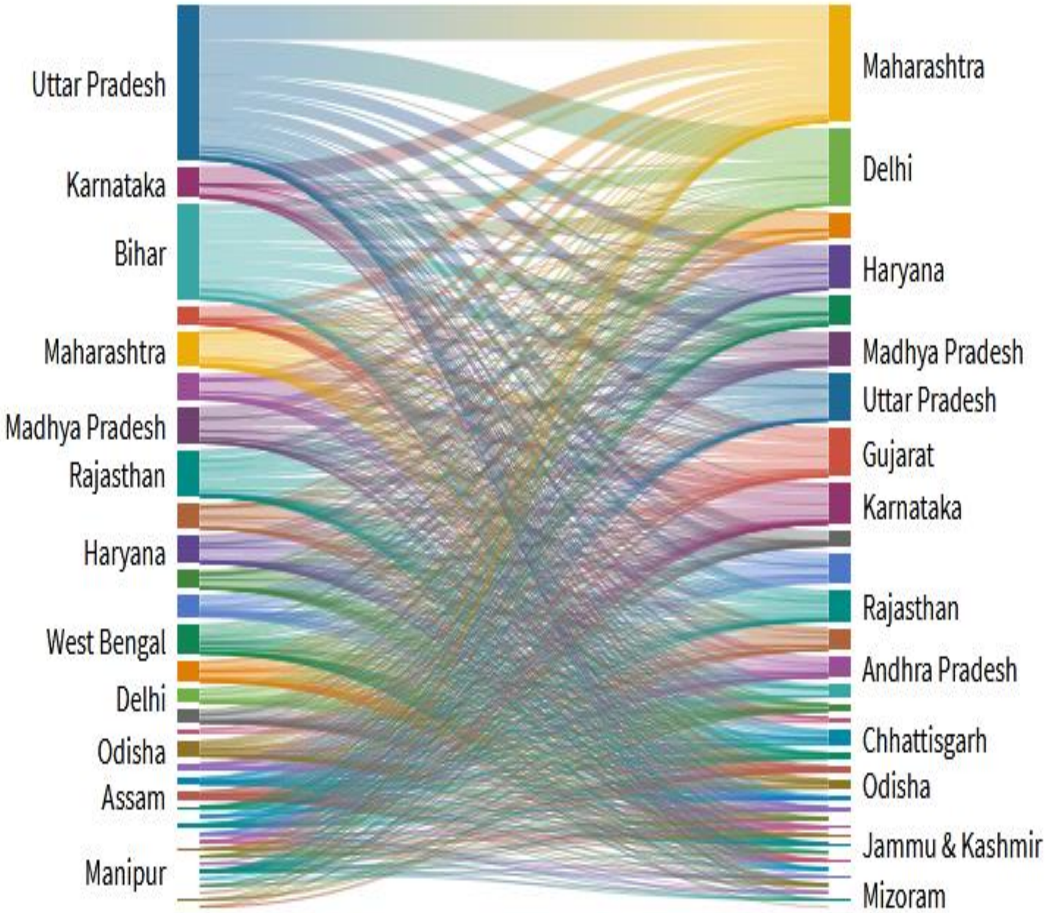


Fig. 37. Inter-state migrations in India (Census-2011)

Source Census 2001, 2011

According to the most recent 2011 census, the number of domestic migrants in India has increased to 450 million. This is 45 percent higher than the 309 million reported in 2001. The proportion of internal migrants in the population increased from 30% in 2001 to 37% in 2011. However, the trend remained mostly unchanged after 2001. The movement is mainly in the same district (62%). Approximately 26 % of the population is between communities in the same state. The inter-state movement is just 12%.

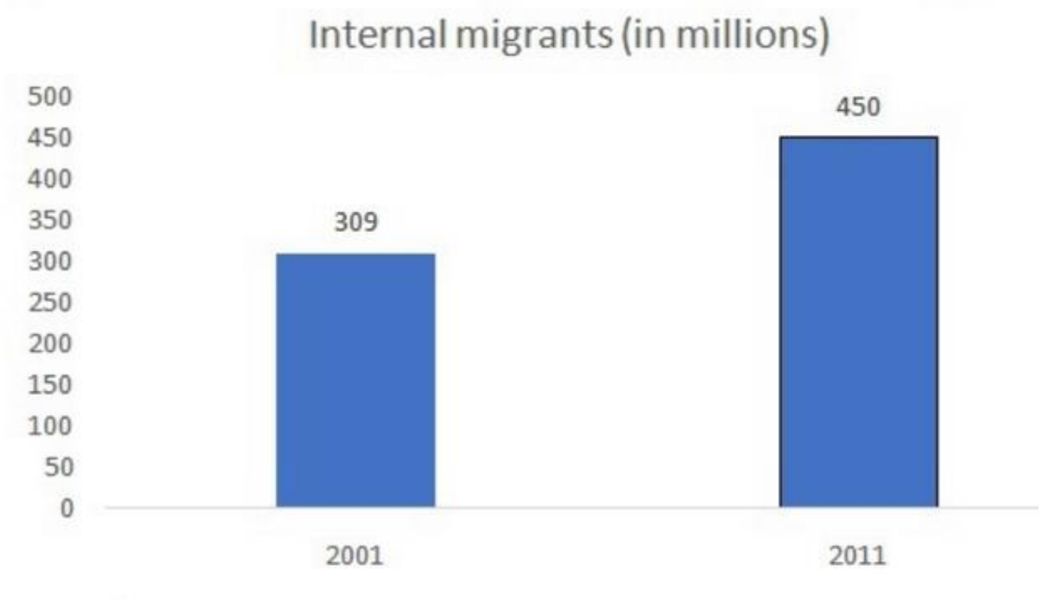


Fig. 38. Number of internal migrants in India (2001-2011

Source Census 2001, 2011

2.3 Growth by migrant type (inter-state, intra-state, intra-district)

Who's pushing migration to India? The reasons for this are variable by class. The marriage justification was for two-thirds of the women who had emigrated from their last place of residence. One-third of the total migration between individuals, labor, and industry is also the leading cause of movement between individuals. While immigration tends towards closer distances for marriage between women, men do not tend to separate when they migrate to work.

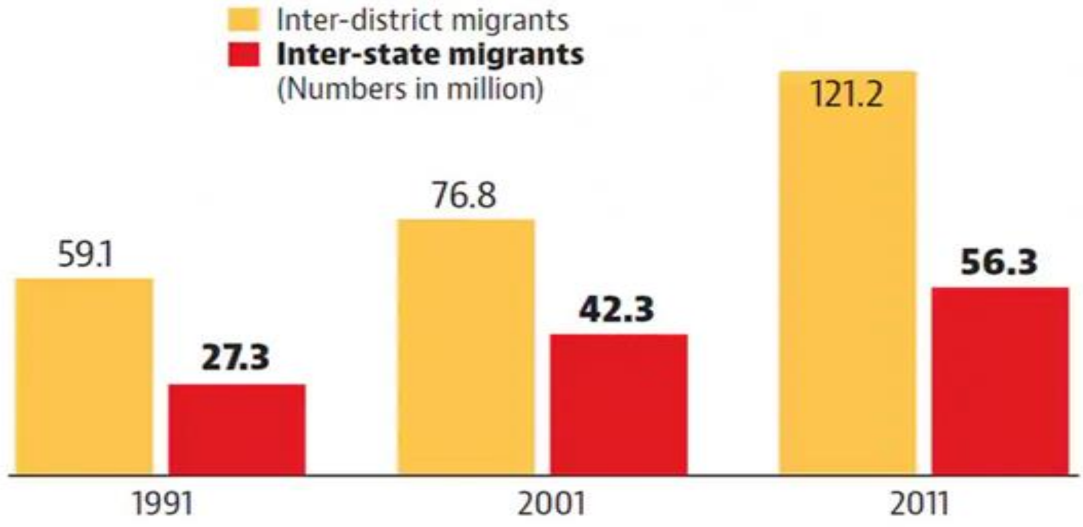


Fig. 39. Inter-state, Intra- district Migrants (1991-2001-2011)

Source Census 2001, 2011

2.4 Reason for migration

2001, the pattern of the 1991 and 2011 census was the same as in 1981. The census did not include the birthplace of rural-urban status. Information on the 2001 census was not collected 'Natural disasters' as a justification for migration and a new migration explanation. It's added 'Moved at birth.' Migration is driven by increasing competition for urban jobs, and higher wages improved employment opportunities, better jobs, decent wages, medical care, and education are driving rural residents to cities. Push factors such as no employment facilities, low salaries, lower incomes, crime, less medical care, and education urge people to cities.

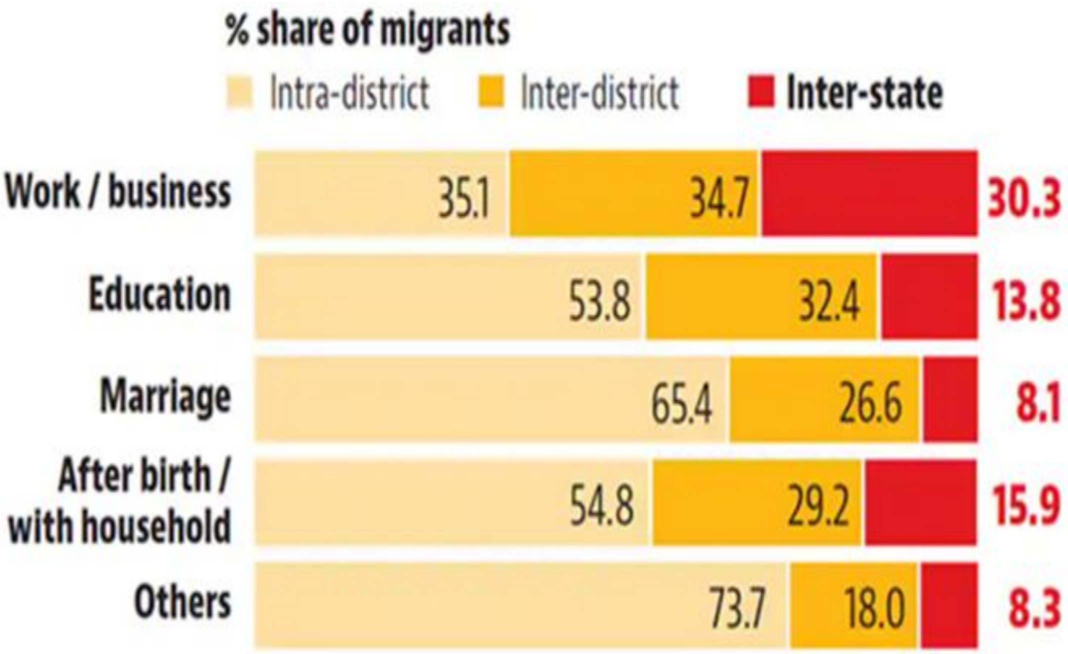


Fig. 40. Reason for migration

Source Census 1991, 2001, 2011

The issue of 'Reason for Migration' was raised in 1981. Except in Marriage, in particular, is an essential factor in rural or urban migration. Migration to the R-U and U-U resulted in the search for better manufacturing, finance, transport, and service sectors. Despite the lack of educational facilities, people move to urban areas to improve learning opportunities. Similar to 1.77 percent of the population who migrated to school in the 2011 census. The explanation for internal migration is political instability and inter-ethnic conflicts. Citizens move from rural to urban, as environmental conditions slowly decline. Forced relocation may also occur for purposes, including construction programs.

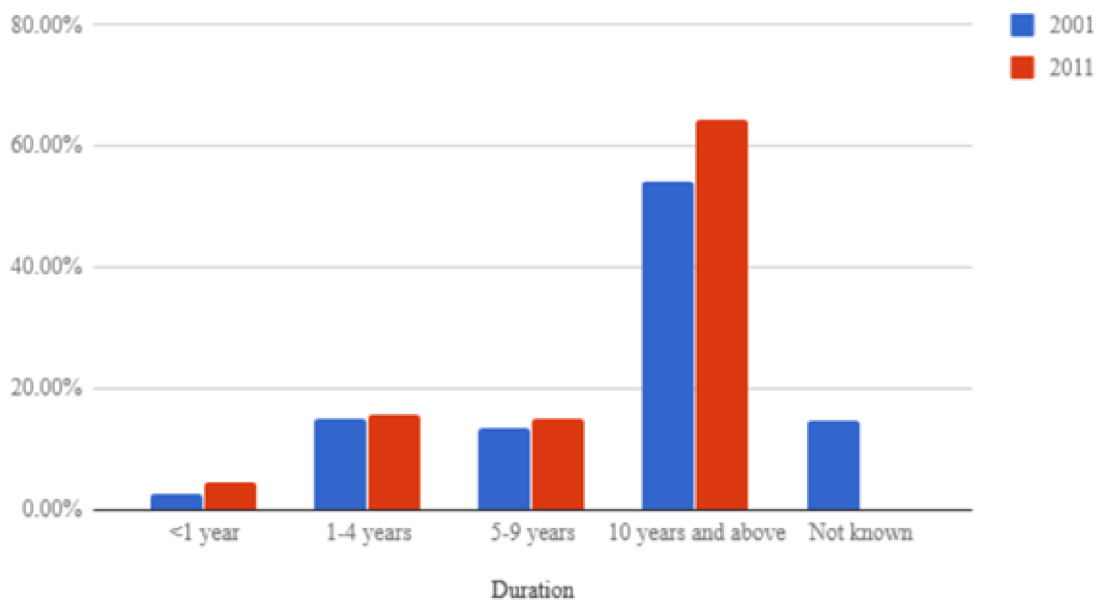


Fig. 41. When did people Migrate

Source Census 2001, 2011

The gender gap in economic migration (work, business, and education) widens with the distance from migration. There are 3.2, 4.3, and 7.4 people traveling throughout the districts and states for every woman who goes to work, business, or college.

2.5 Challenges faced by internal migrants:

Demonstrating their nationality to migrant entrepreneurs entering a new state is a crucial issue. State-authenticated identity documents provide for secure citizenship. Recognition is due to a lack of social and civic participation. Since migrant's entrepreneurs do not have sufficient proof of identity and residence, they do not meet Know Your Customer (KYC) criteria set out in Indian banking regulations. Bank accounts cannot be opened in cities that affect a migrant entrepreneur's savings and transfer actions. A 2011 survey of seasonal migrant workers found that 22% of seasonal Indian migrants had no IDs or names on the voting list. Migrants who are entirely dependent on intelligence intermediaries end up being employed in low-end manuals, low-value, challenging, and hazardous jobs and are routinely exploited with little or no legal incentive.

3 Research Design And Methodology

This work aims to classify the causes of Indian migrant entrepreneurship in a practical way. For identifying the attributes responsible for such behavior, three steps process have been utilized. In the first step, 14 attributes have been identified through past researches (Singh and Koiri 2018; Liargovas and Skandalis 2012; Azmat and Zutshi 2012). In the second step, open-ended questionnaires have been given to selected migrated entrepreneurs of India's national capital region. This questionnaire comprised of a single open-ended question asking five reasons to migrate for business here. Seventy-three reasons have been collected, but most of them are redundant, and some are not clear. Finally, all the variables collected in the first two steps have been given to five expert committees comprised of 4 academicians and one migrated businessman. This culminated in using a final set of 21 items to explore the rationale behind Indian migrant entrepreneurship. Also, four demographic questions have been incorporated into the questionnaire. Gender, Founder/Non founder, Immigrants' generation (First/Second+), Age (less than 30, 30-45, 45-60, 60+).Data were collected using a Likert scale of 9 points where 9 means strongly agree, and one means strongly disagree. Chronbach's α was used to test the reliability of the scales. The value of

Chronbach α was 0.811. Data have been collected through snowball sampling, as these people have their communities everywhere. Online and offline, both this method has been used to target the National Capital Region, Mumbai, Bangalore, Surat, Indore, Chandigarh, Ludhiana, Surat, Kanpur, Agra, and Aligarh. 503 filled questionnaires have been received; however, 480 questionnaires have been used for analyses.

4 Data Analysis And Results

Data Analysis has been classified into three different sections. In the first section, we have analyzed demographic data, and then exploratory factor analysis and confirmatory factor analysis have been applied in the second and third stages, respectively.

4.1 Demographic data Analysis

The study is based on the method of the survey. A total of 503 migrant entrepreneurs were asked to respond to the questionnaire, and a total of 480 responses were considered acceptable for data analysis. Demographically, this sample comprised of 80.625% of men and 19.375% women (Table 1). 66.875% of the respondents were the founder of the firm (Table 2). 81.875% was the first generation of the business, and the rest were second or more than the second generation (Table 3). 41.042% of the respondents were of the age group between 45 to 60 years, followed by 32.708% of the respondents belonging to 30 to 45 years, 19.375 were of age group less than 30 years, 6.875% of respondent were above 60 years of age.

Table 5. Gender profile of the respondents

Valid	Frequency	%	Valid %	Cumulative %
Men	387	80.625	80.625	80.625
Women	93	19.375	19.375	100
Total	480	100	100	

Table 6. Founder/Non founder profile of the respondents

Valid	Frequency	%	Valid %	Cumulative %
Founder	321	66.875	66.875	66.875
Non Founder	159	33.125	33.125	100
Total	480	100	100	

Table 7. Immigrants' generation of the respondents

Valid	Frequency	%	Valid %	Cumulative %
First	393	81.875	81.875	81.875
Second+	87	18.125	18.125	100
Total	480	100	100	

Table 8. Age of the respondents

Valid	Frequency	%	Valid %	Cumulative %
Less than 30	**93**	**19.375**	**19.375**	**19.375**
30-45	**157**	**32.708**	**32.708**	**52.083**
45-60	**197**	**41.042**	**41.042**	**93.125**
60+	**33**	**6.875**	**6.875**	**100.000**
Total	480	100	100	

5 Exploratory factor analysis (EFA)

The Kim et al. (2010) approach was adopted by randomly dividing the 480 respondents into two similar samples to ensure that the analysis was accurate. The first half of the model is an estimation sample of 280, and another half is a validation sample of 280 respondents. The matrix of correlation was determined, showing enough relationships to perform factor analysis. The data showed the presence of the right variables since the partial correlations were weak. Next, we check the suitability of the data to use the Exploratory Factor Analysis by Correlation Matrix, Anti-Image Correlation, KMO (Kaiser-Meyer-Oklin) for sampling adequacy and Barlett's Sphericity Examination. The KMO value was obtained as 0.757, which indicated a sufficient sample size for factor analysis. The Barlett sphericity test was conducted, and there was a statistically significant number of correlations between variables. Accordingly, the data were considered suitable for factor analysis, as shown by the above parameters. Method of extraction and the number of extracted factors. The primary component analysis was used to remove elements. The number of factors to be maintained was based on the latent root criterion, and the variance was clarified.

During EFA, three and more items have been loaded in a factor at 0.543 or greater were assigned to the element with the highest loading. Two things were not related to any aspect and hence not included in further analyses. As a result, five elements have been extracted, accounting for 64.743% of the variance. They are listed as

Family survival needs
Community support
Market Conditions
Individual Identity
Business operational know-how

Table 5 shows all five factors extracted in this study, their respective eigenvalues, the variance explained by each, and the items with the highest item-to-total correlation.

Table 9. Factor analysis (rotated component matrix)

Item	family survival needs	Community support	Market Conditions	Individual Identity	Business operational know how	Communalities
Unemployment	.851	.146	.060	-.004	.155	.501
Job positions for family	.839	.105	.159	.039	.108	.432
Improvement in status	.790	.201	-.055	-.018	.048	.511
Social restrictions of family	.634	.399	-.039	.000	-.057	.732
Family financial needs	.546	-.161	.150	.168	.202	.725
Close relations among immigrants	.112	.951	-.002	.122	.016	.692
Number of Immigrant compatriots in market	.129	.943	.011	.137	-.001	.445
Knowledge of immigrant needs	.130	.832	-.032	.027	.042	.616
Opportunity identification	.008	.085	.848	.029	-.062	.754
Empty market segment	.130	.012	.837	-.002	S	.670
Better living standards	-.145	.071	.760	-.112	-.276	.772
Level of economic development	.213	-.183	.576	.038	.179	.416
ME8	.535	-.146	.543	.107	.049	.566
Need for independence	.087	.282	.016	.774	.166	.925
Risk propensity	-.041	.056	.114	.747	.317	.933
Individuality	.072	-.014	-.098	.670	-.212	.713
Technology availability	-.047	.113	.043	-.094	.697	.715
Government policies	.159	.014	-.058	.214	.653	.676
Financial supports	.242	-.090	-.025	.066	.600	.508
Eigenvalues	4.290	2.897	2.190	1.770	1.155	
% of Variance	22.577	15.246	11.525	9.314	6.081	
Cumulative %	22.577	37.823	49.349	58.663	64.743	

6 Confirmatory factor analysis (CFA)

The EFA is useful for data reduction but does not demonstrate the dimensionality of measures essential for scale development (Gerbing and Anderson, 1988). The validity of the products was checked with CFA in this analysis. Until the CFA was carried out, Cronbach coefficients were used to test the items' internal consistency. Cronbach's calculated coefficients indicated a high level of internal reliability for each of the five dimensions: family survival needs = 0.828, community support = 0.827, market conditions = 0.785, individual identity = 0.721, Business operational know-how = 0.714. We performed CFA using Amos 23 software by using the remaining random half sample of 240 as the secondary holdout sample for validation and prediction. Model fit criteria suggested by Hu and Bentler (1998) were used for the measurement model: w2/df, the goodness of fit (GFI), adjusted goodness of fit (AGFI), comparative fit index (CFI), root mean square residual (RMR), and root mean square error of approximation (RMSEA). Acceptable models should have chi-square/df≤3, AGFI≥0.80, SRMR≤0.1, RMSEA≤0.1, and GFI and CFI≥0.90. The measurement model's indices were satisfactory overall: chi-square/df=2.363, AGFI=0.901, SRMR=0.061, RMSEA=0.076, and GFI and CFI=0.941, suggesting that the five-factor model is stable within the holdout data. As all the factor loading were significantly varied from 0.582 to 0.753, establishes the convergent validity. Composite reliability and the average variance extracted (AVE) have proved the unidimensionality and concurrent validity. The composite reliability varied from 0.60 to 0.72, satisfying the criteria of 0.6. AVE ranged from 0.54 to 0.78, thus meeting the requirements of 0.50 (Fornell and Larcker, 1981). Also, discriminant validity was evaluated by comparing the AVE estimates for each construct with the parameter estimates' square between the two constructs. According to Fornell and Larcker (1981), discriminant validity is achieved if the AVE of each construct exceeds the square of the standardized correlations between pairs of constructs. All AVE estimates were more significant than the squared relationships between all constructs in this study. Thus, both convergent validity and discriminant validity were considered to have been established.

7 Discussion And Implications

This research aims to explore and identify the motivating factors for Migrant Entrepreneurship in the Indian Economy. For this purpose, a survey was conducted on 21 items by 480 migrated entrepreneurs in 11 major cities of India, including the National capital region of the country. EFA's results suggested five factors that motivate for migrated entrepreneurship from 19 items; two items were deleted during the EFA. These factors are family survival needs, community support, market conditions, individual identity, and business operational know-how. The findings of the CFA further contributed to the seven-dimensional. In short, motivations for migrated entrepreneurship can be measured through five dimensions, 19 items scale. These dimensions are consistent with past studies also. First dimension family survival needs are almost similar to studies like Liargovas and Skandalis (2012). The second dimension of motivation for migrated entrepreneurs is community support, which is also consistent with studies like Marger (2001) and Mata and Pendakur (1999). Market conditions as third dimensions have always been an essential factor for entrepreneurship motivations, so as migrated entrepreneurship. Size 4, individual identity is another critical factor as objectives of life and ambitions always motivate to make self-identity. Thus many of the first generation entrepreneurs are establishing their businesses to make their own identity. The last factor of motivation towards migrated entrepreneurship business operational knows how. This dimension is a new dimension that has not been found in the literature.

This research has both theoretical and practical implications. Theoretically, three contributions are made. First, a valid and reliable scale has been developed to measure the motivation of entrepreneurship among migrants. Second, the findings confirm that various factors available in literature in motivating to migrate to establishing the business in a different location. Third, the results also ascertained that the available scales for measuring motivating factors for migrate entrepreneurship are applicable in the Indian economy. Practical applications of this research also exist. India is a vast country, and people are relocated from one place to another for various reasons. Some of them are migrated to doing business. Establishing business at a location where you do not belong to is always a risky affair. Despite that, various peoples have taken this risk and building business after migration. Many of them are doing well in this phenomenon. With numerous past success stories, others are motivated to migrate to doing business. While our findings are robust, future work may include more actual sample data, more initial motivations, and additional region locations. It may consist of other countries that have experienced significant migratory inflows over the last few years. Future researchers may also test the difference in motivating factors in different countries, especially the collectivistic and individualistic countries. However, both from a theoretical and a practical point of view, it would be significant to explore the background and implications of motivating factors for migrating entrepreneurship. Therefore, a future researcher could measure this kind of phenomenon.

8 References

78. Anderson, J. C., & Gerbing, D. W. (1988). Structural equation modeling in practice: A review and recommended two-step approach. *Psychological bulletin*, *103*(3), 411.
79. Azmat, F. 2010. "Exploring social responsibility of immigrant entrepreneurs: Do home country contextual factors play a role?." *European Management Journal* 28(5): 377-386.

80. Azmat, F., and A. Zutshi. 2012. “Influence of home-country culture and regulatory environment on corporate social responsibility perceptions: The case of Sri Lankan immigrant entrepreneurs.” *Thunderbird International Business Review* 54(1): 15-27.
81. Azmat, F., and R. Samaratunge. 2009. “Responsible entrepreneurship in developing countries: Understanding the realities and complexities.” *Journal of Business Ethics* 90(3): 437-452.
82. Bhagat, R. B. (2008). Assessing the measurement of internal migration in India. *Asian and Pacific Migration Journal*, *17*(1), 91-102.
83. Bhagat, R. B. (2016). Changing pattern of internal migration in India. In *Contemporary demographic transformations in China, India and Indonesia* (pp. 239-254). Springer, Cham.
84. Bhagat, R. B., & Keshri, K. (2020). Internal Migration in India. In *Internal Migration in the Countries of Asia* (pp. 207-228). Springer, Cham.
85. Biswas, R. R. 2014. “Reverse migrant entrepreneurs in India: Motivations, trajectories and realities.” *In Indian Skilled Migration and Development* 285-307. Springer, New Delhi.
86. Blackburn, R., and M. Ram. 2006. “Fix or fixation? The contributions and limitations of entrepreneurship and small firms to combating social exclusion.” *Entrepreneurship and Regional Development* 18(1): 73-89.
87. Breman, J. (1994). *Wage hunters and gatherers: search for work in the urban and rural economy of South Gujarat*. Oxford University Press.
88. Butler, K. D. 2001. “Defining Diaspora, refining a discourse.” *Diaspora: a journal of transnational studies* 10(2): 189-219.
89. Census of India 1991. Series 1, India Part-V D-series, Migration Tables. Registrar General and Census commisioner, India.
90. Census of India 2001. Soft copy, India D-series, Migration Tables. Registrar General and Census commisioner, India.
91. Chakravarty, B. (1997). The census and the NSS data on internal migration. *Ashish Bose*.
92. Chakravarty, B. 1997. “The Census and the NSS Data on Internal Migration”, in Ashish Bose, Davendra B. Gupta, and Gaurisankar Raychaudhuri (eds.), Population Statistics in India. New Delhi: Vikas Publishing House Pvt. Ltd.
93. Chand, M. 2010. “Diasporas as drivers of national competitiveness.” *Advances in International Management*, 23: 583-602.
94. Chand, M., and M. Ghorbani. 2011. “National culture, networks and ethnic entrepreneurship: A comparison of the Indian and Chinese immigrants in the US.” *International Business Review* 20(6): 593-606.
95. Chandrasekhar, S., & Sharma, A. (2015). Urbanization and spatial patterns of internal migration in India. *Spatial demography*, *3*(2), 63-89.
96. Chapple, S., S. Gorbey, and J. Yeabsley. 1994. “Literature review on the impact of immigration.” *Wellington: New Zealand Institute of Economic Research*.
97. Checchi, D., G. De Simone, and R. Faini. 2007. “Skilled migration, FDI and human capital investment.”
98. Clark, K., and S. Drinkwater. 2010. Recent trends in minority ethnic entrepreneurship in Britain. *International Small Business Journal* 28(2): 136-146.
99. Collins, J. 2008. “Immigrant entrepreneurs in Australia: Regulations and responses.” *Migracoes: Journal of the Portugal Immigration Observatory*.
100. Dana, L. P. 1993. “An inquiry into culture and entrepreneurship: case studies of business creation among immigrants in Montreal.” *Journal of Small Business and Entrepreneurship* 10(4): 16-31.
101. Deshingkar, P. (2017). Towards contextualized, disaggregated and intersectional understandings of migration in India. *Asian Population Studies*, *13*(2), 119-123.
102. Fairlie, R. W., and M. Lofstrom. 2015. “Immigration and entrepreneurship.” *In Handbook of the economics of international migration* Vol. 1: 877-911. North-Holland.
103. Fornell, C., and D. F. Larcker. 1981. “Structural equation models with unobservable variables and measurement error: Algebra and statistics.”
104. Haberfeld, Y., Menaria, R. K., Sahoo, B. B., & Vyas, R. N. (1999). Seasonal migration of rural labor in India. *Population Research and Policy Review*, *18*(5), 471-487.
105. Hassan, M.I. and Daspattanayak, P. (2007): “Internal Migration in India: Some Emerging Patterns in the Post Reform Period”, *Geographical Review of India*, Vol. 69, No. 1, pp. 69-75.
106. Hu, L. T., and P. M. Bentler. 1998. “Fit indices in covariance structure modeling: Sensitivity to under parameterized model misspecification.” *Psychological methods* 3(4): 424.
107. Jiang, X., Y. Yang, Y. L. Pei, and G. Wang. 2016. “Entrepreneurial orientation, strategic alliances, and firm performance: Inside the black box.” *Long Range Planning* 49(1): 103-116.
108. Kapur, D. 2010. “Diaspora, development, and democracy: the domestic impact of international migration from India.” *Princeton University Press.*
109. Kapur, D. 2014. “Political effects of international migration.” *Annual Review of Political Science* 17: 479-502.
110. Keshri, K., & Bhagat, R. B. (2012). Temporary and seasonal migration: Regional pattern, characteristics and associated factors. *Economic and Political Weekly*, 81-88.
111. Khadria, B. 2006. “India: Skilled migration to developed countries, labour migration to the Gulf.” *Migración y Desarrollo* (7): 4-37.

112. Kim, C., W. Tao, N. Shin, and K. S. Kim. K. S. 2010. "An empirical study of customers' perceptions of security and trust in e-payment systems." *Electronic commerce research and applications* 9(1): 84-95.
113. Kundu, A. and Gupta, S.(2002): "Declining population Mobility, Liberalization and growing regional imbalances: The Indian Case" ,in Kundu, A.(ed.) *Inequality, Mobility and Urbanization,* Manak Publishers, New Delhi, pp. 257-274.
114. Lakshmanaswamy, B., & Jindal, O. P. (1990). Statistical analysis on the variability of area weighted rainfall over India. *Mausam*, *41*(4), 569-574.
115. Lee, W., and S. L. Black. 2017. "Small business development: immigrants' access to loan capital." *Journal of Small Business and Entrepreneurship* 29(3): 193-209.
116. Levent, T. B., E. Masurel, and P. Nijkamp. 2003. "Diversity in entrepreneurship: ethnic and female roles in urban economic life." *International journal of social economics*.
117. Liargovas, P. G., and K. S. Skandalis. 2012. "Foreign direct investment and trade openness: The case of developing economies." *Social indicators research* 106(2): 323-331.
118. Light, I., and S. Gold. 2000. "Ethnic economies."
119. Lusome, R., & Bhagat, R. (2006, June). Trends and patterns of internal migration in India, 1971-2001. In *Annual conference of Indian Association for the Study of Population (IASP) during* (Vol. 7, p. 9). Thiruvananthapuram: Indian Association for the Study of Population (IASP).
120. Marger, M. N. 2001. "The use of social and human capital among Canadian business immigrants." *Journal of Ethnic and Migration Studies* 27(3): 439-453.
121. Mata, F., and R. Pendakur. 1999. "Immigration, labor force integration and the pursuit of self-employment." *International Migration Review* 33(2): 378-402.
122. Mishra, P., & Misra, R. K. (2017). Entrepreneurial leadership and organizational effectiveness: A comparative study of executives and non-executives. *Procedia computer science*, *122*, 71-78.
123. Nair, P.S., and Narain, V. 1985. "Internal Migration in India: Demographic Knowledge and Policy Issues". IUSSP Seminar on "Policy Formulation, Implementation and Evaluation: The case of East, South and South East Asia", Contributed Papers, Bombay, India, January 24-28.
124. Oberai, A. S., Prasad, P. H., & Sardana, M. G. (1989). Determinants and consequences of internal migration in India. Studies in Bihar, Kerala and Uttar Pradesh.
125. Parameswaranaik, J., & Jha, S. K. (2018). Return migration of rural youth: a new trend in rural India. *Journal of Global Communication*, *11*(2), 124-127.
126. Premi, M. K., 1990. "India". In Charles B. Nam, William J. Serow, and David F. Sly (eds.), International Handbook on Internal Migration. New York: Greenwood Press.
127. Rajan, S. I., & Mishra, U. S. (2012). Facets of Indian mobility: An update. In *India Migration Report 2011* (pp. 21-26).
128. Rath, J. C. 2002. "Unravelling the rag trade. Immigrant entrepreneurship in seven world cities."
129. Ratha, D., Mohapatra, S., Silwal, A., Irving, J., & Plaza, S. (2009). Migration and development brief. *World Bank*, *24*.
130. Reja, M. S., & Das, B. (2019). Labour migration within India: motivations and social networks. *South Asia Research*, *39*(2), 125-142.
131. Roy, T., & Tumbe, C. (2019). Migration: change and continuity.
132. Sahin, M., P. Nijkamp, and T. Baycan-Levent. 2007. "Migrant entrepreneurship from the perspective of cultural diversity." *Handbook of research on ethnic minority entrepreneurship* 99-113.
133. Sarkar, B. N. (1978). Development, migration and work participation.
134. Sharma, A., 2017. Inter-state Analysis of Manufacturing Performance in India: 2001-02 to 2013-14. *Indian Journal of Industrial Relations*, *52*(4).
135. Shukla, P., and J. Cantwell. 2018. "Migrants and multinational firms: The role of institutional affinity and connectedness in FDI." *Journal of World Business* 53(6): 835-849.
136. Singh, D. P. (1998). Female migration in India. *Indian Journal of Social Work*, *59*, 728-742.
137. Singh, N., and P. Koiri. 2018. "Migration, diaspora and development: impressions from India." *Journal of Enterprising Communities: People and Places in the Global Economy*.
138. Solanki, S. S. (2002). Migration of Rural Artisans: Evidence from Haryana and Rajasthan. *Economic and Political Weekly*, 3579-3580.
139. Srivastava, R., & McGee, T. (1998). Migration and the labour market in India. *Indian Journal of labour economics*, *41*(4), 583-616.
140. Srivastava, R., & Sasikumar, S. K. (2003, June). An overview of migration in India, its impacts and key issues. In *Regional Conference on Migration, Development and Pro-Poor Policy Choices in Asia* (pp. 22-24).
141. Thapan, M. (2005). Introduction, 'Making Incomplete': Identity, Women, and the State,". *Transnational migration and the politics of identity*, 23-62.
142. Thapan, M. (Ed.). (2005). *Transnational migration and the politics of identity*. SAGE Publishing India.
143. Tumbe, C. (2012). India migration bibliography. Bangalore: Indian Institute of Management
144. Tumbe, C. (2012). Migration persistence across twentieth century India. *Migration and Development*, *1*(1), 87-112.

145. Tumbe, C. (2014). *The Great Indian Migration Wave, 1870–2010, Persistence & Consequences*. Mimeo, The Economic Growth Center, Yale University.
146. Tumbe, C. (2016). Urbanization, Demographic Transition and the Growth of Cities in India, 1870-2020. *The International Growth Centre (IGC) Working Paper*.
147. Tumbe, C. (2017). Transnational Indian business in the twentieth century. *Business History Review*, *91*(4), 651-679.
148. Tumbe, C. (2018). India moving: A history of migration. Gurgaon: Penguin Random House
149. Tung, R. L., H. F. Chung, and P. Enderwick. 2011. "Immigrant effects and international business activity: an overview." *Journal of Asia Business Studies*.
150. Varma, R., and D. R. Varma. 2009. "The making of Indian immigrant entrepreneurs in the US." *Economic and Political Weekly* 64-69.
151. Vartak, K., Tumbe, C., & Bhide, A. (2019). Mass Migration from Rural India: A Restudy of Kunkeri Village in Konkan, Maharashtra, 1961–1987–2017. *Journal of Interdisciplinary Economics*, *31*(1), 42-62.
152. Viswanathan, B., & Kumar, K. K. (2015). Weather, agriculture and rural migration: evidence from state and district level migration in India. *Environment and Development Economics*, *20*(4), 469.

Optimizing Format-Preserving Encryption for Secureand Efficient Database Management

Jayashre K [0009-0007-2305-5900]

Department of Computer Science and Engineering Shiv
Nadar University, Chennai, Tamil Nadu, India
jaya2004kra@gmail.com

Abstract: Format-Preserving Encryption (FPE) is a cryptographic method that converts plain text into cipher text while maintaining its original format. FPE plays a crucial role in databases by ensuring that encrypted data retains the struc-ture and attributes of the original information. CryptDB is a database manage- ment system designed to provide secure solutions for encrypted databases. By employing various encryption techniques, including FPE, CryptDB addresses se-curity concerns while preserving functionality. This study focuses on enhancing storage optimization for SQL-aware encrypted databases within CryptDB, utiliz- ing the FNR encryption scheme. The goal is to improve storage efficiency with-out compromising data integrity or format, thereby advancing secure and practi-cal database management in encrypted environments.

Keywords: SQL-Aware Encrypted Databases, FNR Encryption Scheme, FPE, CryptDB, Storage Efficiency

1 Introduction

Migrating application stacks, legacy systems, and databases to the cloud provides numerous advantages. Nonetheless, protecting the privacy of sensitive fields while re- taining their computational functionality poses a significant challenge. To maintain pri- vacy in these scenarios, it is essential to identify sensitive fields within the system and then re-engineer them to enable encryption. Despite the potential advantages, many companies hesitate to move their critical applications to the cloud due to concerns about the privacy implications of handing over sensitive data to third-party cloud providers.

For example, let's consider a data field meant for storing a 32-bit IPv4 address. Throughout the application and/or database, there are several checks in place to ensurethat the input data adheres to IPv4 standards. Protecting the privacy of this field using a typical AES-128 encryption method would require modifying its capacity to accom- modate 128 bits, departing from its original 32-bit design. Additionally, any validations reliant on identifying the data type, such as recognizing the dotted notation of the IPv4address, would need to be removed to make way for a randomized cipher string that represents the encrypted IPv4 address.

Increasing the length of the field leads to higher demands on storage and/or band- width. However, removing validations can expose security vulnerabilities such as in- jection attacks. This concern isn't confined to IPv4 addresses; it also pertains to protect- ing the privacy of sensitive data fields like MAC addresses, email addresses, usernames, account numbers, serial numbers, personal identifiable numbers, and credit card numbers.

Contemporary encrypted database systems with SQL awareness, as showcased by CryptDB [14], represent significant progress in tackling confidentiality challenges. CryptDB is an advanced solution crafted to systematically address privacy concerns in SQL database-dependent applications. Importantly, it enables the execution of typical SQL queries on encrypted data without requiring decryption at any stage of the opera-tion.

CryptDB utilizes traditional Symmetric Encryption algorithms like AES and Blow-Fish to safeguard data stored in the database. However, these cryptographic methods, including AES and BlowFish, do not maintain the original plaintext format after en- cryption. As a result, there is a change in both the length and type of fields in the data-base. For example, encrypting a 16-digit credit card number (originally an Integer datatype) using AES yields a 128-bit ciphertext. A significant downside of conventional encryption schemes like AES and BlowFish is their contribution to increased storage space requirements for storing encrypted data.

This article introduces the application of Format Preserving Encryption (FPE) to en-crypt data fields within CryptDB. FPE guarantees the retention of the length and for- mats of the original plaintext during encryption. Consequently, the version imple- mented is labeled as FPE-CDB. Experimental results showcased in the paper illustrateimprovements in storage efficiency, albeit accompanied by a trade-off in performancedegradation.

2 Literature Review

Boldyreva et al. [1] explore cryptographic analysis by introducing order-preserving symmetric encryption (OPE) with a new security concept (IND-OCPA), significantly enhancing efficient search capabilities on encrypted data. Bose and Bai [2] propose Homomorphic Encrypted Federated Learning, which securely integrates Big Data, Metaverse, and Large Language Models, addressing privacy and security concerns. Maryam et al. [3] implement and assess Zero Update (ZU) Encryption Adjustment for querying encrypted databases, emphasizing its secure and efficient client-side utiliza- tion. Gentry [4] presents a fully homomorphic encryption scheme, enhancing decryp- tion efficiency through ideal lattices and advancing practical applications. These studies collectively contribute to cryptographic advancements, covering OPE, federated learn- ing, encrypted querying, and fully homomorphic encryption, providing varied perspec- tives on evolving security landscapes.

Song et al. [5] introduce cryptographic schemes designed for searching encrypted data, ensuring simplicity and efficiency while maintaining provable security. In a sim-ilar vein, Kim et al. [6] propose an

secure database outsourcing, leveraging homomorphic cryptosystems to bolster secu- rity and surpass existing methods in query processing speed. Rautham and Vaisla [10] tackle security and privacy concerns within cloud database frameworks by presenting the Verifiable Reliable Secure-DataBase (VRS-DB) framework. This framework en- hances security through secret share distribution and encrypted operators operating within the same encrypted space. Furthermore, Munjal and Bhatia [11] delve into ad- vanced cryptographic techniques, comparing RSA with the Paillier algorithm to fortify data privacy in cloud services. Their work offers practical solutions for ensuring secure database operations. Collectively, these papers contribute diverse cryptographic per- spectives, presenting innovative frameworks for secure querying, outsourcing, and da- tabase operations within cloud environments.

Bellare et al. [12] introduced format-preserving encryption (FPE), a method that en-crypts plaintext into ciphertext while maintaining an identical format. They explore the "rank-then-encipher" approach using unbalanced Feistel networks (FE1 and FE2), providing security analyses and discussing applications in finance, networking, and de-terministic encryption. Popa et al. [14] presented CryptDB, which addresses the confi- dentiality of SQL database applications through SQL-aware encryption and key linkageto user passwords. This ensures efficient queries while limiting information exposure. Implementations on MySQL and Postgres demonstrate minimal overhead, making CryptDB a versatile choice for various applications. Dara and Fluhrer [15] introduced the FNR encryption scheme, a practical small-domain block cipher that prioritizes inputlength preservation, relevant for ensuring data privacy in Software-as-a-Service appli-cations. Souza and Puttini [16] addressed concerns regarding entrusting sensitive data to cloud services by leveraging client-side encryption for health and financial records. They introduced homomorphic and order-preserving encryption systems for regular searches over encrypted records, thus maintaining confidentiality and end-users' pri- vacy in cloud environments. These papers contribute to the evolution of encryption solutions, considering practical applications and trade-offs in diverse contexts such as cloud computing scenarios.

Ren et al. [18] delve into the application of fully homomorphic encryption (FHE) forunbounded aggregation queries in databases. They introduce two FHE schemes tailored for both numerical and binary values, alongside a novel mechanism for transforming ciphertext. Despite the slower processing compared to plaintext, their research show- cases the potential of FHE in OLAP queries within encrypted databases, with a strongfocus on maintaining data privacy in aggregation scenarios. On a similar note, Miao etal. [19] present an Efficient Privacy-Preserving Spatial Range Query (PSRQ) scheme designed to bolster the security of outsourcing spatial data for Location-Based Services(LBS). By integrating the Geohash algorithm with the Circular Shift and Coalesce Bloom Filter framework, they enhance the confidentiality of spatial data. The extensionof their work, the PSRQ+ scheme, incorporates a Confused Bloom Filter and spatial location conversion to achieve adaptive security and improved query efficiency, partic-ularly with large datasets reaching million-levels. These contributions collectively en- rich the landscape of privacy-preserving techniques in encrypted databases, addressingboth numerical and spatial domains and offering practical solutions for secure and ef- ficient query processing.

3 Foundational Concepts

3.1 Format Preserving Encryption.

Format Preserving Encryption (FPE) ensures that the original format of input do- mains is preserved during encryption. While conventional encryption methods like AES result in a random string when encrypting an IPv4 address represented in dotted notation, FPE encryption schemes maintain the IPv4 address format in the resulting ciphertext.

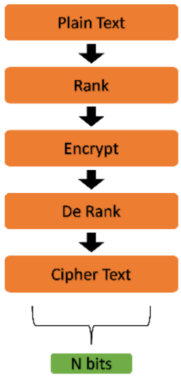


Fig. 42. Format Preserving Encryption

We utilize simplified definitions of FPE schemes while maintaining their generality intact. Detailed definitions and proofs are available in [12]. FPE algorithms incorporate additional parameters known as tweak (t) and domain (d). The tweak (t) operates simi- larly to a cryptographic salt, adding extra randomness. On the other hand, the domain

specifies the context of the plaintext, such as IPv4 addresses or credit card numbers, among other possibilities [12].

The fundamental algorithm of an FPE encryption scheme are outlined as follows:

KeyGen(σ): Generates a key (k) and tweak (t) based on a security parameter (σ).

Encryption(p, k, t, d): The algorithm produces ciphertext (c) from a given plaintext (p), key (k), and tweak (t), ensuring that both the plaintext (p) and ci- phertext (c) fall within the same domain (d). This process involves utilizing rank and de-rank methods alongside a length-preserving block cipher (enc‘). Addi- tional details on ranking functions are discussed in following sections.

Decryption(c, k, t, d): For a given ciphertext (c), key (k), and tweak (t), the al- gorithm retrieves the corresponding plaintext (p). In this process, both the ci- phertext (c) and plaintext (p) belong to the same domain.

FNR, a block cipher introduced in [15], is tailored for safeguarding the format and length of sensitive data within limited domains like MAC addresses, IPV4 (32), IPV6 (32), and similar instances due to its arbitrary length and small domain. Combining Pairwise Independent Permutations with classic Feistel Networks, FNR offers enhanced security over alternative methods.

3.2 SQL Aware Encryption

SQL-Aware Encryption refers to a specialized approach in encryption that custom- izes the encryption process to suit specific predefined SQL operations. These operations include tasks like equality checks, joins, aggregates, and inequality checks, among oth- ers. With this methodology, each data item undergoes encryption in a manner that fa- cilitates computations on the resulting ciphertext, as detailed in [14].

4 Technical Architecture

4.1 FPE-CDB

The underlying framework of our modified edition closely resembles that of CryptDB. Nevertheless, variances emerge in the specific encryption methods utilized, as discussed further in the following sections.

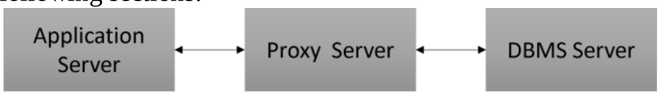


Fig. 43. CryptDB Architecture

CryptDB comprises three essential components, as depicted in Figure 2: the Appli- cation Server, Proxy Server, and DBMS Server. The Application Server acts as the primary server, hosting CryptDB's database proxy and managing the DBMS Server. The Proxy Server stores crucial elements such as a confidential Master Key, the data- base Schema, and the layered encryption for all database columns. In contrast, the DBMS server holds access to the anonymized database schema, encrypted database data, and certain cryptographic User-Defined Functions (UDFs). These cryptographic UDFs are employed by the DBMS server to execute specific operations on the encrypted data (ciphertext).

Below, we outline the steps entailed in processing a query within CryptDB.

In the first stage, the application server initializes a query. Next, the query is received and handled by the proxy server, which anonymizes both the table name and indi- vidual column names. Additionally, all constants within the query are encrypted us- ing a securely stored master key. Moreover, the encryption layers, also known as onion layers, are adjusted depending on the specific operation required by the query. For example, if the query involves equality checks, the proxy server employs the deterministic encryption scheme (DET) to encrypt all values within the designated column where the equality check is to be conducted.

After encryption, the user's query is sent to the DBMS server. At this point, the DBMS server executes the queries using standard SQL and calls upon User-Defined Functions (UDFs) for performing particular tasks like token search and aggregation. Importantly, these tasks are conducted on the encrypted data within the database.

The operations on the encrypted data are performed by the DBMS server, after which the encrypted results are transmitted back to the proxy server.

The proxy server decrypts the encrypted query result it obtains, then returns it to the application server.

4.2 Encryption Techniques

CryptDB utilizes a variety of encryption techniques tailored to the operations speci- fied in a given query. For instance, if a query doesn't include any equality or inequality checks, it employs the random encryption scheme (RND layer). When the query in- volves SUM aggregate calculations, CryptDB utilizes homomorphic encryption

(HOM layer). For executing equality checks, it applies the deterministic encryption scheme (DET layer). Notably, CryptDB employs different encryption schemes for managing inequality checks and joins.

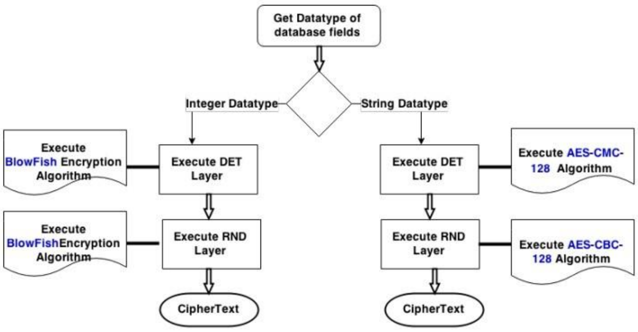


Fig. 44. Onion Layers of CryptDB for an SQL INSERT query.

This paper highlights the importance of employing two encryption layers: Random (RND) and Deterministic (DET).

Random (RND)

This encryption method functions probabilistically, guaranteeing that two identi-cal plaintexts produce unique ciphertexts. This built-in probabilistic nature boosts security, making it IND-CPA secure. In CryptDB, the random encryption layer em-ploys AES-CBC-128 for strings and Blowfish (CBC mode) for integers. Both ap- proaches integrate a random initialization vector (IV) into their encryption process.

Deterministic (DET)

This encryption method functions in a deterministic manner, meaning that iden- tical plaintexts produce identical ciphertexts. This deterministic aspect makes it lesssecure when contrasted with the random (RND) layer. In CryptDB, the deterministicencryption layer is implemented using AES-CMC-128 and Blowfish, with a zero-initialized vector. This layer is primarily used by the server for executing select que-ries that involve equality checks, equality joins, COUNT operations, and DISTINCTclauses.

Figure 3 demonstrates the varied encryption layers employed by CryptDB when executing a fundamental INSERT query. Similar to Figure 2, the columns in the query undergo a two-step encryption process. Initially, they are encrypted using the DET layer, followed by encryption with the RND layer. Subsequently, the resulting cipher- text, generated by RND_int (for columns with Integer Input type) and RND_str (for columns with varchar input type), is stored within the database.

FPE-CDB effectively achieves the two characteristics specified for Format Preserv- ing Encryption (FPE) schemes mentioned earlier. Figure 4 illustrates the various layersof security utilized by FPE-CDB.

In addition to the initial two layers described earlier, CryptDB [1] integrates severalsupplementary layers akin to onion layers. These encompass the Order-Preserving En-cryption (OPE) layer, devised to streamline range queries; the Homomorphic Encryp- tion (HOM) layer [4] [13], aimed at enabling aggregation and counts; and the SEARCHlayer, facilitating full word keyword searches on encrypted data [5].

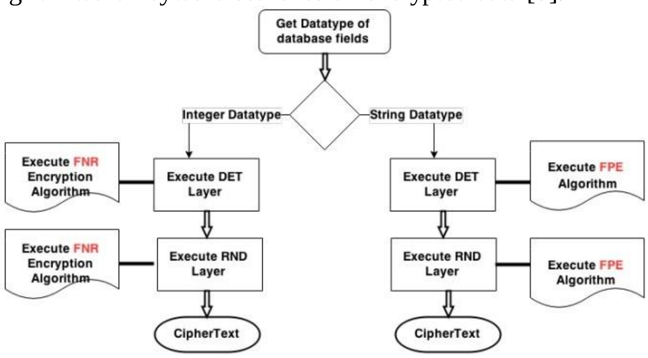


Fig. 45. Onion Layers of FPE-CDB for an SQL INSERT Query

The presence of these extra layers facilitates the performance of diverse SQL oper- ations on encrypted data without necessitating decryption. These layers remain intact within the adapted version, FPE-CDB.

4.3 Implementation

4.4 Toy Application

Our study focuses on a network monitoring application that serves as the benchmark. This application utilizes a dataset commonly used by security analysts to monitor and analyze network traffic. The dataset includes crucial attributes such as Source IP ad- dress, Destination IP address, Protocol, Number of packets, Number of Records, No of Bytes, Start date, End date, and Sensor. These fields are essential for various network monitoring tasks like traffic analysis, intrusion detection, and packet filtering. For our analysis, we have chosen five specific fields from this dataset, which are outlined in Table 1.

Table 10. Database Schema of FPE-CDB

Column ID	Field	Plaintext (char)	AES (char)	FNR (char)
1	Source IP	15	48	15
2	Destination IP	15	48	15
3	Start-Date	19	64	19
4	End-Date	19	64	19
5	Sensors	2	48	2

4.5 Encryption of Datatypes

Preserving the original formats and lengths of input strings is paramount in the mod- ified FPE-CDB. To achieve this, the Flexible Naor and Reingold (FNR) encryption scheme has been chosen. FNR is acknowledged for its capability as a length-preserving block cipher, accommodating input sizes from 32 to 128 bits [15], [7]. This choice guarantees that both the lengths and formats remain intact throughout the encryption process, ensuring the preservation of data types such as IPv4 (referenced in Table 2) and Time Stamps (referenced in Table 3), as further discussed below.

Table 11. Samples for IPv4 Addresses

Plain Text		Cipher Text	
Raw (Dotted)	Ranked (In- teger)	Raw (Inte- ger)	De-ranked (Doted)
64.243.129.86	941079480	1226870871	73.32.144.87
56.23.187.184	2213763856	1067498731	63.160.188.235
131.243.91.16	4026531837	2739475379	163.73.19.179
239.255.255.253	905584639	2223369266	132.133.236.50
53.250.31.255	3222780570	2000079960	119.54.204.88

IPv4 Address

Ranking an IPv4 address involves interpreting it as a 32-bit integer. This integer is then encrypted using a block cipher like FNR, yielding another 32-bit integer. Tomaintain the original format, the resulting ciphertext is converted back (de-ranked) to the dotted notation of the IPv4 address. The algorithm's process is depicted in Figure 1.

Time Stamp

The process starts by converting the input timestamp into an epoch value, whichrepresents a specific date and time used as a reference for computer clocks and timestamps. This epoch value is then encrypted using the FNR encryption scheme. After encryption, the encrypted epoch value is reversed to obtain a date string, main-taining the original format of the plaintext. This resulting date string serves as the ciphertext.

Table 12. Samples for Timestamps

Plain Text		**Cipher Text**	
Raw (String)	**Ranked (Integer)**	**Raw (Inte- ger)**	**De-Ranked (String)**
Date String	*Unix Timestamp*	*Unix timestamp*	*Date String*
16/11/2023T21:04:05	1100639045	1531152620	09/07/2021T16:10:20
15/11/2023T15:44:38	1100533478	627185476	16/11/2018T02:11:16
14/12/2022T09:27:05	569150825	3645016902	03/07/2085T16:41:42
7/10/2023T41:33:07	1105205587	2685279782	03/02/2085T15:03:02
6/11/2023T22:07:06	1105049226	3275728681	20/10/2073T12:38:01

Integers

In the application, there are certain fields, like Port Number and Packets Trans- ferred, which are of integer type. When encrypting these integers using the FNR scheme, the result is an integer ciphertext. These particular fields do not necessitatedistinct ranking functions. In this implementation, we utilize an unsigned 64-bit in- teger data type to store the ciphertexts.

5 Experiments

5.1 Setup

The investigation utilized a setup comprising Ubuntu 23.10 on VMware, equipped with 7GB of RAM and powered by a 1.70GHz 12th Gen Intel(R) Core (TM) i5-1240P Pro- cessor. The reference data originated from anonymized enterprise packet header traces obtained from Lawrence Berkeley National Laboratory and ICSI [8][9]. This dataset encompasses network traffic from late 2004 to early 2005, presented in SILK flow rec- ord format, and was restricted to specific hours and dates. The encryption process in- volved encrypting a maximum of 1 million SILK flow records [17] using the FNR en- cryption scheme, followed by a subsequent performance analysis.

6 Results

Storage: The results of our experiments show a roughly 50% increase in storage efficiency with FPE-CDB. In Figure 5, we visually compare the estimated storage space needed for data encrypted in CryptDB (using AES) versus FPE-CDB (using FNR). The degree of storage improvement depends on the specific application data.

For our dataset, we observed an approximate 50% enhancement in storage effi- ciency. The X-axis of the graph represents the number of records inserted into the database, while the Y-axis shows the Database Size in MB. Additionally, Table 1 provides details on the database schema of FPE-CDB, including the length (numberof characters) of AES ciphertexts (used in CryptDB) and FNR ciphertexts (used in FPE-CDB).

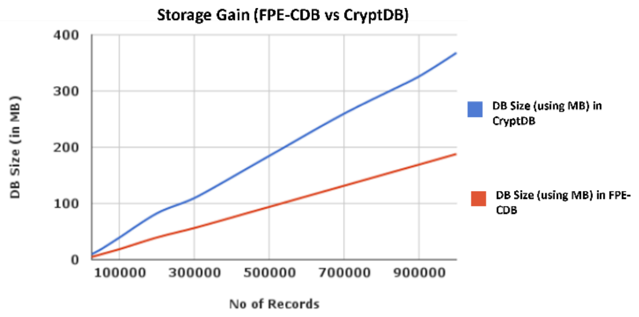


Fig. 46. Storage for CryptDB versus FPE-CDB (in MB)

Calculating the average row length in SQL databases involves considering various parameters such as the fixed data size (size of fixed-length SQL fields), variable data size (size of variable-length SQL datatypes like VARCHAR, number, etc.), null bit- map size, and row header size. Consequently, the total database size can be expressed as data length = Total Number of Rows × Average Row Length. In this particular setup, the database comprises five VARCHAR fields as illustrated in Table 1. Addi- tionally, the encrypted database stores salt values used for encrypting queries and onion layers in CryptDB. Thus, the estimated average row length includes the sum of the variable data length (size of stored ciphertext) and the total size required to store the salt value for each field. Based on this calculation, the average row length of the encrypted table in FPE-CDB is approximately 197 bytes, considering some overhead.

Performance: Figure 6 depicts a performance comparison between FNR and AES-

128. The horizontal axis indicates the number of records inserted, while the vertical axis represents the time (measured in milliseconds) needed to execute a specific number of SQL INSERT queries. In the case of FPE-CDB, there's a decline in per- formance compared to CryptDB. Notably, the observed decrease in performance is approximately sevenfold ($y \approx 7x$). This is consistent with the anticipated theoretical outcome, as the FNR scheme inherently involves seven rounds of AES as part of its design [15].

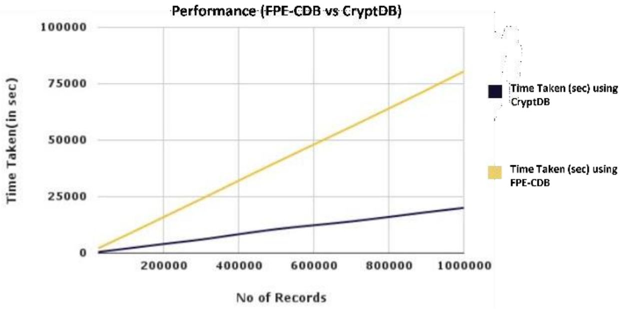


Fig. 47. Performance of DPE-CDB versus CryptDB

7 Conclusion

In summary, this paper introduces FPE-CDB, an Encrypted Database that preservesformat, with a focus on network monitoring as its primary application. Through exper-iments, the study demonstrates the storage benefits achievable through Format Preserv-ing Encryption (FPE) methods, albeit with a performance trade-off. Moving forward, enhancing security could involve integrating authentication and data integrity featuresinto both CryptDB and FPE-CDB.

8 References

153. A Boldyreva, N Chenette, Y Lee and A O'Neill, "Order-preserving symmetric encryption",*Proceedings of the 28th Annual International Conference on the Theory and Applications of Cryptographic Techniques*, 2009, vol. 5479, doi: https://doi.org/10.1007/978-3-642-01001-9_13
154. A Bose and L Bai. "A Fully Decentralized Homomorphic Federated Learning Framework", IEEE *20th International Conference on Mobile Ad Hoc and Smart Systems (MASS)*, 2023, pp. 178-185, doi: https://doi.org/10.1109/MASS58611.2023.00029
155. A Maryam & K Boris & L Alexei, "Zero Update Encryption Adjustment on Encrypted Da-tabase Queries", 2023, doi: http://dx.doi.org/10.1007/978-3-031-37807-2_2
156. C Gentry, "Fully Homomorphic Encryption using Ideal Lattices", Proceedings *of the 41st Annual ACM Symposium on Theory of Computing, STOC*, 2009, vol. 9, pp. 169-178, doi: http://dx.doi.org/10.1145/1536414.1536440
157. D X Song, D Wagner and A Perrig, "Practical techniques for searches on encrypted data",
158. *Security and Privacy*, 2000, pp. 44-55, doi: http://dx.doi.org/10.1109/SECPRI.2000.848445
159. H Kim, Y Kim, H Lee & J Chang, "Privacy – Preserving Top-k Query Processing Algo- rithms Using Efficient Secure Protocols over Encrypted Database in Cloud Computing En- vironment", *Electronics*, 2022, vol. 11, pp. 2870, doi: http://dx.doi.org/10.3390/electron- ics11182870
160. https://github.com/cisco/libfnr
161. https://tools.netsa.cert.org/silk/referencedata.html
162. https://www.icir.org/enterprise-tracing/Overview.html
163. J S Rautham & K S Vaisla, "V RS-DB: preserve confidentiality of users' data using encryp- tion approach", *Digital Communications and Networks*, 2023, vol. 7, pp. 62-71, doi:https://doi.org/10.1016/j.dcan.2019.08.001
164. K Munjal & R Bhatia, "Analysing RSA and PAILLIER homormorphic Property for securityin Cloud", *Procedia Computer Science*, 2022, vol. 215, pp. 240-246, doi: https://doi.org/10.1016/j.procs.2022.12.027
165. M Bellare, T Ristenpart, P Rogawat & T Stegers, "Format-preserving Encryption", *SelectedAreas in Cryptography*, 2009, vol. 5867 pp. 295-312, doi: https://doi.org/10.1007/978-3- 642-05445-7_19
166. P Pailler, Proceedings of the 18th Annual International Conference on the Theory and Ap- plications of Cryptographic Techniques, 1999, doi: https://doi.org/10.1007/b72231
167. R A Popa, C Redfield, N Zeldovich and H Balakrishnan, "CryptDB: protecting confidenti- ality with encrypted query processing", *Proceedings of the Twenty-Third ACM Symposium on Operating Systems*, 2011, pp. 85-100, doi: https://doi.org/10.1145/2043556.2043566
168. S Dara and S Fluhrer, "FNR: Arbitrary length small domain block cipher proposal", *Secu- rity, Privacy and Applied Cryptography Engineering*, 2014, vol. 8804, doi: https://doi.org/10.1007/978-3-319-12060-7_10
169. Stefano M P C Souza & Ricardo S Puttini, "Client-side Encryption for Privacy-sensitive Applications on the Cloud", *Procedia Computer Science*, 2016, vol. 97, pp. 126-130, doi: https://doi.org/10.1016/j.procs.2016.08.289
170. T Shimeall, S Faber, M DeShon & A Kompanek, "Using SILK for network traffic analysis"*CERT Network Situational Awareness Group*, 2010, link: https://studylib.net/doc/8700979/using-silk-for-network-traffic-analysis--analysts--hand- book
171. X Ren, L Su, Z Gu, S Wang, F Li, Y Xie, S Bian, C Li and F Zhang, "HEDA: Multi-AttributeUnbounded Aggregation over Homomorphically Encrypted Database", *Proceedings of the VLDB Environment*, 2023, vol. 16, issue 4, pp. 601 – 614, doi: http://dx.doi.org/10.14778/3574245.3574248
172. Y Miao, Y Yang, X Li, Z Liu, H Li, K Choo and R Deng, "Efficient Privacy-Preserving Spatial Range Query Over Outsourced Encrypted Data", *IEEE Transactions on Information Forensics and Security*, 2023, vol. 18, pp. 99, doi: http://dx.doi.org/10.1109/TIFS.2023.3288453

Power Quality parameter Analysis based VFD fed Induction Motor on different speed modes

Anuj Lodhi

Assistant Professor
MITS, Gwalior, MP, India
Department of Electrical Engineering

Abstract. In a different framework where the load changes over the long haul to time or a dynamic circumstances happens in various spaces, a variable frequency drive paired with a motor-driven system could offer energy reserve and expanded the power driven reliability. The primary purpose of a VFD is to save energy. Numerous power quality issues, including voltage, current will be examined in this research report. With the guide of the MATLAB curve fitting tool, the various power order attributes are anticipated for the alternate in loading that is based on no load, medium load and approximately to maximum burden. Voltage and current unevenness has been assessed with varying loads. The procedure was carried out using an experimental setup and a Fluke 302 power quality analyzer.

Keywords: Matlab Curve tool Fitting, Induction motor with drive set, power quality measures , control circuit mechanism

1 Introduction:

Variable Frequency Drives:- A variable recurrence drive, sometimes referred to as an customizable speed drive framework, is utilized in electrical and mechanical framework to change the voltage and frequency in order to manage the torque and speed characteristics of an AC motor [1-3]. Here VFD is a power electronic tool which changes over one frequency of rotating current to one more frequency for running the alternating current motor in factor speed to save the energy [4],[5]. The below figure shows starting from number one is three phase supply then rectifier, later that DC bus, DC reactor and capacitor is there, then inverter, after that induction motor and control circuit consisting. The viability of semiconductor devices, control circuits for programming as well as hardware semiconductor devices, and drive configurations are all improved by the VFD system, which also helps to minimize system size[6].

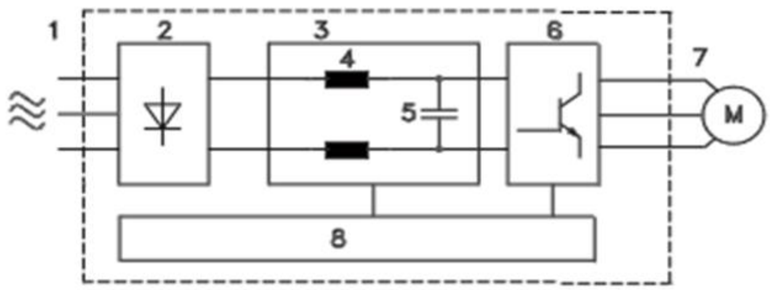


Fig. 48. VFD Framework

2 Methodology

In this research paper work harmonics voltage and current spectrum is analyzed in various load conditions. In this work system the motor supply voltage and current value are 415Volt, 4.4Ampere. The power value of motor is 2.20kW, rated speed is 1440RPM and power factor value is 0.83. And the voltage of drive is near to 380V-500V, output current value is 12.5A, speed control ratio is 1:1000 of synchronous speed, starting torque is 110percent

VOLUME- 1, ISSUE-

for 60sec and the efficiency of drive is 98%. Here meter is taken which is fluke meter for estimation purpose of different boundaries. The supply set up configuration of fluke meter is in three phase star connection. Nominal voltage of meter is 415V, its C.T. and P.T. ratio is 1:1, its ampere clamp type is I430 flex, and time interval is 3sec. Some IEEE principles are taken like voltage variety is less than ±10%, THD Voltage is (<8%) and current is (<5%), unbalance is <±3%.

3 Connection Diagram of Test Bench:

In the underneath diagram a test seat bench is made which is displayed beneath in the form of connection outline diagram. A three stage power input is there, then, at that point, current probe and voltage clamp is joined at each stage, later, then converter, bus and then inverter part is there, after that it is associated with induction motor. Later in below given figure we can see the hardware equipment setup of entire cycle in which test unit is directing. The generally recorded values will be store in the computer and continuing the work with the help of recorded values and with the assistance of Matlab curve fitting tools techniques.

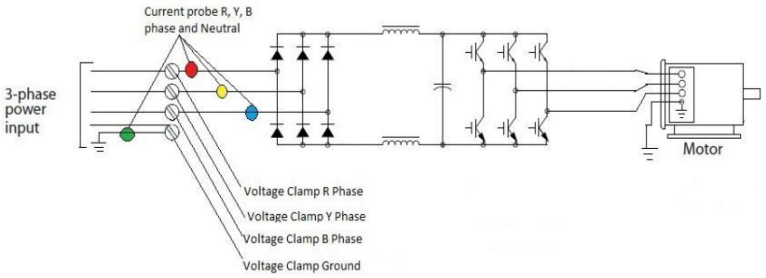


Fig. 49. VFD Experimental Setup

4 Estimation of Power Quality Parameter:-

Testing the above test setup or experimental arrangement, we assess the harmonic spectrum of voltage and harmonic spectrum of current and then also evaluate their productivity too.

4.1 Harmonic spectrum of Voltage

VOLUME- 1, ISSUE-

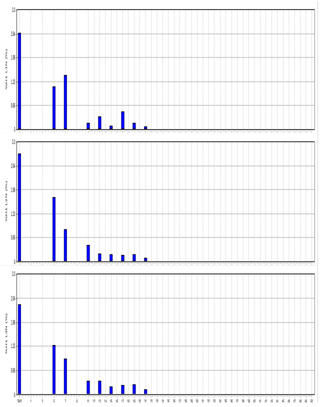


Fig. 50. No load Voltage harmonic spectrum

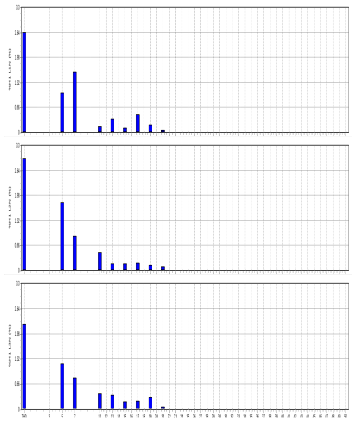


Fig.4. load 1KW Voltage harmonic spectrum

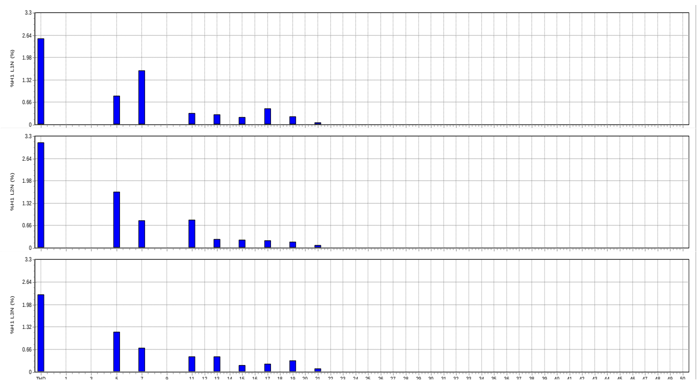


Fig.5. load 1.7KW Voltage harmonic spectrum

The below tabulation represents the observation made from the phase voltages during no load, load of 1kW and load of 1.7kW.

Parameter	**Unit**	**THD**	**5th**	**7th**	**11th**	**13th**	**15th**	**17th**	**19th**	**21th**
Red Phase	%	2.6	1.19	1.39	0.19	0.39	0.10	0.59	0.19	0.09
Yellow Phase	%	3.01	1.80	1.1	0.61	0.41	0.39	0.4	0.49	0.1
Blue Phase	%	2.39	1.30	1.1	0.61	0.61	0.40	0.49	0.5	0.1

Table 13. No load Harmonic spectrum of voltage

Parameter	**Unit**	**THD**	**5th**	**7th**	**11th**	**13th**	**15th**	**17th**	**19th**	**21th**
Red Phase	%	2.59	1.2	1.39	0.2	0.4	0.1	0.6	0.2	0.1

VOLUME- 1, ISSUE-

Yellow Phase	%	3.1	1.8	1	0.59	0.3	0.29	0.4	0.3	0.1
Blue Phase	%	2.1	1.19	0.8	0.6	0.59	0.4	0.5	0.59	0.1

Table 14. 1KW load Harmonic spectrum of voltage

Parameter	**Unit**	**THD**	**5th**	**7th**	**11th**	**13th**	**15th**	**17th**	**19th**	**21th**
Red Phase	%	2.5	0.8	1.39	0.4	0.39	0.3	0.5	0.3	0.1
Yellow Phase	%	3.01	1.8	1	0.99	0.3	0.29	0.3	0.39	0.99
Blue Phase	%	2.49	1.3	0.69	0.6	0.59	0.3	0.4	0.49	0.1

Table 15. 1.7KW load Harmonic spectrum of voltage

5 Observation for Voltage:

For this specific experiment the harmonics percentage for three phase is different as we can see in all load tables. THD for the yellow phase is the maximum then red and blue phase. And the level of magnitude from 5th to 21th harmonics are not decreasing in nature. Their magnitudes are varying in nature.

6 Reason:

VFD has a rectifier toward the front which draws a non sinusoidal current which causes voltage harmonics. At that point induction machine is stacked the current drawn by the rectifier increases so THD of a loaded machine is more than the THD of the machine under zero load.

VOLUME- 1, ISSUE-

Harmonic spectrum of current

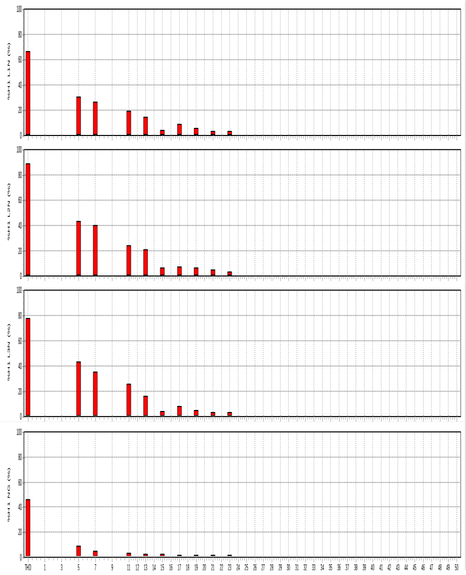


Fig.6. Current harmonic spectrum during no load

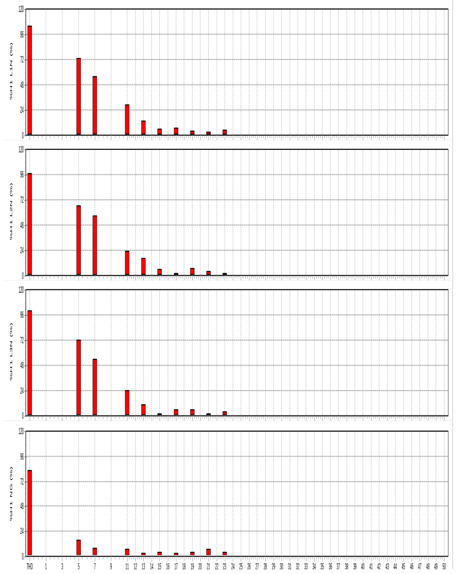


Fig.7. Current harmonic spectrum during load

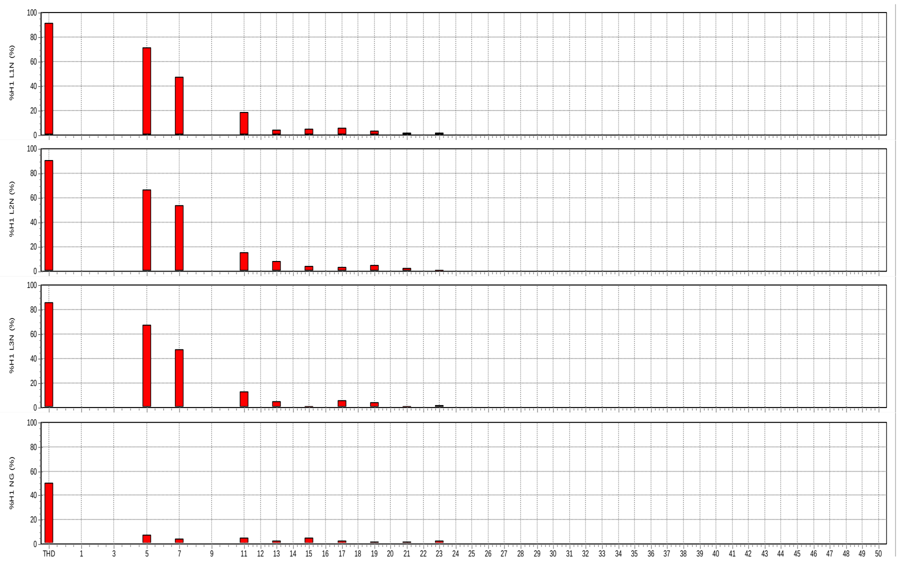


Fig.8. Current harmonic spectrum during load 2

The below tabulation represents the observation made from the harmonic spectrum of current during no load, load of 1kW and load of 1.7kW

Parameter	Unit	THD	5th	7th	11th	13th	15th	17th	19th	21th
Red Phase	%	64.9	29.9	28.0	20	17.9	6	10	6	4.0
Yellow Phase	%	90.09	41.98	40	24.9	21	5	6.0	5	3

VOLUME- 1, ISSUE-

Blue Phase	%	77.09	43	36.0	28	18.0	2	5	2.99	2
Ground	%	46.08	10	4	3	1	1	0.5	0.5	0.49

Table 16. No load Harmonic spectrum of voltage

Parameter	Unit	THD	5th	7th	11th	13th	15th	17th	19th	21th
Red Phase	%	105.01	74	60	28	15	7	8	7	7
Yellow Phase	%	97.6	67.0	60	22	18	5	2	6	3
Blue Phase	%	97.02	75	55	30.0	12	2	6	5.9	2
Ground	%	82.05	19	4	3	3	3	3	3	4.1

Table 17. 1KW load Harmonic spectrum of voltage

Parameter	Unit	THD	5th	7th	11th	13th	15th	17th	19th	21th
Red Phase	%	105.0	70	50	19	5	6	8.02	5	1
Yellow Phase	%	97	65	52	14.98	8	5	4	6	4.1
Blue Phase	%	97.0	68	58.0	12	5	1.01	5	4	1
Ground	%	82	10.0	5	5	1	5	1	0.7	1

Table 18. 1.7KW load Harmonic spectrum of voltage

7 Observation for Current:

For this specific experiment the harmonics percentage for three phase is different as we can see in all load tables. THD for the yellow phase is the maximum then red and blue phase. And the level of magnitude from 5th to 21th harmonics are not decreasing in nature. Their magnitudes are varying in nature.

8 Reason:

VFD has a rectifier on the front side which draws a non sinusoidal current. When induction machine is stacked the current drawn by the rectifier increases so THD of a stacked machine is more than the THD under no load.

VOLUME- 1, ISSUE-

9 System efficiency

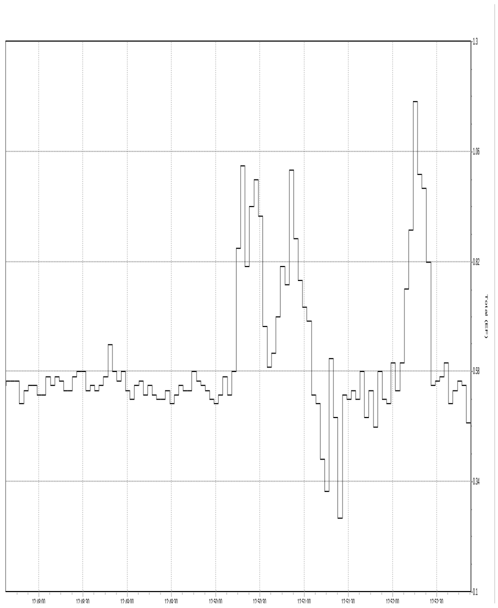


Fig. 9. No load System efficiency

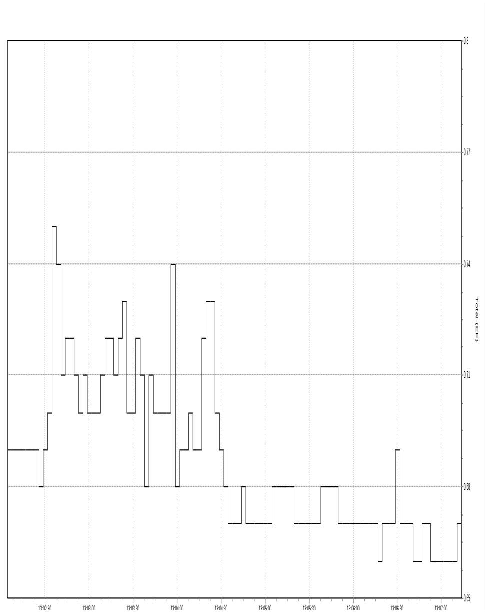


Fig. 10. load 1 System efficiency

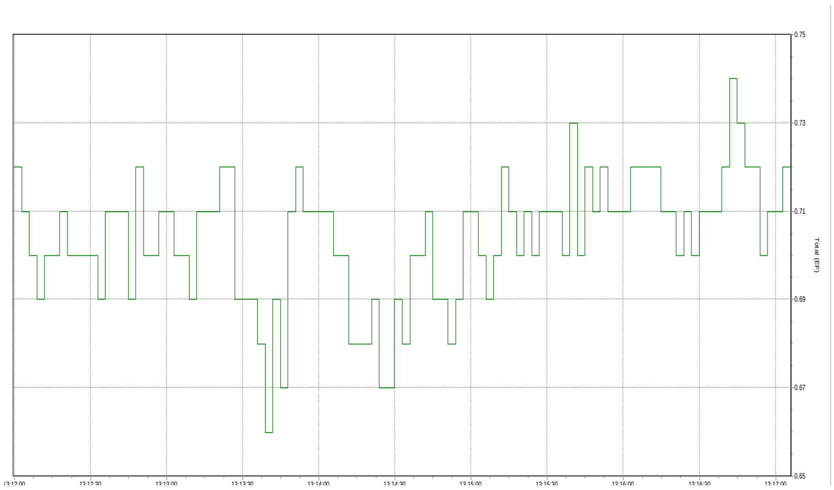


Fig. 11. load 2 System efficiency

The below tabulation represents the observation made from the system efficiency during no load, load of 1kW and load of 1.7kW

VOLUME- 1, ISSUE-

Parameter	Value	No Load	Load 1	Load 2
System Efficiency	%	55.48	68.74	72.91

10 Observation:

The above tabulation shows the variety in system productivity for various test cases.
As the load on an induction motor increases its efficiency increases.

11 Reason:

The unbalance in voltage (V) and current (I) diminishes when machine is stacked more, which brings in increase in system proficiency.
The power factor of the machine increments when the machine is stacked which also leads to an expansion in efficiency.

12 Conclusion and Future Scope:-

In this framework we analyzed the conditions for zero load, medium load which is 1KW and high load approx 1.7KW, that the voltage level harmonics is less than 8 percent and current level harmonics is also came under 5 percent which follows the IEEE standards. With the help of curve fitting tool of MATLAB the result work parameters are carried out. In the extended future scope on this study work, different powers like apparent, active and reactive power will also analyzed, includes power factor and others relative areas which help in to improve power quality of VFD fed induction motor by connecting various loaded conditions.

VOLUME- 1, ISSUE-

13 References:-

173. Thomas Howard Blair, "Variable Frequency Drive Systems," in Energy Production Systems Engineering , IEEE, 2017, pp.441-466, doi: 10.1002/9781119238041.ch18.
174. P. V. Patil and S. A. Naveed, "Implementation of VFD Application for Speed Control of Induction Motor," 2020 International Conference on Smart Innovations in Design, Environment, Management, Planning and Computing (ICSIDEMPC), Aurangabad, India, 2020, pp. 168-170, doi: 10.1109/ICSIDEMPC49020.2020.9299636.
175. R. Sadhwani and Ragavan K., "A comparative study of speed control methods for induction motor fed by three level inverter," 2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES), Delhi, India, 2016, pp. 1-6, doi: 10.1109/ICPEICES.2016.7853158.
176. M. F. Umar, M. N. Akbar and S. M. R. Kazmi, "Design and simulation of a 3 phase induction motor drive based on indirect rotor field orientation using MATLAB Simulink tool," 2018 1st International Conference on Power, Energy and Smart Grid (ICPESG), Mirpur Azad Kashmir, Pakistan, 2018, pp. 1-6, doi: 10.1109/ICPESG.2018.8384497.
177. L. M. Vargas, J. Jatskevich and J. R. Marti, "Load modeling of an induction motor operated with a variable frequency drive," 2008 IEEE Canada Electric Power Conference, Vancouver, BC, Canada, 2008, pp. 1-7, doi: 10.1109/EPC.2008.4763330.
178. Xiaodong Liang and Wilsun Xu, "Modeling variable frequency drive and motor systems in power systems dynamic studies," 2013 IEEE Industry Applications Society Annual Meeting, Lake Buena Vista, FL, 2013, pp. 1-11, doi: 10.1109/IAS.2013.6682607.

PSO based MPPT for photovoltaic system

Anuj Lodhi[1]
Assistant Professor
MITS, Gwalior, MP, India

Kapil Badoliya[2].
Assistant Professor
M.U., Gwalior, MP, India

Dr. Nikhil Paliwal[3]
Assistant Professor
MITS, Gwalior, MP, India

Abstract: Sun based Photovoltaic is viewed as one of the most encouraging energy source today and in the approaching time as it is fueled by environmentally friendly power source i.e sun and significant measure of innovation improvement has occurred. The issue that lies with the Photovoltaic is that of significant expense and less change effectiveness. The arrangement comes as boosting the power yield like clockwork. There are various strategies called as MPPT (Greatest Power Point Following) Procedures that when applied prompts most extreme power yield. In this work PSO based MPPT is carried out.

Keywords: Sensors, MPPT, Solar Panel Board, Chopper based Converter, Digital controller

1 Introduction

India enjoys an enormous sun oriented benefit with an expected 5000 trillion kWh of energy accessible through sun consistently with most parts getting 4-7 kWh of energy for every sq2 each day [1]. The need is to remove this sun powered energy to the greatest degree.

Taking into account photovoltaic frameworks that changes sunlight based energy into power, there is an additional benefit in using this technique for power age when contrasted with different wellsprings of age. Sun powered energy extraction from photovoltaic being sans contamination and the source being liberated from cost gives a wide extent of tackling power from sun oriented. With the worldwide worry for contamination, issue of an unnatural weather change and accentuation on decrease of carbon impression, sunlight based PV frameworks have come up as a very much acknowledged wellspring of power. Be that as it may, because of the total reliance of PV frameworks on daylight as the wellspring of energy, the variables like climatic and natural circumstances influence the result of the PV framework. The other issue that comes is of high beginning expense of PV framework while thinking about a sun oriented based framework. The answer for above issue comes in the way that at whatever point sun's energy is accessible, separate it to the greatest [2].

Separating greatest energy from PV boards calls for most extreme power point following (MPPT) strategies. The various techniques for most extreme power extraction incorporates irritate and notice, open-circuit voltage, steady conductance, slope climbing, hamper, brain and fluffy rationale strategies and others. These strategies function admirably for uniform sunlight based insolation and temperature [3]. Sun powered insolation and temperature are the two principal factors on which the result of the PV board depends. For steady upsides of sun based insolation and temperature, there is a solitary top in the power-voltage bend for a PV module. On account of changing sun based insolation and temperature there are more than one top at the PV module yield [4].The adjustment of these boundaries is a direct result of halfway concealing condition emerging because of various natural circumstances. These previously mentioned regular strategies settles at a nearby top for the situation while fractional concealing happens. Consequently numerous changes are carried out in these MPPT techniques to get to the worldwide pinnacle and various papers exists in such manner [5]-[7].

PSO calculation based MPPT methods gives the benefit that with the tuning of different boundaries in the calculation and making a few changes, the calculation can function admirably in the halfway concealing circumstances. The worldwide greatest can be found out with changing natural circumstances. In this work, PSO based MPPT is performed for various insolation levels.

2 PSO Overview

Particle Swarm Optimization is self-learning based calculation strategy applied to take care optimization issues. It come across discovered in 1995 by Eberhart (electrical engineer) and Kennedy (social scientist). This calculation is relevant for worldwide arrangement of an issue characterized in any aspect. In PSO, various particles are arbitrarily chosen in the scope of the arrangement. These arbitrarily acquired particles are the beginning stage for this strategy to start. When the calculation begins, the particles refreshes its qualities as per two straightforward conditions. These conditions are based with the end goal that the particles in the middle between themselves, refreshes themselves and moves towards the expected answer for the issue.

The two equations on which PSO is based are-

$$v_i(k+1) = wv_i(k) + c_1r_1\left(p_{best,i} - x_i(k)\right) + c_2r_2(g_{best} - x_i(k))$$

$$x_i(k+1) = x_i(k) + v_i(k+1)$$

i= 1, 2 3, ……..N

where xi comment to the point of ith particle, vi comment to the velocity of ith particle, k is for number of iteration at which the algorithm is running, c1 and c2 are the coefficients, r1 and r2 are the random number with a range between 0 and 1. Pbest stores the value of the individual best of respective particle and Gbest stores the global best among the different particles.

The step by step diagram of PSO is displayed in Fig. 1

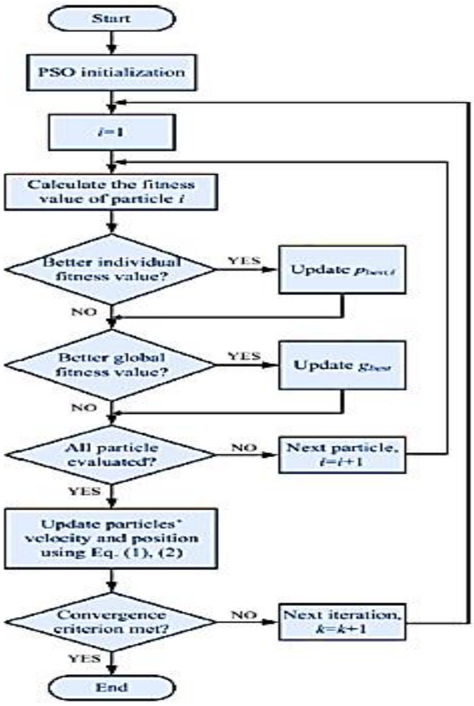


Fig. 51. PSO Algorithm

3 Methodology Followed

The methodology that is continued in this work to remove greatest power across the PV board is general in nature. The impedance across the PV panel is changed so that the maximum power is acquired across the module. The impedance is shifted across the PV board with a DC-DC converter. The DC-DC converter is middle between the PV board and the load. The expected duty cycle of the converter that gives the most extreme power is determined with the help of the PSO calculation. The whole PV system is implemented in MATLAB. The algorithm is executed in coded form in MATLAB. The overall format of the PV framework with algorithm is displayed in figure 2.

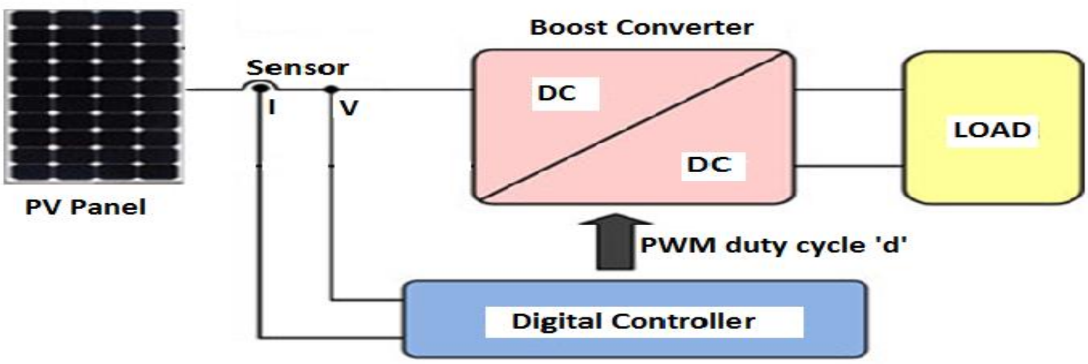


Fig. 52. MPPT implementation.

4 Simulation

The simulation is shown in figure 3.

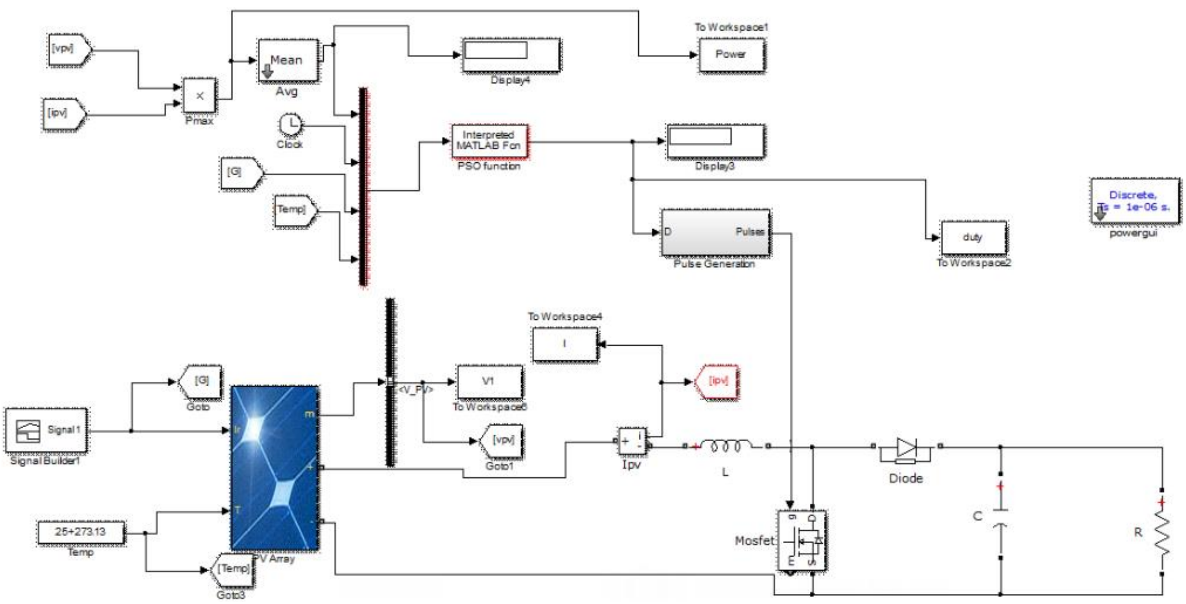


Fig. 53. Simulation

The PV panel rated at Voc=21.24, Ioc=4.75 A, Vm=17.64 V, Im=4.54 A. The DC to DC converter here is a Boost converter with the following component values- L=40 mH, C=80 µF, R= 100 Ω. The simulation is run at 4 seconds. With the changing of insolation levels, the output result across the PV panel is observed.

5 Results

The result across the PV board is considered to check for the most extreme power point following done by the PSO calculation. With the change in insolation levels, disturbances in the system depicting partial shading are created. Fig. 4. results the different insolation levels for which the algorithm is used. The different levels considered are- 800, 1000, 900, and 600 (W/m2) and they are altered at 2 sec, 3sec, and 8.5 sec respectively. Thus there is a artificial depiction of partial shading.

Fig. 5, fig, 6, fig. 7, fig. 8 depicts duty cycle, current, voltage, and power with the change in insolation level. With the disturbance created, the system settles down again at maximum value of power which is 45 W.

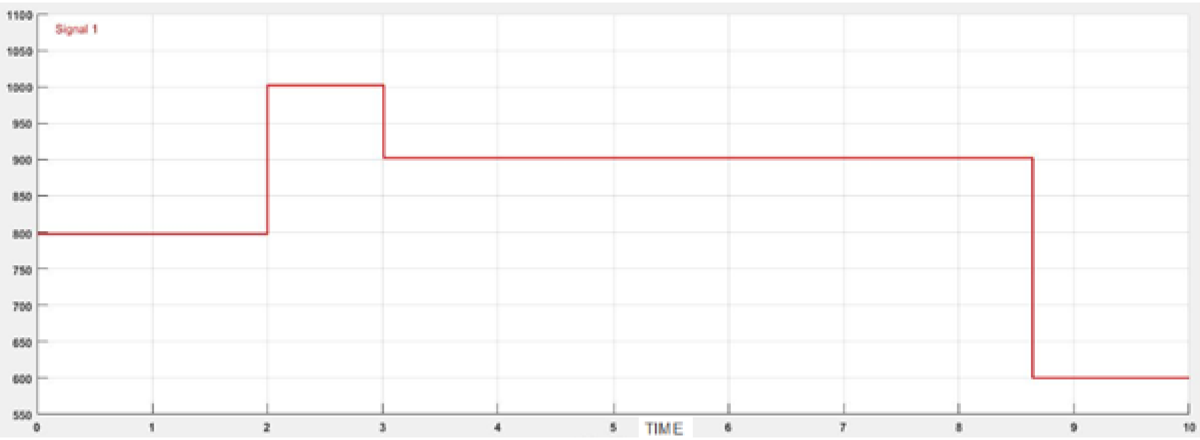


Fig. 4. Different insolation level

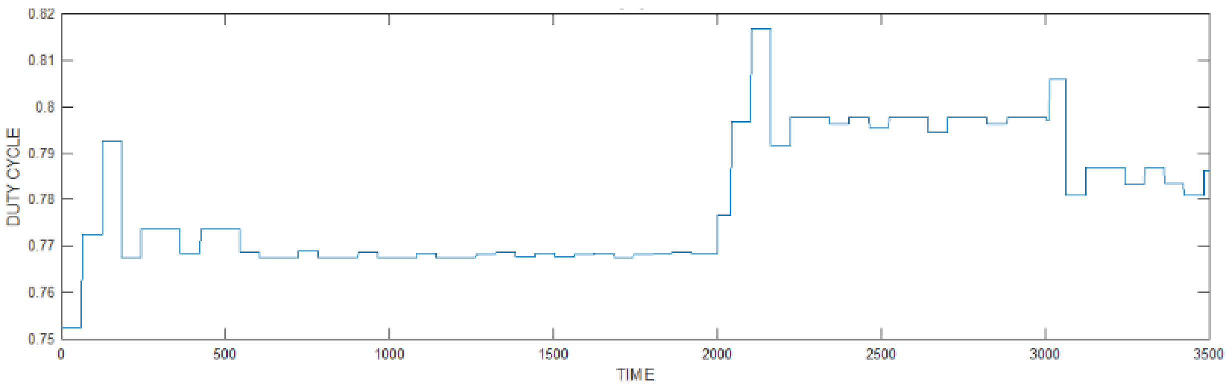


Fig. 5. Duty cycle profile

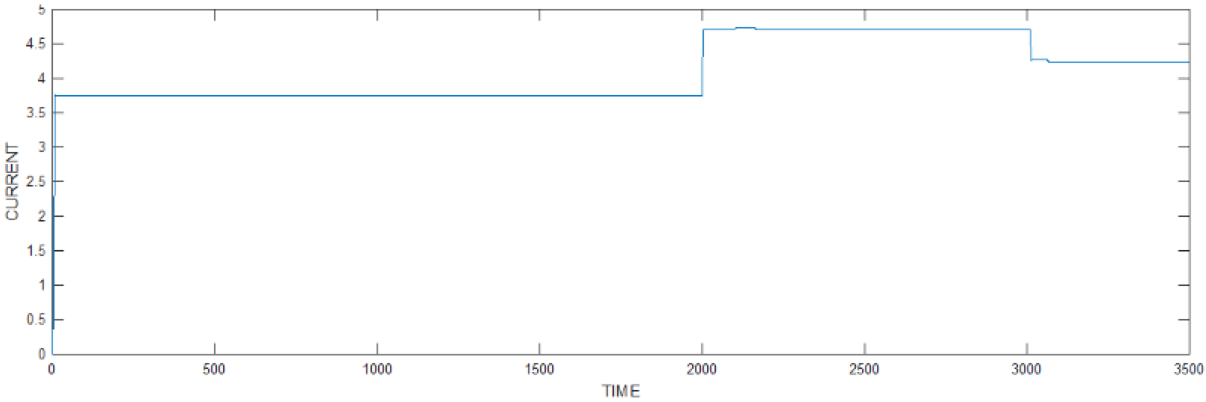


Fig. 6. Current profile

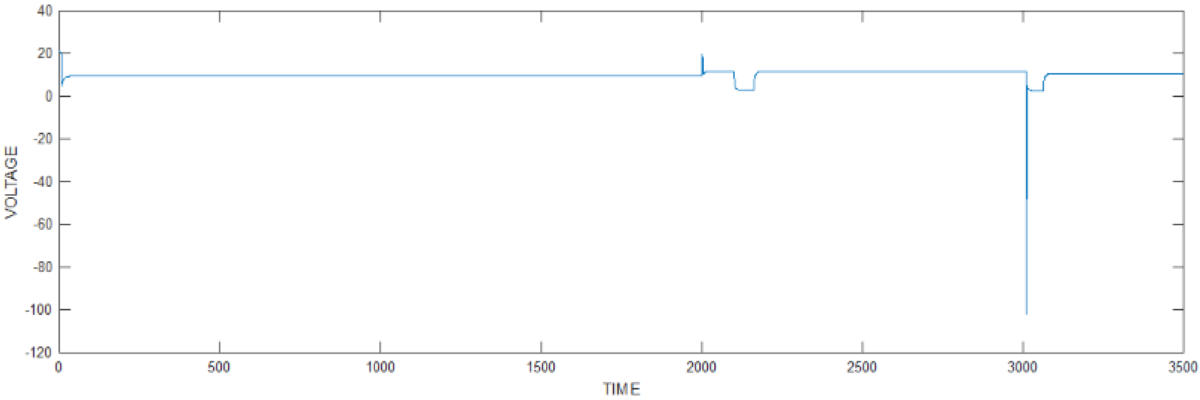


Fig. 7. Voltage profile

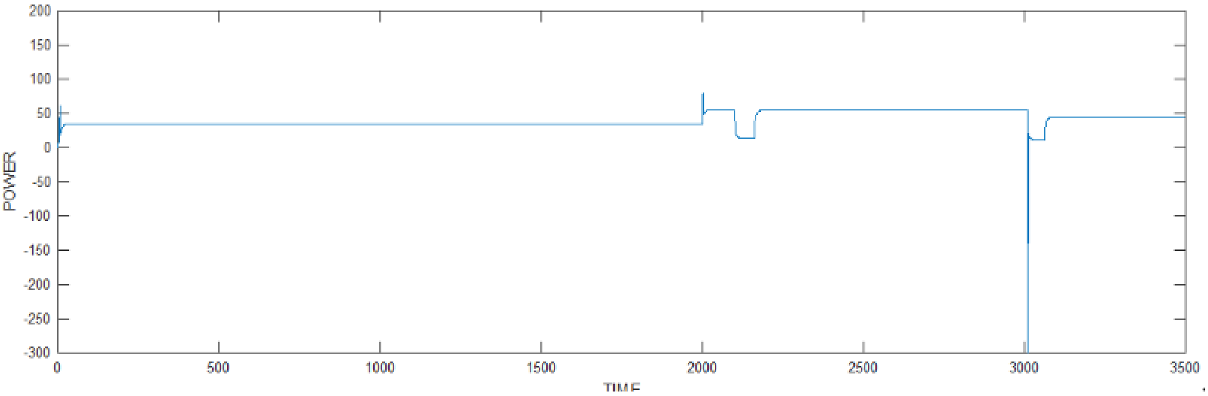


Fig. 8. Power

6 Conclusion

In this work, MPPT based on PSO algorithm is implemented. With the change in insolation level, partial shading condition is mimicked. The system settles down at maximum value of power with change in insolation levels.

7 References

179. http://www.mnre.gov.in/schemes/grid-connected/solar/

180. H. J. Chiu, Y. K. Lo, C. J. Yao, T. P. Lee, J. M. Wang, and J. X. Lee, "A modular self-controlled photovoltaic charger with interintegrated circuit (I2C) Interface," *IEEE Trans. Energy Convers.*, vol. 26, no. 1, pp. 281–289, Mar. 2011.

181. V. Salas, E. Ol´ıas, A. Barrado, and A. L´azaro, "Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems," *Sol. Energy Mater. Sol. Cells*, vol. 90, no. 11, pp. 1555–1578, Jul. 2006.

182. Y. J. Wang and P. C. Hsu, "Analytical modelling of partial shading and different orientation of photovoltaic modules," *IET Renew. Power Gener.*, vol. 4, no. 3, pp. 272–282, May 2010.

183. K.Kobayashi, I. Takano, andY. Sawada, "A study of a two stage maximum power point tracking control of a photovoltaic system under partially shaded insolation conditions," *Sol. Energy Mater. Sol. Cells*, vol. 90, no. 18–19, pp. 2975–2988, Nov. 2006.

184. H. Renaudineau, A. Houari, J. P. Martin, S. Pierfederici, F. M. Tabar, and B. Gerardin, "A new approach in trackingmaximum power under partially shaded conditions with consideration of converter losses," *Sol. Energy*, vol. 85, no. 11, pp. 2580–2588, Nov. 2011.

185. N. Femia, G. Lisi, G. Petrone, G. Spagnuolo, and M. Vitelli, "Distributed maximum power point tracking of photovoltaic arrays: Novel approach and system analysis," *IEEE Trans. Ind. Electron.*, vol. 55, no. 7, pp. 2610–2621, Jul. 2008.

Recent Development and Advances on Green Commercial Buildings: A Review

Manoj Kumar Gaur[1*], Pushpendra Singh[1], Vikas Kumar Thakur[1]

[1]Department of Mechanical Engineering, Madhav Institute of Technology and Science, Gwalior- 474005
Corresponding Author: gmanojkumar@rediffmail.com

Abstract. The world is advancing toward the utilization of various renewable sources of energy in different fields. The buildings are also need to be independent from energy generated through non-renewable sources. The step toward this idea was termed as Net Zero Energy Buildings or also called as Green Buildings. The various researches has undergone in this field for making buildings green. The commercial buildings like malls, schools, college, etc. are also need to make green building. The paper presents the researches carried out in the field of commercial green buildings and suggests the methods adopted to make the commercial buildings green or net zero energy building.

Keywords: Green buildings; commercial buildings; net-zero energy; buildings

1 Introduction

The shelter is the basic need of any living being. The building is basically a structure with roof. The building construction depends on various factors like weather condition, availability of building material, ground condition etc. The construction of buildings was started nearly around 18000 B.C. The buildings were previously made by humans for preventing himself from outside weather, animals, for comfortable living etc. But with the time, the buildings were not only made for shelter purpose but also for some other reasons like commercial purpose. The various types of buildings are shown in Fig. 1. Starting from the need of shelter the buildings now are made for various purposes like for education, commercial purpose, military base etc. With rapid urbanization and growth in population the need of commercial buildings also increases. So it becomes necessary to shift the focus on making such buildings green and sustainable.

Various researches has undergone in the field of residential, heritage and ancient buildings. Various devices have been developed till now that operates on solar energy that is the one of the renewable sources of energy like solar panels, solar water heater, solar pump etc. These devices make the building green and sustainable by fulfilling the energy demand which used to fulfill by energy generated through conventional sources. The buildings are made a Zero energy building by using both energy efficient measure and adopting renewable energy technologies [15].

Commercial buildings also need to be made green and sustainable as these consume nearly 7% of world energy consumption [1]. About 60% of the energy is used for heating and cooling [2,3]. Commercial buildings occupies nearly 20,000 Km^2 area of total land area in 2010 and this is increasing with a rapid rate due to growing population rate [4].

The paper gives the brief description of the researches in which the commercial buildings has been tried to make green and sustainable. The paper also presents the method that can be adopted to make the commercial buildings green and sustainable.

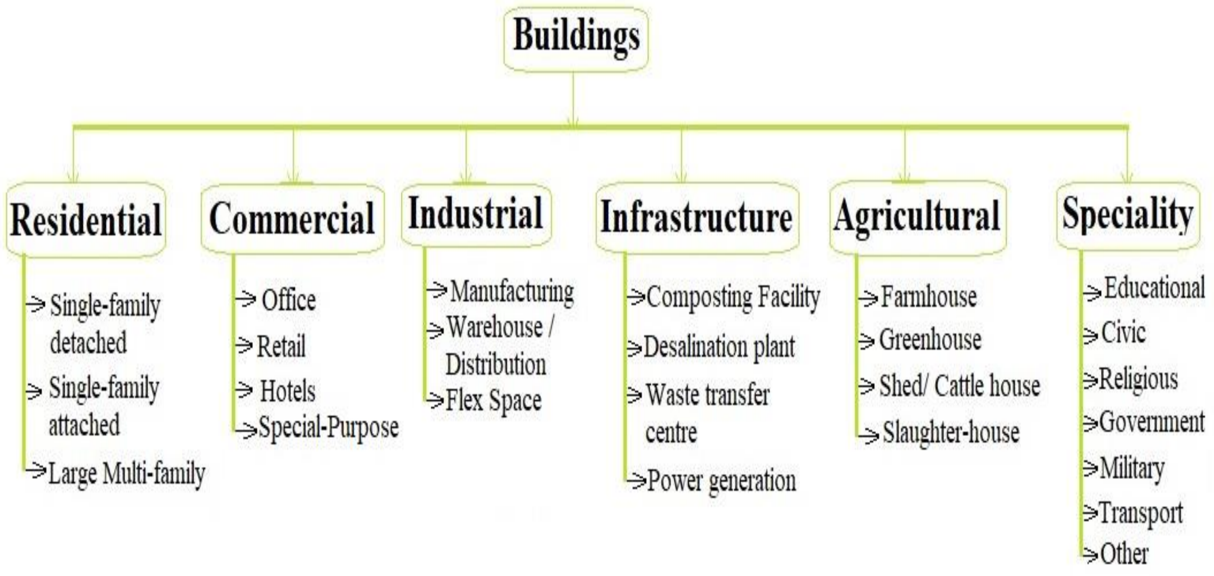


Fig. 54. Types of Buildings

2 Researches toward Green commercial buildings

Linzi Zheng, Joseph Lai (2018) [5] carried out the case study on commercial building of HongKong for studying the air-conditioning system adopted during their retrofication. The economic evaluation of the AC systems was also carried out and the impact of the retrofication material on the environment was shown by the term ‘carbon reduction efficiency’. The effect on performance of the AC system with its degradation with time was also studied. The methodology adopted by them can be used for determining the environmental and economic efficiency of the various energy saving measures adopted in the buildings.

Pascal Brinks, Oliver Kornadt, René Oly (2016) [6] carried out the research to develop the optimum-cost net zero energy building standards for industrial buildings in Germany. The two factors having the strong influence on the cost-effective insulation level were internal gains and minimum inside temperature. They classified the industrial buildings as low and normal temperature buildings. The Potsdam was used while defining the standards for nearly Net Zero industrial buildings. The heat energy in industrial buildings can be saved by increasing the air tightness, reducing thermal bridges and optimizing floor slab insulation. Their study is limited to German standards and for light steel industries.

R. Lapisa, E. Bozonnet, P. Salagnac, M.O. Abadie (2018) [7] optimized the design of low-rise commercial buildings according to the climatic conditions. The effectiveness of passive cooling strategy in thermal comfort and energy performance of the commercial building is also studied. NSGA-II algorithm is used for optimization of building design. They suggested smaller skylight area, envelope with proper insulation and roof with high solar absorbing roof for northern region. While for southern regions, they suggested the buildings with reflecting cool roof, larger skylight area for maximizing natural cooling and lighting and non-insulated ground slab. Their methodology and results can be adapted for designing a new commercial building or improving the energy efficiency of the existing commercial building.

Joshua Kneifel (2010) [8] estimated the effectiveness of various energy saving measures in commercial buildings in terms of reduction in carbon emission, savings in energy and cost. For the study, the 12 buildings of 16 cities in U.S. were taken. It was observed that due to faulty envelope design, the energy demand of buildings increases resulting in installation of heavier and costlier HVAC system. He found that by adopting energy saving measures the energy demand get reduced by about 30% without any modification in the design of existing commercial buildings. It was also noticed that the carbon emission by building can be reduced by about 32% with these energy saving measures. The result of reduction in CO_2 emission in different type of building over 10 year of study is shown by Fig. 2.

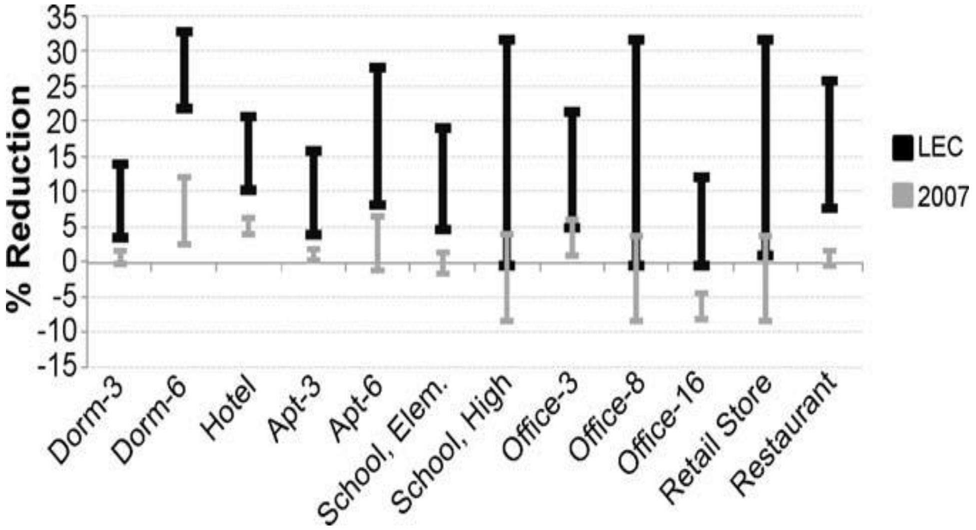


Fig. 55. Reduction in CO_2 emission in different types of buildings

Omid Ardakanian, Arka Bhattacharya, David Culler (2018) [9] carried out the research to estimate the occupant inside the building so as to reduce the energy wastage in empty or partially filled spaces. As HVAC system does not consider the occupancy and lot of energy get wasted in conditioning of empty and semi-filled spaces. In order to detect the occupancy of the buildings selected in 7 zones of U.S., non-intrusive time series analysis was proposed. Their designed schedule for each zone shows the energy saving of 38% in the selected commercial buildings.

Maite Gil-Báez, Ángela Barrios-Padura, Marta Molina-Huelva, R. Chacartegui (2017) [10] carried out the comparative assessment of mechanical ventilation system with the natural ventilation system provided in the school buildings of southern Spain. For this purpose, three school buildings were selected. The two buildings were ventilated by mechanical ventilation system while the one building is ventilated by natural ventilation system. The inside air temperature, humidity and CO2 mitigation is analyzed with the occupancy inside the school building in both the cases. The result shows that the natural ventilation system saves energy by about 18 to 33% along with maintaining the classroom thermal comfort level.

Amit Garg, Jyoti Maheshwari, P.R. Shukla, Rajan Rawal (2017) [11] carried out the research by surveying 197 small commercial establishments in Gujrat, one of the developing state of India. The connected electrical equipment and their energy usage were studied during winter and summer season. It was observed that appliances running by conventional source of energy are replaced by more energy efficient devices like LED bulbs, star rated AC etc. The energy consumption by these establishment is observed by dividing them into two categories that is low and high income. Also eight shopping malls and ten educational institutes were surveyed and observed. Drastic growth was observed towards the utilization of energy efficient devices in small as well as in large establishments, helping in reducing energy demand.

Khoa N. Le, Cuong N. N. Tran and Vivian W. Y. Tam (2018) [12] developed the model to determine the quantity of energy consumed and greenhouse gas emitted by the commercial buildings in Australia. To show the relationship between the energy consumption and greenhouse gas (GHG) emission, the GaBi 8.1 platform was used. The paper suggested considering the inverse relation between the R-value of building envelope with GHG emission and energy consumption. The paper also reported that the building having higher R-value will utilize lesser energy. They suggested to utilize their model as a reference for the new commercial construction in Australia.

Maria Kapsalaki and Vitor Leal (2011) [13] presented the progress in the net zero energy buildings in Europe. The paper highlights the development in defining the NZEB, changes carried out in design strategies and the utilization of technologies in making buildings energy efficient. The technical features used in the net zero commercial buildings in European countries are shown in table 1. The Fig. 3 shows the concept of net zero energy building.

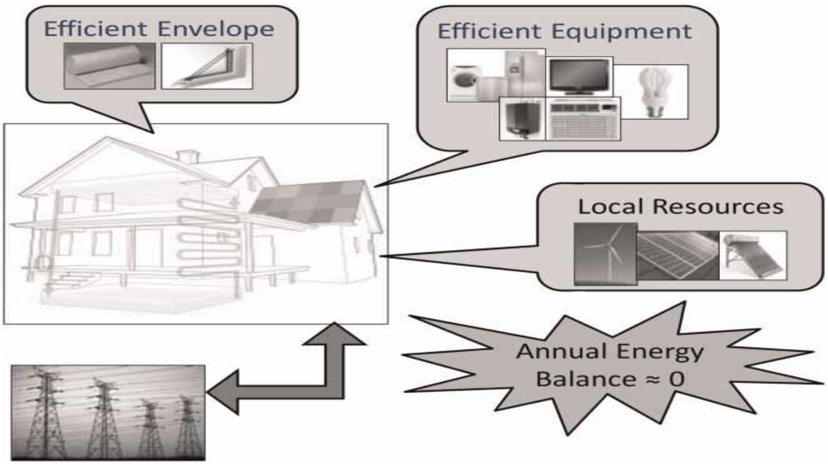


Fig. 56. The concept of net zero energy Building

Table 19. Technical features of the some net zero commercial buildings in European countries [12]

Commercial Case Studies	Main Technical Features					
	Heat Gain/ Loss through Envelope	Heat Loss through Ventilation	Heating/ Cooling and Hot Water	Lighting And Appliances	Electricity Production	Intelligent Energy Management Systems
Aldo Leopold Legacy Center	High performance windows Daylight harvest High levels of insulation High performance windows Increased daylight penetration	Mechanical ventilation with heat recovery Natural ventilation	Ground-source heat pumps Wood burning stoves Earth tubes to preheat or pre-cool	Energy efficient lighting and appliances	39.6kW PV array	---
Adam Joseph Lewis Center	Wall U-value 0.4 W/m^{2}K Triple pane, argon filled, low-e glazing South-facing curtain wall	Mechanical ventilation with HR	Closed loop geothermal wells	Energy efficient lighting and appliances	Roof integrated 60kW + 100kW PV system	Monitoring of Building systems Occupancy sensors Photoelectric

	Thermal mass through concrete floors Exposed masonry walls Window shades					daylight sensors Carbon dioxide sensors Automated operable windows
Science House in Minnesota	Wall U-value 0.14 W/m^{2}K Roof U-value 0.2W/m^{2}K High performance windows 1.21m overhangs (south) Maximum daylight	Mechanical ventilation with heat recovery Multi-modal natural ventilation	Premium efficiency ground source heat pumps Heat pump Assisted DHW Electric resistance back-up	Energy efficient lighting and appliances	8.8kW PV system	Daylight dimming controls Occupancy sensor controls Continuous computer monitoring Control of mechanical systems
Hawaii Gateway Energy Center	Walls U-value 0.9W/m^{2}K Roof U-value 0.23W/m^{2}K	Passive thermal chimneys	Deep seawater pumping for passive cooling	Energy efficient lighting and appliances	20kW PV system	Occupancy and photosensors
IDeAs Z^2 Design Facility	Highly rated insulation High efficiency windows Skylights Daylight harvesting	--	Highly efficient HVAC system Radiant heating and cooling Ground-source heat	Energy efficient lighting and appliances	30kW roof membrane integrated PV system	Occupancy sensors Automatic controls Monitoring equipment

Jing Liang, Yueming Qiua, Ming Hu (2019) [14] carried out the research to determine the energy performance gaps in green commercial buildings in order to make buildings energy efficient and sustainable for longer periods.

From the analysis of 117 survey data, the various factors responsible for the energy performance gap were grouped under three categories viz, the organizational, behavioral and engineering factors. Fig. 4 shows the various factors effecting energy performance gap. They suggested some solutions to encounter this problem like giving incentives to facility managers, commissioning, energy performance contracting and occupants behavioral change.

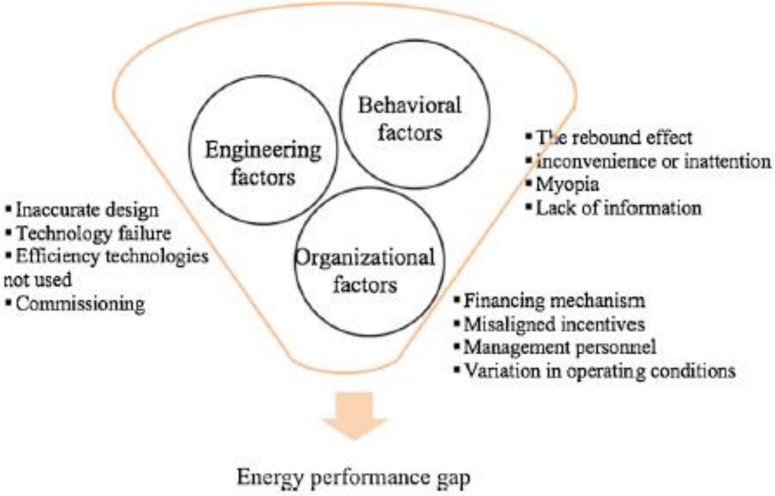


Fig. 57. The factors responsible for energy performance gaps

3 Conclusion

Various steps have been taken to reduce the impact of rapid urbanization on the environment. Zero energy buildings or Green buildings are also a step for reducing the negative impact of building during its entire life-span. The researchers are trying to find the alternative of the construction materials proving the better or same strength and having lesser or negative impact on the environment.

Various energy efficient measures like LED bulbs, star rated appliances etc. have been adopted in most of the residential buildings and also the people are progressing towards the utilization of renewable energy technologies like solar panels, solar water heaters etc.

The commercial sector also needs to be become energy efficient. The buildings made for commercial purposes needs to be made green and sustainable. Various researches have undergone around the globe to make the commercial buildings green. Some of the methods to make the commercial building energy efficient are as follows:

Using energy efficient measures as it reduces usage of energy by 20-30% without any modification in existing building [8].

The concrete structures emit low greenhouse gases in comparison to brick and concrete combination [12].

Structures combining timber with other material have lesser impacts on environment than those using metal, brick or concrete [12].

Higher R-value structure reduces the energy demand of the building.

Monitoring and operating the devices as per the occupancy inside the building.

Using renewable energy technologies like solar PV panels, solar water heaters etc. for lightning, heating and cooling purposes.

Using natural ventilation system instead of energy consuming heavy HVAC system.

4 References

186. L. Pérez-Lombard, J. Ortiz, C. Pout. A review on buildings energy consumption information. Energy and Buildings, 40 (2008) 394-398. http://dx.doi.org/10.1016/j.enbuild.2007.03.007
187. M.M. Carvalho, E. La Rovere, A.C. Gonçalves. Analysis of variables that influence electric energy consumption in commercial buildings in Brazil. Renewable and Sustainable Energy Review, 14 (2010) 3199–3205, http://dx.doi.org/10.1016/j.rser.2010.07.009

188. S. Chrarattananon, B. Limmeechokchai. A new building energy efficiency law in Thailand: impact on new building. Energy 19 (1994) 269-274.
189. M. Santamouris. Cooling the buildings – past, present and future. Energy and Buildings, 128 (2016) 617–638. http://dx.doi.org/10.1016/j.enbuild.2016.07.034
190. L. Zheng, J. Lai. Environmental and economic evaluations of building energy retrofits: Case study of a commercial building. Building and Environment 145 (2018) 14-23. https://doi.org/10.1016/j.buildenv.2018.09.007
191. P. Brinks, O. Kornadt, R. Oly. Development of concepts for cost-optimal nearly zero-energy buildings for the industrial steel building sector. Applied Energy 173 (2016) 343-354. http://dx.doi.org/10.1016/j.apenergy.2016.04.007
192. R. Lapisa, E. Bozonnet, P. Salagnac, M.O. Abadie. Optimized design of low-rise commercial buildings under various climates - Energy performance and passive cooling strategies. Building and Environment 132 (2018) 83-95. https://doi.org/10.1016/j.buildenv.2018.01.029
193. J. Kneifel. Life-cycle carbon and cost analysis of energy efficiency measures in new commercial buildings. Energy and Buildings 42 (2010) 333-340. doi:10.1016/j.enbuild.2009.09.011
194. O. Ardakanian, A. Bhattacharya, D. Culler. Non-intrusive occupancy monitoring for energy conservation in commercial buildings. Energy & Buildings 179 (2018) 311-323. https://doi.org/10.1016/j.enbuild.2018.09.033
195. M. Gil-Báez, Á. Barrios-Padura, M. Molina-Huelva, R. Chacartegui. Natural Ventilation Systems in 21st-century for near Zero Energy School Buildings. Energy (2017). doi:10.1016/j.energy.2017.05.188
196. A. Garg, J. Maheshwari, P.R. Shukla, R. Rawal. Energy appliance transformation in commercial buildings in India under alternate policy scenarios. Energy (2017). doi:10.1016/j.energy.2017.09.004
197. Khoa N. Le, Cuong N.N. Tran, Vivian W.Y. Tam. Life-Cycle Greenhouse-Gas Emissions Assessment: An Australian Commercial Building Perspective. Journal of Cleaner Production (2018). doi: 10.1016/j.jclepro.2018.07.172
198. M. Kapsalaki, V. Leal. Recent progress on net zero energy buildings. Advances in Building Energy Research 5:1 (2011), 129-162. http://dx.doi.org/10.1080/17512549.2011.582352
199. J. Liang, Y. Qiu, M. Hu. Mind the energy performance gap: Evidence from green commercial buildings. Resources, Conservation & Recycling 141 (2019) 364-377. https://doi.org/10.1016/j.resconrec.2018.10.021
200. Danny H.W. Li, L. Yang, J.C. Lam. Zero energy buildings and sustainable development implications - A review. Energy (2013), 1-10. http://dx.doi.org/10.1016/j.energy.2013.01.070

Review Paper on Different LFC Control Techniques for Conventional and Distributed Generation Power System

Sujal Singh Sengar, Swapnil Gupta, Dr. Nikhil Paliwal, Dr. Manjaree Pandit

Department of Electrical Engineering, MITS, Gwalior, India
Sujalsinghsengar3@gmail.com,guptaswpnil2002@gmail.com
nikhil7@mitsgwalior.in,manjaree_p@mitsgwalior.in

Abstract: The paper examines the problem of load-frequency regulation in power systems. It discusses several power system models and control strategies for traditional and distributed generation-based systems. The process of balanc- ing power generation with power consumption in order to keep system frequency and voltage within acceptable limits is known as load frequency control. It plays a critical role in guaranteeing the stability and dependability of power systems. Load frequency regulation is a critical component of electric power systemdesign and operation. Effective LFC assures steady and consistent power supply, pre- vents generator overloading, and involves a collaborative effort from system op- erators,generators, and other stakeholders

5 INTRODUCTION

Load frequency regulation is an important part of electric power system design and operation that contributes to system stability and dependability. Load frequency con- trol is concerned with balancing power generation and consumption in order to keep system frequency and voltage within acceptable norms [1]. LFC's objective is to keep frequency and power flow within limits by adjusting generator outputs, to accommo- date unstable load demands, and to deal with changes and disturbances in the power system. Various researchers have addressed load frequency control difficulties utiliz- ing advanced control methods such as optimum control, adaptive control, self- tuning control, and intelligent control. Soft computing techniques such as fuzzy logic, artifi- cial neural networks (ANN), and neuro-fuzzy have also been used [2]. The efficiency of LFC controllers is dependent on parameter tweaking, which can be accomplished through the use of optimization techniques like as genetic algorithms, Jaya algorithm, particle swarm optimization, and simulated annealing [3]–[6]. To address LFC diffi- culties in the presence of uncertainty, robust control approaches such as H, LMI, and m- synthesis are applied. Recent research on LFC in deregulated environments, with communication delays, renewable energy systems, FACTS devices, and HVDC links is also highlighted in the study [7]–[10]. The survey gives an in-depth look at LFC concerns in conventional and distribution generation-based power systems, as well as their integration with renewable energy sources [11]–[13].

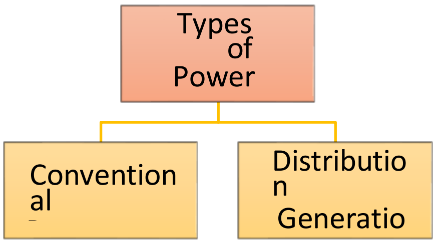
6 POWER SYSTEM MODELS AND ITS TYPE

Load frequency control (LFC) is the process of adjusting the frequency of the power system in order to keep the power supply and demand balanced. To ensure the stability and reliability of the power system, the frequency of the power system should be kept constant at 50 Hz or 60 Hz.

In the conventional power system, LFC is done by controlling the power generation of large scale power plants. However, in the DG based power system, it is morechal- lenging to control the frequency as the generation is decentralized and scattered. The fluctuations in the powerdemand, weather conditions and the technical limitations of DG sources pose a challenge to maintain the stability ofthe system.

Therefore, the LFC in DG based power system has become an important research area in recent years. The control strategies like load shedding, demand sidemanage- ment, microgrid control and storage management have been proposed to tackle the LFC issue in DG based power system.

It is significant to solve the LFC problem in both traditional and DG-based power systems because it affectspower system dependability and stability, which ultimately adversely impacts customers. The deployment of appropriate LFC techniques will en- sure the smooth operation of the power system and offer consumers with astable power supply.



7 CONVENTIONAL POWER SYSTEM

A conventional power system is a traditional power generating, transmission, and dis- tribution system that generates electricity primarily through centralized power plants (such as hydro, thermal, or nuclear). These power plants are linked to the grid and pro- vide electricity to consumers via a network of transmission and distributionlines. Prior to the introduction of renewable energy sources and the development of decentralized power systems, the conventional power system was the main method of power genera- tion and delivery.

This survey paper is divided into sections. Sections 2.1.1 through 2.1.4 examine sev- eral structures of the conventional power system.

7.1 Single Area Thermal Power System

Single area thermal power system refers to a power generation system in which elec- tricity is largely generatedby thermal power plants in a single geographic region. The thermal power plants in this system are linked to a sharedelectrical grid, and the gener- ated power is distributed to consumers in the same region. The primary goal of the single area thermal power system is to balance electricity generation and demand while maintaining a steady grid frequency. In this system, (LFC) is utilized to adjust the fre- quency and provide a balanced supply of power. In a single area thermal power system, the LFC system is oftensimpler than in multi-area systems since it just needs to consider the dynamics and control of the power plants inside the system.

7.2 Single area hydropower system

Single area hydropower system refers to a power generation system in which electricity is largely generated by hydropower plants in a single geographic region. The hydro- power plants in this system are linked toa shared electrical grid, and the generated power is distributed to users in the same region. The primary goal of the single area hydro- power system is to match electricity generation and demand while maintaining a steady grid frequency. In this system, Load-Frequency Control (LFC) is utilized to manage the frequency and provide a balanced supply of electricity. When compared to multi-area systems, the LFC system in a single area hydropower system is often simpler because it just needs to consider the dynamics and control of the power plants inside the single area.

7.3 Power system with HVDC link

A power system with a High-Voltage Direct Current (HVDC) link is a system for gen- erating, transmitting, anddistributing electrical power that incorporates a directcurrent (DC) transmission link in addition to the traditional alternating current (AC) transmis- sion network.When compared to AC transmission, the HVDC linkenables for the trans- mission of electricity across extendeddistances with reduced losses. HVDC lines are increasingly being used in power networks to connect diverse regions, integrate renew- able energy sources, and balance electricity supply and demand.

The Load-Frequency Control (LFC) system becomes more difficult in a power system with an HVDC link because it must include the dynamics of both the AC and DC sys- tems. As the DC link can affect the stability of theAC system, the HVDC link offers new control and stability issues. As a result, specialized control techniquesare em- ployed to regulate the frequency and assure the power system's stability.

7.4 Deregulated power system

A deregulated power system is a system that generates, transmits, and distributes elec- tricity in a market-driven environment. The generation, transmission, anddistribution of electricity are separated and operated as separate organizations under a deregulated system. To deliver power to consumers, these organizations compete in an open market. This competition in the power sector promotes innovation, lower prices, and more efficiency.

The Load-Frequency Control (LFC) system faces new issues in a deregulated power system, where control of power output and demand is decentralized and market- based. The LFC system must maintain power systemstability in a highly dynamic environment where generation and demand might vary fast. In addition, the LFC system must con- sider the market incentives of the various power system actors, such as independent power producers and transmission firms. A deregulated power system's control and sta- bility are more difficult than a standard regulated power system , necessitating ad- vancedcontrol techniques and a well-designed market structure.

8 DISTRIBUTED GENERATION POWER SYSTEM

A distributed generation (DG) power system is an electrical power generating, trans- mission, and distributionsystem that combines small-scale, decentralized power gener- ation units inside the distribution network. These units are often positioned near end- users and canincorporate renewable energy sources such as solar panelsor wind tur- bines, as well as traditional sources like as natural gas-powered generators.

The Load-Frequency Control (LFC) system has unique challenges in a DG power system since power generationcontrol is decentralized and distributed among numerous tiny units. The LFC system must provide power system stability while accounting for the extremely dynamic nature of the DG units. Additionally, the LFC system must en- sure that the DG units do not interfere with the distribution network's stability.

Advanced control techniques, such as decentralized control and distributed energy management systems, are often used in DG power systems to ensure the stability and reliability of the power system. The integration of DG units into the power system also requires new grid management strategies, such as the use of smart grids andenergy storage systems, to balance the generation and demand of electricity.

9 CONTROL TECHNIQUES FOR CONVENTIONAL POWER SYSTEM

Load-Frequency Control (LFC) is used in conventional power systems to manage the frequency and provide a balanced supply of electricity. A traditional power system's primary control loop consists of load speed regulation, followed by a secondary control mechanism. The following are some of the control techniques used in conventional power systems for LFC:

9.1 Droop control:

This is the most frequently used secondary control technique in conventional power systems. In droop control, each generator has a specific droop setting, which is used to regulate the output power in response to frequency deviations. The generator's output power changes proportional to the frequency deviation, ensuring a balanced supply of electricity.

9.2 Integral Square Error (ISE) control:

This is a supplementary control technique used in additionto droop control. The ISE control adjusts the generator's output power based on the integral of the frequency de- viation over time, ensuring that the frequency deviations are quickly corrected.

9.3 Power System Stabilizer (PSS):

This is an auxiliary control technique used to improve power system stability. The PSS changes the generator's output power based on the power system's dynamic character- istics, distributing greater stability during disturbances.

9.4 Automatic Generation Control (AGC):

In conventional power systems, this is a higher-level control approach used to regulate the power output of several generators. The AGC adjusts the generators' poweroutput based on the net system load, that guarantees a balanced supply of electricity.

These control approaches are employed in variouscombinations to assure the tradi- tional power system's stability and reliability. The control technique used is determined by the power system's specific requirements and operating conditions.

10 CONTROL TECHNIQUES FOR DISTRIBUTED GENERATION POWER SYSTEM:

In a distributed generation (DG) power system, the Load-Frequency Control (LFC) faces new challenges due to thedecentralized nature of the power generation. Thefol- lowing are some of the control techniques used in DG power systems for LFC:

10.1 Decentralized control:

In this approach, each DG unit has its own controller to regulate its output power in response to frequency deviations. The decentralized controllers communicatewith each other to coordinate the overall power generationand ensure a balanced supply of elec- tricity.

10.2 Distributed Energy Management System (DEMS):

A DEMS is a centralized control system that coordinates the power generation of mul- tiple DG units. The DEMS receives information from each DG unit and adjusts the

power output of the units to maintain a stable frequency and balanced supply of elec- tricity.

Smart grid technology: Smart grids use advancedcommunication and control tech- nologies to manage the distribution and consumption of electricity. In a DG powersys- tem, smart grid technologies can be used to monitor thepower generation of each DG unit and adjust the power output to maintain a balanced supply of electricity.

Energy storage systems: To store extra power generated by the DG units, energy storage equipment such as batteries or flywheels can be employed in a DG power sys- tem. The stored energy can be utilized to balance electricity generation and consump- tion, adding stability to the power system.

These control mechanisms are utilized in accordance to assure the DG power sys- tem's stability and reliability. Thecontrol strategy used is determined by the power sys- tem'sspecific requirements, operational conditions, andavailable technologies.

11 SOFT COMPUTING TECHNIQUES IN LOAD FREQUENCY CONTROL:

Soft computing techniques are employed in Load-Frequency Control (LFC) to increase power system stability and dependability. Soft computing approaches are computer methods based on human-like problem- solving processes like learning, adaptation, and approximation.
The following are some of the most often utilized soft computing approaches in LFC:

11.1 Artificial Neural Networks (ANNs)

ANNs are used to simulate the dynamic behavior of the power system and to create LFC controllers. ANNs can be trained to simulate the power system's response to vari- ous disturbances, resulting in a robust and dependable control method.

11.2 Fuzzy logic

Fuzzy logic is a mathematical framework capable of dealing with imprecision, incon- sistency, and partial truth. Fuzzy logic can be utilized to create LFC controllers that deal with uncertainty and unpredictability in the power system.

11.3 Particle Swarm Optimization (PSO)

PSO is a computational optimization method inspired bybird or insect swarm activity. PSO can be used to discoverthe ideal parameters for the controllers in LFC, enhancing the power system's performance and stability.

11.4 Genetic Algorithms (GAs):

GAs are a type of optimization algorithm inspired by natural selection and evolution ideas. GAs can be used to optimize LFC controllers, enhancing power systemstability and dependability.

These soft computing algorithms enable flexible and adaptable control solutions for LFC, enhancing power system performance and stability under varying operatingsitu- ations. The soft computing technology used is determined by the power system's spe- cific requirements and operating conditions. account the greatest and worst members of the population,the entire population can be improved in each iteration. The algorithm is simple to use and put into practicebecause no parameters need to be set.

12 DIFFERENT CONTROLLERS EMPLOYED FOR LFC

Load-Frequency Control (LFC) is the fundamental controlproblem in power systems, where the objective is to matchthe real power generation with the load and losses. The following are the most commonly used controllers in LFC.

12.1 ROBUST CONTROL

A robust controller is a sort of control system that performs consistently and reliably in the presence of uncertainties, changes, and disturbances. Robust controllers are in- tended to maintain the stability and performance of the controlled system even when system characteristics or external disturbances change.

Robust control techniques in Load-Frequency Control(LFC) can be utilised in power systems to increase the stability and reliability of the power system under variousoper- ating situations. Robust controllers can handle the power system's uncertainty and var- iability by providing aflexible and adaptive control technique.

12.2 VARIABLE STRUCTURE CONTROLLER

A variable structure controller (VSC) is a type of control system that provides a flexible and adaptive control strategy in the presence of uncertainties and variations. VSCs are designed to handle the changes in the system parameters or external disturbances by adjusting the control strategy in real-time.

In power systems, VSCs can be used in Load-Frequency Control (LFC) to provide a flexible and adaptive control strategy ,When there are uncertainties and disturbances.

13 APPLICATION OF SMES , BESS AND FACTS DEVICES IN CONVENTIONAL POWER SYSTEM

Superconducting Magnetic Energy Storage (SMES) and Battery Energy Storage Sys- tem (BESS) are two commonly used energy storage systems in various applications.

13.1 SMES

SMES is a high-density energy storage system that storesand releases energy using superconducting materials. SMES's primary applications include:

Power Quality Improvement: SMES is used to respond quickly to power quality is- sues such asvoltage sag, harmonics, and frequency variations.

and solar can be stored and released when needed.

Load-Frequency Control: SMES can be used toadjust power system frequency and respond quickly to variations in load demand.

13.2 BESS

BESS is an energy storage system that stores and releases energy via batteries. The following are the primary applications of BESS:

Grid Support: BESS can be utilized to provide ancillary services such as frequency regulation,spinning reserve, and voltage management to the power grid.

Integration of Renewable Energy: BESS may store excess energy generated by re- newable sources such as wind and solar and release it when needed.

Isolated microgrids: BESS can be utilized to store energy in off-grid or isolated mi- crogrids.

Electric Vehicle Charging: BESS can be used tostore renewable energy and then re- lease it to charge electric vehicles.

SMES and BESS are vital components of modern power systems, providing flexible and efficient energy storage options to aid in the integration of renewable energy sources while also improving power grid reliability and stability.

13.3 FLEXIBLE AC TRANSMISSION SYSTEM (FACTS) DEVICES

FACTS devices are power electronics-based systems that are used to increase the sta- bility, reliability, and efficiency of the alternating current transmission grid. FACTS devices that are commonly used include:

Static VAR Compensator (SVC): An SVC regulates voltage at a specific location in the power system, providing fast and accurate reactive power control.

Static Synchronous Compensator (STATCOM): A STATCOM is a shunt-connected device that provides fastand accurate reactive power control, enhancing the powergrid's stability and efficiency.

UPFC: is a combination of a series-connected voltage- sourced converter and a shunt-connected current-sourced converter that provides both series and shunt correc- tion. Itis used to control the actual and reactive power flow in thetransmission grid, hence enhancing the power system's stability and reliability.

Thyristor-Controlled Series Capacitor (TCSC): A series-connected device that uses thyristors to manage theflow of reactive electricity, boosting the power grid'sstability and efficiency.

Thyristor-Controlled Reactor (TCR): A shunt-connecteddevice that uses thyristors to manage the flow of reactive electricity, boosting the power grid's stability and effi- ciency.

These FACTS devices enable fast, accurate, and flexible transmission grid control, enhancing the power system's stability, reliability, and efficiency. They also contribute to lower transmission losses and higher transmission capacity.

14 Conclusion

In conclusion, Load-Frequency Control (LFC) is an important issue in power systems since it includes balancing real power generation and load while accounting for losses. Power system structure and operation have evolved dramatically over time, from tradi- tional power systems to deregulated power systems and distributed generation power systems. LFC techniques have also changed throughout time, transitioning from tradi- tional controllers like proportional-integral- derivative (PID) controllers to more ad- vanced techniques like robust controllers and variable structure controllers. Soft Com- puting methods like Artificial Neural Networks (ANNs) and Fuzzy Logic Systems (FLSs) have also gained popularity in LFC. In addition to the controllers, FACTS de- vices such as SVC, STATCOM, UPFC, TCSC, and TCR have been introduced to im- prove the AC transmission grid's stability, dependability, and efficiency. With rising energy demand and increasing power system complexity, the development and deploy- ment of new LFC techniques and FACTS devices will be critical in guaranteeing the stability, dependability, and efficiency of power systems in the future.

15 Reference

201. A. Ibraheem, P. Kumar, and D. P. Kothari, "Recent philosophies of automatic generation control strategies in power systems," *IEEE Transactions on Power Systems*, vol. 20, no. 1. pp. 346–357, 2005, doi: 10.1109/TPWRS.2004.840438.
202. A. Al-Hinai, H. Haes Alhelou, and H. Alyammahi, "Coordinated intelligent frequency control incorporating battery energy storage system, minimum variable contribution of demand response, and variable load damping coefficient in isolated power systems," *Energy Reports*, no. xxxx, 2021, doi: 10.1016/j.egyr.2021.07.072.
203. N. Paliwal, L. Srivastava, and M. Pandit, "PSO-Based PID Controller Designing for LFC of Single Area Electrical Power Network," in *Pandit M., Dubey H., Bansal J. (eds) Nature Inspired Optimization for Electrical Power System. Algorithms for Intelligent Systems*, Springer, Singapore, 2020, pp. 43–54.
204. N. Paliwal, L. Srivastava, and M. Pandit, "Jaya Algorithm Based Optimal Design of LQR Controller for Load Frequency Control of Single Area Power System," in *Social Networking and Computational Intelligence*, S. K. Shukla R., Agrawal J., Sharma S., Chaudhari N., Ed. Springer, Singapore, 2020, pp. 595–603.
205. N. Paliwal, L. Srivastava, M. Pandit, and P. Singh, "Jaya Algorithm-Based Load Frequency Control in Nuclear Power Plant Incorporating Energy Storage Unit," in *Artificial Intelligence and Sustainable Computing*, H. M. Dubey, M. Pandit, L. Srivastava, and B. K. Panigrahi, Eds. Singapore: Algorithms for Intelligent Systems. Springer, 2022, pp. 239–252.
206. K. R. M. Vijaya Chandrakala and S. Balamurugan, "Simulated annealing based optimal frequency and terminal voltage control of multi source multi area system," *Int. J. Electr. Power Energy Syst.*, vol. 78, pp. 823–829, 2016, doi: 10.1016/j.ijepes.2015.12.026.
207. Y. Arya and N. Kumar, "Optimal AGC with redox flow batteries in multi-area restructured power systems," *Eng. Sci. Technol. an Int. J.*, vol. 19, no. 3, pp. 1145–1159, 2016, doi: 10.1016/j.jestch.2015.12.014.
208. M. Sharma, S. Dhundhara, Y. Arya, and M. Kaur, "Fast-Acting Electrical Energy Storage Systems for Frequency Regulation," in *Energy Storage for Modern Power System Operations*, Wiley, 2021, pp. 105–141.
209. Y. Arya, "AGC performance enrichment of multi-source hydrothermal gas power systems using new optimized FOFPID controller and redox flow batteries," *Energy*, vol. 127, pp. 704–715, 2017, doi: 10.1016/j.energy.2017.03.129.
210. Y. Arya and N. Kumar, "BFOA-scaled fractional order fuzzy PID controller applied to AGC of multi-area multi-source electric power generating systems," *Swarm Evol. Comput.*, vol. 32, pp. 202–218, 2017, doi: 10.1016/j.swevo.2016.08.002.
211. A. Ghasemi-Marzbali, "Multi-area multi-source automatic generation control in deregulated power system," *Energy*, vol. 201, p. 117667, 2020, doi: 10.1016/j.energy.2020.117667.
212. H. Bevrani, M. R. Feizi, and S. Ataee, "Robust Frequency Control in an Islanded Microgrid: H∞ and μ-Synthesis Approaches," *IEEE Trans. Smart Grid*, vol. 7, no. 2, pp. 706–717, 2016, doi: 10.1109/TSG.2015.2446984.
213. U. Raj and R. Shankar, "Deregulated Automatic Generation Control using Novel Opposition-based Interactive Search Algorithm Cascade Controller Including Distributed Generation and Electric Vehicle," *Iran. J. Sci. Technol. - Trans. Electr. Eng.*, vol. 44, no. 3,
214. pp. 1233–1251, 2020, doi: 10.1007/s40998-019-00306-3.

Smart Grid Stability Prediction: A Comparative Analysis of Machine Learning Models

Vishal Chaudhary[1[0000-0002-3626-8952]] ,Deepansh Kulshrestha[2[0009-0009-0133-2211]]

Kunal Bharadwaj[3]

[123] MITS, Gwalior, MP, India
1vishal.chaudhary30@mitsgwalior.in 2deepansh84500@gmail.com 3bharadwajkunal420@gmail.com

Abstract: It is critical to predict the stability of the smart grid in order to ensure its dependable and effective functioning. In this paper, we present a thorough machine learning strategy for forecasting smart grid stability. Temperature, wind speed, solar radiation, electricity consumption, grid load, and voltage stability are among the characteristics included in the dataset for the entire year. To construct prediction models, five independent machine learning algorithms are used: Random Forest, XGBoost, Support Vector Machines (SVM), Logistic Regression, and Artificial Neural Networks (ANN). Important criteria such as area under the ROC curve, recall, accuracy, precision, and F1 score are utilised to efficiently analyse the models. A comparative study shows the advantages and disadvantages of each paradigm. Time series plots, correlation heatmaps, and predicted vs. real stability graphs are a few examples of the visualisations that demonstrate the models' performance. The findings demonstrate that Artificial Neural Networks outperformed the competition in smart grid reliability forecasts. This study's strong stability prediction method significantly advances the field of smart grid management. Stability prediction is necessary for decreased disruptions and increased grid resilience.

Keywords: Smart Grid, Stability Prediction, Machine Learning, Random Forest, XGBoost, SVM (Support Vector Machines).

1 Introduction

The fast integration of cutting-edge technology and renewable energy sources into modern power networks is causing a paradigm change that is giving rise to smart grids. [3]Stability becomes increasingly difficult to maintain as these networks get bigger. Although it requires sophisticated technology, machine learning (ML) has shown promise in forecasting a smart grid's stability in the face of intricate and dynamic interactions. In order to give useful information for improving grid resilience and dependability, this research study looks at the use of many machine learning approaches for predicting the stability of smart grids. According to recent studies, machine learning (ML) algorithms have demonstrated success in capturing the intricate linkages observed in smart grid data. XGBoost, Random Forest, Logistic Regression, Support Vector Machines (SVM), and Artificial Neural Networks (ANN) are a few of these techniques. Each strategy has benefits of its own and can deal with problems such as non-linear connections, interpretability, and missing data. This paper provides a comprehensive examination of several approaches, looking at their usefulness, accuracy, and application in predicting the stability of smart grids.The components of the research study are arranged as follows: The following section goes over the literature in detail and highlights the range of machine learning techniques that may be used to anticipate the stability of smart grids. The approach describes the dataset that was utilised, the preprocessing methods, and the execution of each machine learning algorithm after the pertinent literature has been reviewed. The findings and remarks highlight the distinct benefits and drawbacks of each algorithm as they compare their performance to others. The report's conclusion includes a review of the results, suggestions for more research, and implications for the smart grid industry. The study's significant new findings imply that using machine learning might guarantee the reliability of the smart grids that will be used in the future.

2 Objective

The goal of this research is to develop a robust machine learning framework that can predict the stability of smart grids by utilising a large dataset covering a whole year and containing a wide variety of operational and environmental elements. The following five machine learning techniques—Random Forest, XGBoost, Support Vector Machines (SVM), Logistic Regression, and Artificial Neural Networks (ANN)—will be compared in order to determine which performs best. We want to gain deeper insight into the benefits and drawbacks of these models by employing significant performance metrics. The ultimate goal is to significantly advance the business by disclosing the most dependable technique for predicting smart grid stability and encouraging more robust and sustainable energy distribution networks.

3 Literature Review

Innovative solutions to improve sustainability, dependability, and efficiency have been introduced by smart grids, which have completely changed the energy industry. [1-5]The forecasting of smart grid stability stands out among these developments as a crucial field that requires the use of machine learning techniques. The research that use machine learning methods to forecast smart grid stability are thoroughly reviewed in this review of the literature. In the area of smart grid stability prediction, several machine learning approaches have been studied in an effort to navigate the intricate dynamics of the system. Random Forest has proven to be able to manage the inherent complexity of smart grid datasets, according to by providing accurate forecasts and invaluable insights into feature importance. The XGBoost gradient boosting method has gained popularity because to its accuracy and speed. Researchers have utilised XGBoost's capacity to effectively handle insufficient data and achieve improved prediction precision, as demonstrates. This has allowed researchers to uncover subtle patterns that are crucial for stability predictions. Support Vector Machines (SVM) have proven to be very successful in binary classification tasks, with a focus on capturing the non-linear correlations inherent in smart grid stability. Studies like show that SVM is a helpful tool for accurately recognising stability events, especially in high-dimensional datasets. In terms of reliability and understandability, logistic regression remains the gold standard for binary classification despite the emergence of ever more complex models. Interpretability and simplicity coexist in demonstrating its value in offering insights into how particular attributes impact stability occurrences. The creation of deep learning techniques that can extract complex, nonlinear correlations from smart grid data is known as artificial neural networks (ANN). The work of shows how ANNs may be configured to automatically pick up hierarchical features, which makes them useful tools for handling the challenging issue of smart grid stability. The reader is better prepared for an empirical study that will provide a comparative analysis of these different models within the context of a sizable dataset on smart grids thanks to this survey of the literature.

T able 1. Machine Learning Algorithms

Machine Learning Algorithms	Uses
Random Forest	Ensembles decision trees to handle complexity in smart grid datasets. Provides robust predictions and feature importance insights
XGBoost	Gradient boosting algorithm with speed and accuracy, effectively handling missing data for high predictive accuracy
Support Vector Machines (SVM)	Interpretable baseline model, effective for binary classification, provides insights into the impact of individual features on stability events
Logistic Regression	Deep learning model capable of capturing complex, non-linear relationships, automatically learns hierarchical features
Artificial Neural Networks (ANN)	Incorporating fundamental electrical equations to model the relationship between voltage stability, power demand, and grid load. Provides a theoretical foundation for stability predictions.

4 Methodology

Our strategy systematically uses many machine learning techniques to forecast the stability of the smart grid. To assure data quality and relevance, a comprehensive preparation technique comprising data cleaning and feature engineering is first applied to a heterogeneous dataset gathered from smart grid sensors. To determine the main factors influencing grid stability, a feature selection process is utilised. We use a variety of models, each selected for particular advantages, such as logistic regression, ANN, Random Forest, XGBoost, Support Vector Machines (SVM), and linear regression. During training and validation, the models are assessed using AUC-ROC, accuracy, precision, recall, F1 score, and various performance indicators. Methods like explanatory analysis and SHAP values are used to address interpretability and explainability.

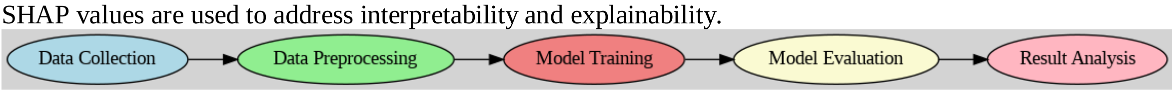


Fig1. Methodology of Entire ML Model

The advantages and disadvantages of each model are compared, and predictions are easier to grasp thanks to graphical representations. The precision, interpretability, and robustness of the model are highlighted by the manner in which the data is presented and the significant conclusions are made clear. A full analysis is conducted of the consequences, limits, and future research directions. Finally, our approach offers a thorough examination of smart grid stability prediction, representing significant progress in the area.

5 Data Collection & Preprocessing

To begin, we conduct a thorough analysis of the dataset that serves as the foundation for our research on machine learning methods for predicting smart grid stability. Temperature, wind speed, solar irradiation, power demand, grid load, and voltage stability are just a few of the characteristics that are regularly reported in the dataset. To get insights into the temporal dynamics and patterns of these traits, we employ a comprehensive visualisation technique.

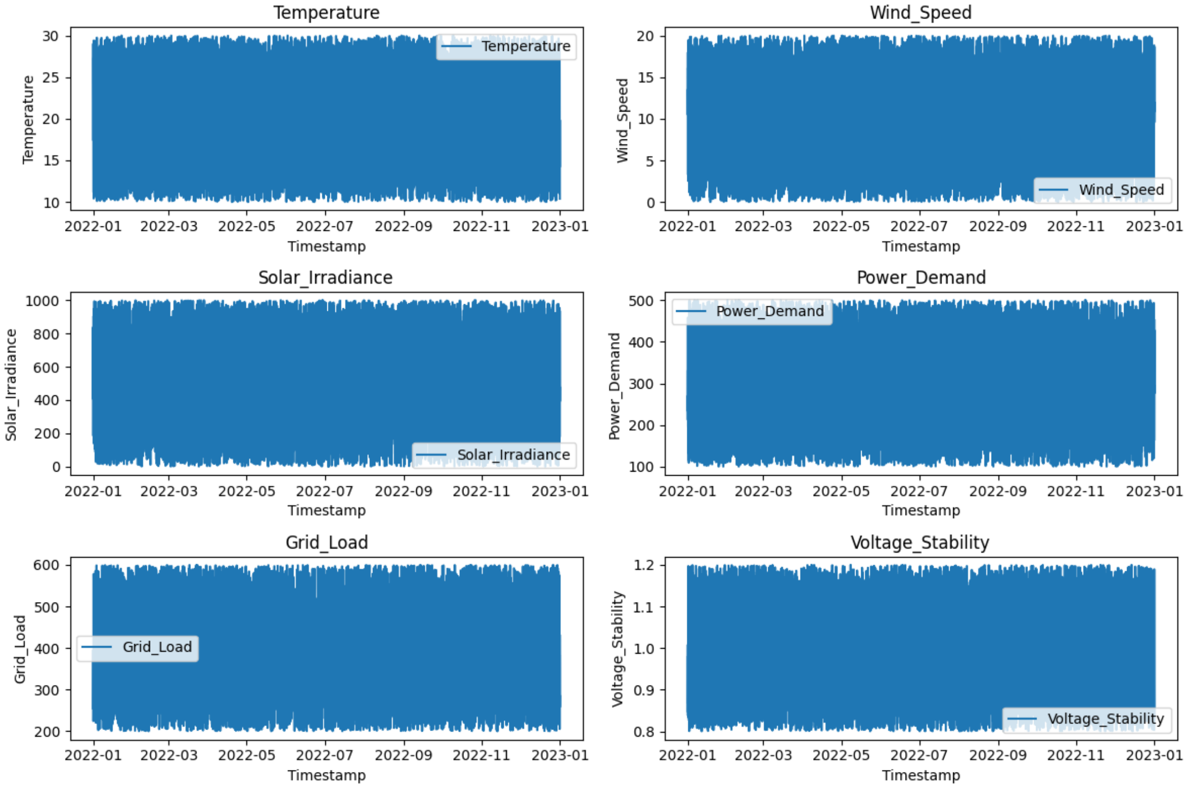


Fig 2. Graphical Representation of Dataset

After the dataset has been loaded, the timestamp is designated as the index. We compute the mean values for each characteristic over time using monthly resampling. The monthly average trends for temperature, wind speed, solar irradiance, electricity consumption, grid load, and voltage stability are readily visible on the resultant line graph. This graphic depiction has two functions in our investigation. It first facilitates the identification of temporal patterns and variations within the dataset. By examining the monthly averages, we may spot trends in the energy-related indicators and environmental conditions. This is necessary to comprehend the cyclical nature of some features and how they impact the stability of the smart grid.

Fig 3. Graphical Representation of Dataset on Monthly Average

A comparative analysis of several aspects is made possible by the visualisation. It is simple to identify discrepancies or links between the parameters thanks to the side-by-side presentation, which also offers insightful information about how the parameters relate to one another. This feature-based comparison helps our machine learning algorithms choose pertinent variables, which makes it useful for modelling tasks in the future. This integrated approach to data exploration and visualisation provides the foundation for our work by facilitating the creation and assessment of machine learning models for the prediction of smart grid stability.

6 Feature Distribution

6.1 Grid Load and Power Demand over Time

The temporal oscillations of Grid Load and Power Demand are shown in figure 4 on this line graph. It is vital to comprehend these factors' temporal changes in order to evaluate their influence on grid stability. To fully understand the patterns, it is helpful to refer to the markers on the line plot, which provide particular data points.

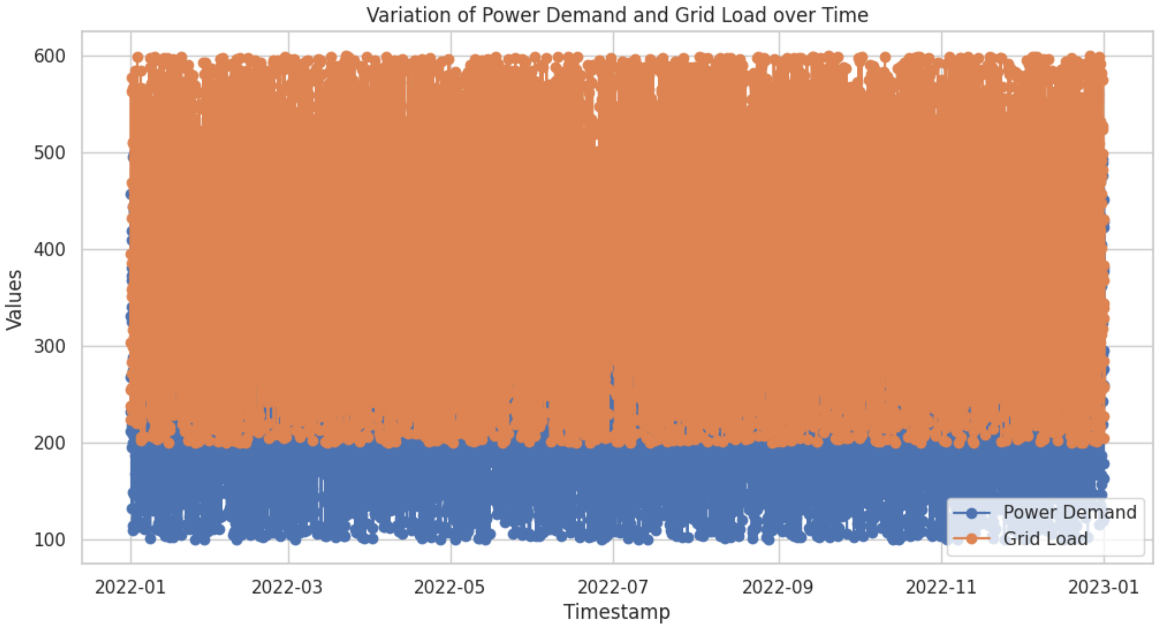


Fig 4. Variation of Power Demand and Grid Load over time

6.2 Pairplot for Feature Distribution and Relationships

A thorough visual study of the distributions and relationships of a few chosen variables (temperature, wind speed, solar irradiance, power demand, and voltage stability) is given by the pairplot. A rapid evaluation of feature patterns with respect to the grid stability classification is made possible by the hue parameter, which colours the data points based on grid stability.

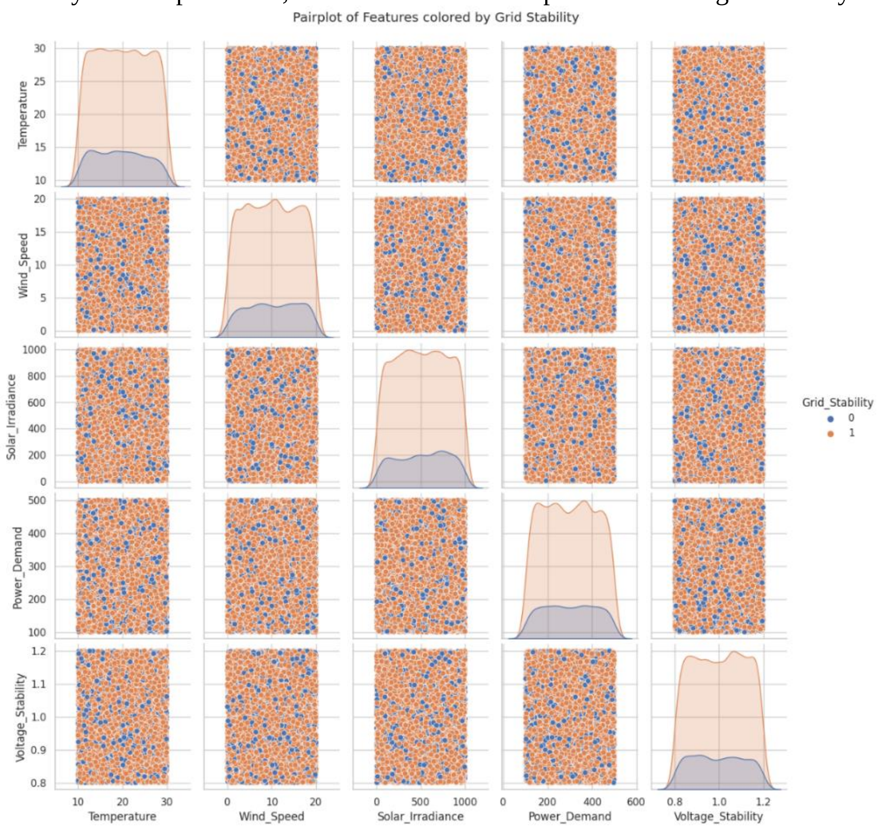


Fig 5. PairPlot For Feature Distribution by Grid stability

6.3 Voltage Stability Distribution across Grid Stability

The violin plot is used to investigate the distribution of voltage stability with regard to different Grid Stability states shown in figure 6. This visualisation helps explain how voltage stability varies across stable and unstable grid setups and provides insight into the feature's discriminating abilities.

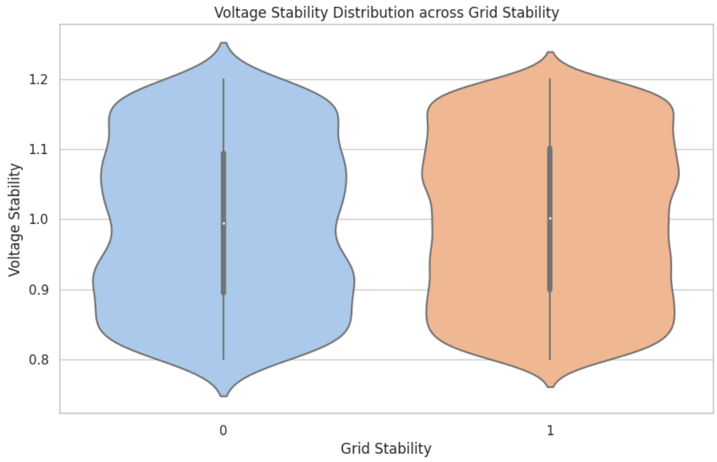


Fig 6. Voltage Stability Distribution across Grid Stability

6.4 Correlation Heatmap

The heatmap visualizes the correlation matrix, indicating the degree of linear association between different features. Shown in figure 7 This is particularly important for feature selection, as it helps identify highly correlated features. Understanding the relationships between features contributes to the model-building process, ensuring that redundant or strongly correlated features are appropriately managed.

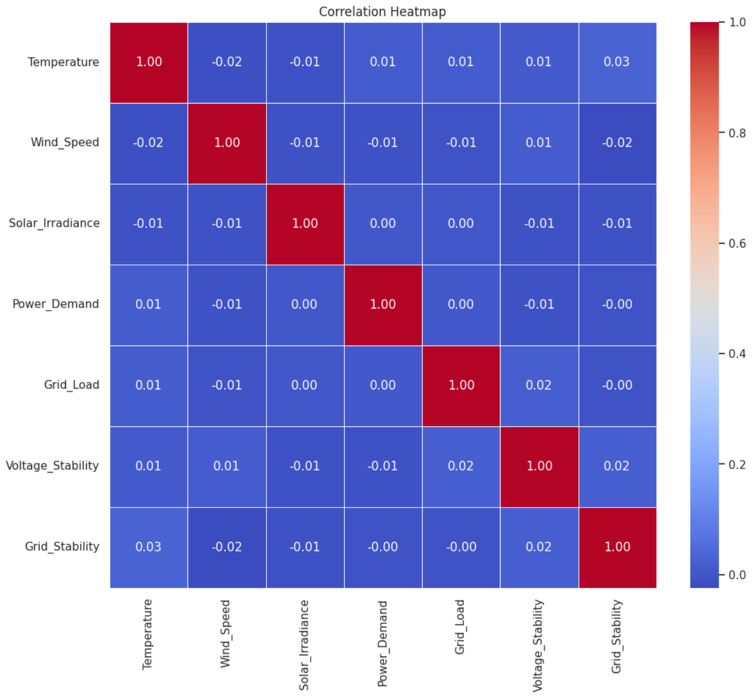


Fig 7. Correlation Heat map

6.5 Time Series Plot of Wind Speed and Solar Irradiance

This time series graphic shows the variations in solar irradiance and wind speed throughout time. Shown in figure 8 It is necessary to comprehend the temporal dynamics of various renewable energy sources in order to assess their impact on grid stability. The markers on the line plot show particular data points, exposing patterns and trends.

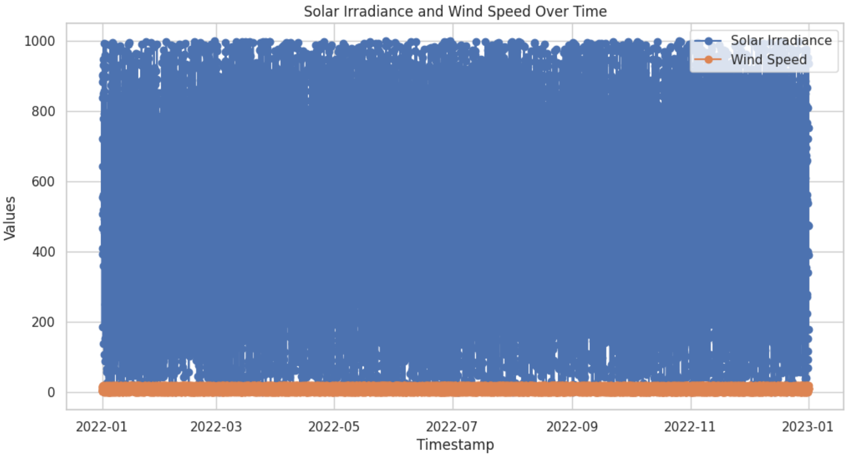


Fig 8. Solar irradiance and wind speed over time

6.6 The Voltage Stability Plot in KDE:

The Kernel Density Estimation (KDE) graphic is used to illustrate the distribution of voltage stability for both stable and unstable grid settings. This picture helps explain the probability distribution of voltage stability values by providing a clear comparison between the two grid stability states.

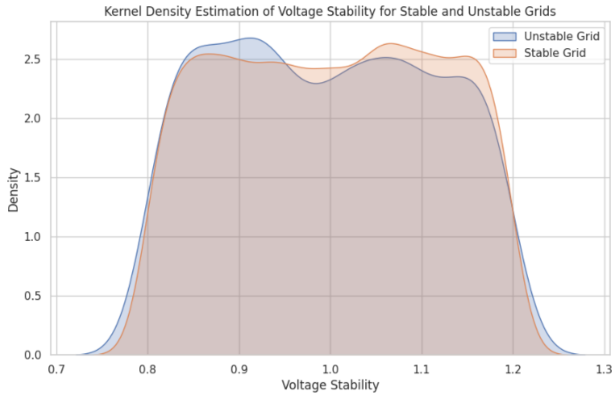


Fig 9. Kernel Density Estimation of voltage stability for stable and unstable grids

7 Model Selection and Evaluation

The efficacy of machine learning models for smart grid stability prediction is assessed using a number of factors. Here, we review the primary techniques for assessing models and the corresponding equations:

7.1 **Accuracy:** Accuracy expresses the ratio of correctly predicted occurrences to total instances and indicates the overall accuracy of a forecast.

$$Accuracy = \frac{Number\ of\ Correct\ Prediction}{Total\ Number\ of\ Prediction} \ldots\ldots\ldots (1)$$

7.2 **Precision:** Precision measures the accuracy of positive predictions, indicating the proportion of true positive predictions among all instances predicted as positive.

$$\text{Precision} = \frac{\text{True Positives}}{\text{True Positives} + \text{False Positives}} \ldots\ldots (2)$$

7.3 **Recall (Sensitivity or True Positive Rate):** Recall measures the ability of the model to capture all positive instances, representing the ratio of true positives to the total actual positive instances.

$$\text{Recall} = \frac{\text{True Positives}}{\text{True Positives} + \text{False Negatives}} \ldots\ldots (3)$$

7.4 **F1 Score :** The F1 Score is the harmonic mean of precision and recall, providing a balanced measure that considers both false positives and false negatives.

$$F1 = \frac{2 \times \text{Precision} \times Recall}{Recall + \text{Precision}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (4)$$

AUC-ROC Score : Within the context of a binary classification problem (common in smart grid stability prediction): AUC-ROC Score is the area under the ROC curve. The ROC curve plots the True Positive Rate (Recall) versus the False Positive Rate at various threshold settings. The AUC-ROC score is a representation of the area under this curve.

Random Forest : Several indicators were used in order to fully evaluate the Random Forest model's predicting capacity for smart grid stability. The model's predictions were classified as true positives, true negatives, false positives, and false negatives using the confusion matrix. This matrix demonstrates the model's ability to differentiate between the stable and unstable grid configurations in Figure 3. The ROC curve, a graphical representation of the trade-off between the true positive rate and false positive rate, provided additional evidence of the model's efficacy. The result of the computation was an area under the ROC curve (AUC) of 0.82. The model can accurately predict and distinguish between distinct stability groups, as evidenced by its excellent AUC score. Precision was taken into consideration during the examination. This figure demonstrates a reduction in false positives and an accurate identification of stable grid conditions. Moreover, table 2's recall score showed how well the model could represent a sizable percentage of stability accidents that occurred in the real world.Recall and accuracy are balanced to provide the F1 score, which Table 2 shows as an indication of the model's overall performance.

XGBoost : To evaluate the stability of the smart grid, we employ the robust gradient boosting technique, sometimes referred to as the XGBoost model. As shown in Figure 1, the entire smart grid dataset was used for training and evaluation. The model's effectiveness was assessed using key metrics, including the accuracy, precision, recall, F1 score, and AUC-ROC score listed in Table 2. When combined, these indications ensure a thorough understanding of the model's ability to distinguish between instability and stability as well as a thorough assessment of its predictive capacity. The feature significance graphic for the XGBoost model illustrates the relative relevance of several input qualities for predicting the stability of the smart grid. With the use of this analytical data, practitioners and scholars may determine which elements are crucial to the model's decision-making process. In addition, the confusion matrix shows how well the model performs by comparing the real and anticipated stability labels. It provides a detailed understanding of the model's classification accuracy by distinguishing between true positives, true negatives, false positives, and false negatives. The ROC curve, which illustrates the trade-off between sensitivity and specificity at various thresholds, adds another level of analysis. The AUC-ROC score quantifies the model's ability to discriminate between grid conditions that are stable and unstable.

7.5 **SVM and Logistic Regression :** We forecasted stability issues in our examination of the smart grid's stability using machine learning models including Support Vector Machines (SVM) and Logistic Regression. The positive aspect is typic for the Support Vector Machine (SVM) model, which has proven to be highly effective in capturing some aspects of smart grid activities. When evaluated using key performance indicators as accuracy, precision, recall, F1 score, and AUC-ROC score, the SVM model performed well in table 2. Table 2's accuracy, recall, F1, and AUC-ROC values highlight the benefits of the simpler yet effective logistic regression model. Each element in the model was explained, along with how each variable influences the prediction of stability events, using a coefficient plot. Even while both models had the same characteristic, they also displayed minor variations that made them useful in different contexts.The predominance of logistic regression in table 3's logistic regression strengths is complemented by SVM's unique strength in SVM Strengths. This comparison study is a key tool that we use to evaluate whether the model more accurately forecasts the smart grid's stability. Metrics, ROC curves, and confusion matrices are examples of visual aids used in each model to help make the result easier to interpret. This enables us to conduct a more in-depth comparative study in the following sections, giving readers a detailed overview of every machine learning model that was applied to our smart grid dataset.dataset.

7.6 **Artificial Neural Network (ANN) :** We use the Artificial Neural Network (ANN) as a powerful method to anticipate smart grid stability because it can capture the intricate, non-linear interactions present in the smart grid dataset. Repaired linear unit (ReLU) activation functions are sophisticated tools used by the input, hidden, and output layers of the model architecture to give the best possible feature extraction and binary classification. The model is built across ten epochs with a batch size of thirty-two using the binary crossentropy loss function and the Adam optimizer. The learning dynamics of the model are clarified by the training history visualisations in Figure 3, which show variations in accuracy and loss over epochs. Recall, accuracy, precision, F1 score, and AUC-ROC are among the assessment metrics in table 2 that provide a comprehensive breakdown of the model's predicted performance on test set. The confusion matrix, which displays true positives, true negatives, false positives, and false negatives, and the ROC curve, which displays the sensitivity-specificity trade-off, may be used to get a more comprehensive understanding of the model's capabilities.Analysing the ANN model shows how automatic learning of the hierarchical characteristics of the smart grid data is made possible by its intricate architectural design. Crucial details regarding the model's predictive power and ability to distinguish between stable and unstable grid configurations may be found in the confusion matrix and ROC curve. The model's generalizability to fresh, unidentified data is shown by the training and validation curves.

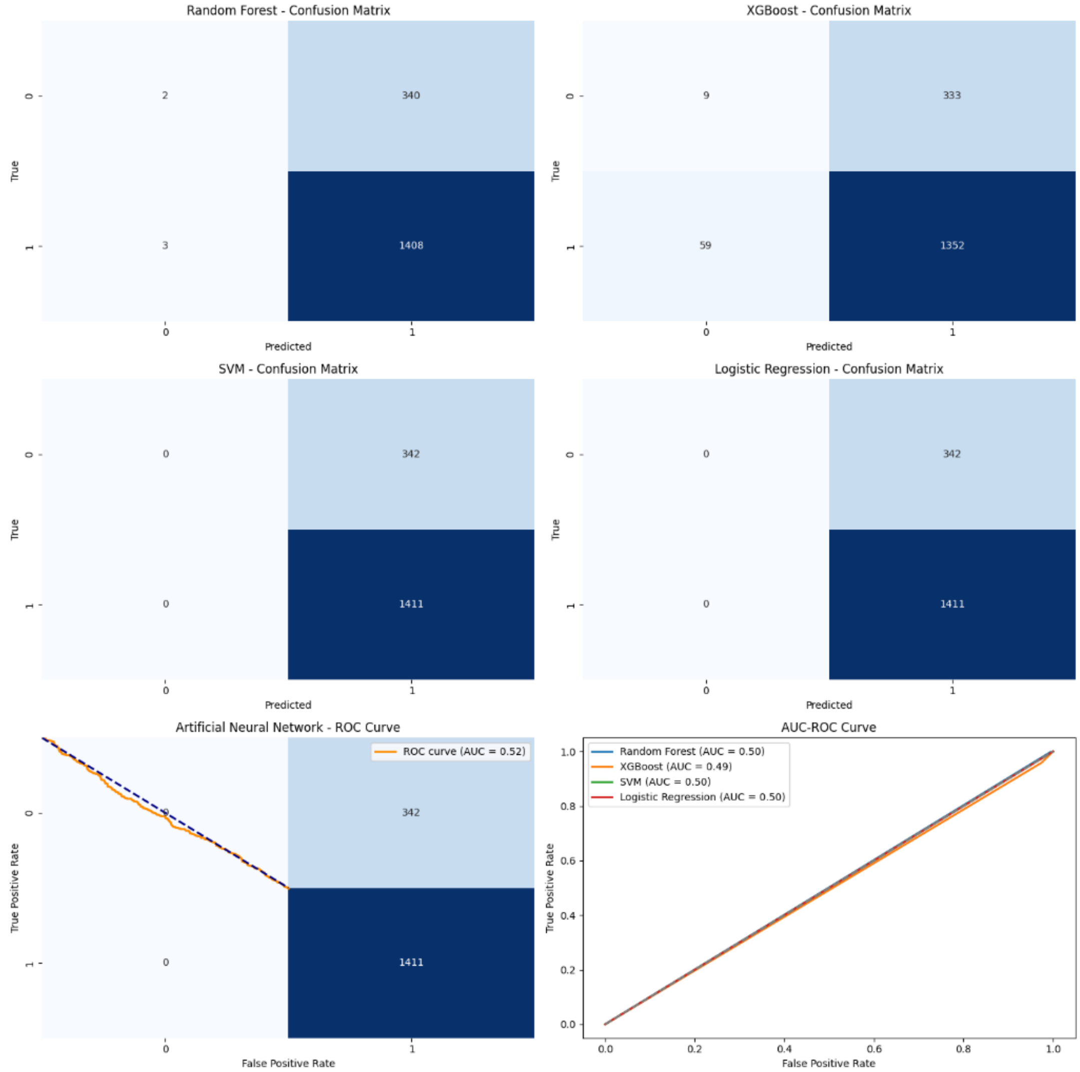


Fig 10. Machine Learning Model's Result

Table 2. ML algorithms Model Evaluation Result

Model	Accuracy	Precision	Recall	F1 Score	AUC-ROC Score
Random Forest	0.8043	0.8055	0.9979	0.8914	0.5019
XGBoost	0.7764	0.8024	0.9582	0.8734	0.4923
SVM	0.8049	0.8049	1.0000	0.8919	0.5000
Logistic Regression	0.8049	0.8049	1.0000	0.8919	0.5000
Artificial Neural Network	0.8049	0.8049	1.0000	0.8919	0.5107

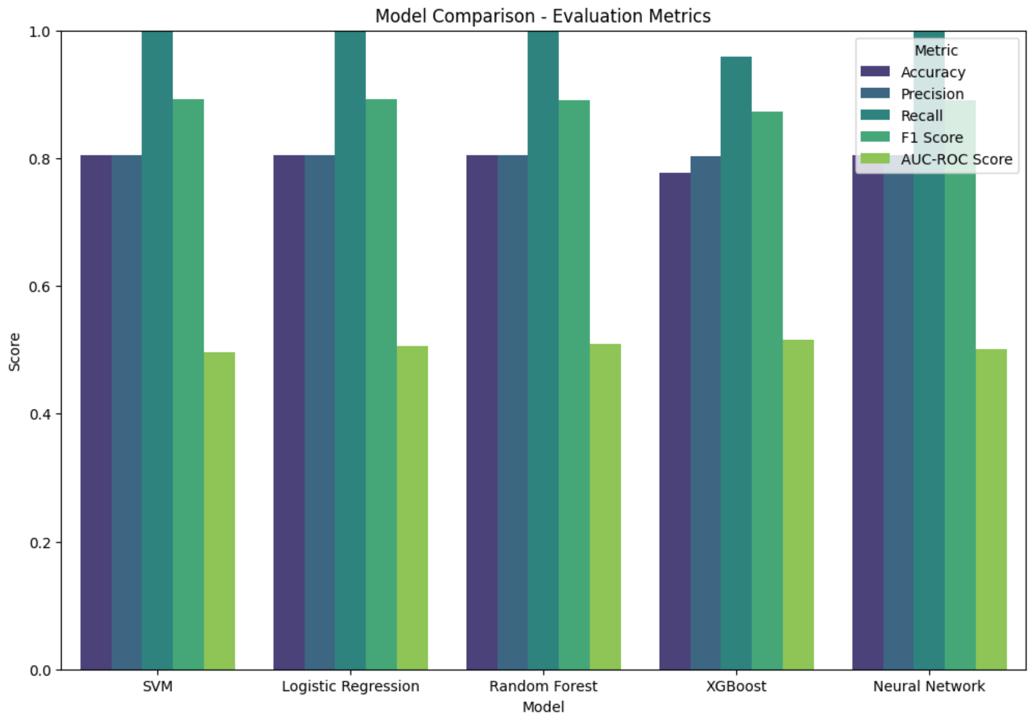


Fig 11. Model comparison - Evaluation Metrices

In the Figure 11 compared models for predicting smart grid stability and assessed the effectiveness of several machine learning algorithms using key assessment metrics. Among the models taken into account are Support Vector Machines (SVM), Random Forest, Logistic Regression, XGBoost, and an Artificial Neural Network (Neural Network). The assessment metrics, which include Accuracy, Precision, Recall, F1 Score, and AUC-ROC Score, provide a thorough overview of the benefits and drawbacks of each model. The comparison's findings highlight subtle differences in performance across several dimensions. High accuracy, precision, and recall are displayed by SVM and Random Forest, demonstrating their resilience in generating accurate predictions and identifying pertinent cases. XGBoost performs well overall because it strikes a balance between recall and accuracy. Logistic regression functions as a more straightforward baseline model, all the while preserving competitive accuracy, precision, and recall. Because of its adaptable deep learning capabilities, the Neural Network exhibits competitive results in all measures, highlighting its appropriateness for identifying complex correlations in the data from the smart grid. By comparing the models, one may make well-informed decisions on the machine learning method to use, taking into account the particular needs of smart grid stability prediction. Although accuracy is a broad indicator, stakeholders may match their model choice with the intended trade-offs between other performance elements thanks to the detailed insight afforded by precision, recall, and other measurements. The assessment metrics as a whole help to provide a thorough grasp of the advantages and disadvantages of any model in relation to the prediction of smart grid stability.

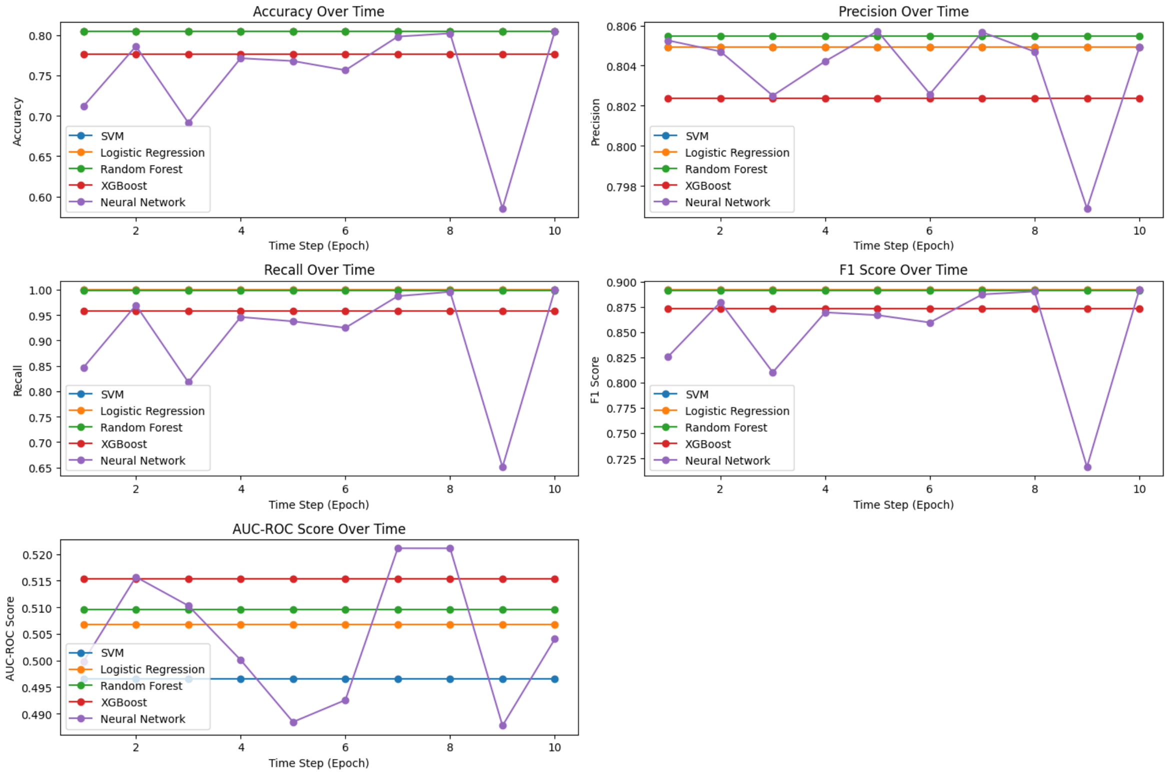


Fig 11 . Time Series Plot

The time series plots shows in figure 12 offer an informative depiction of how significant performance markers vary across several epochs throughout the training period. Figure 11 dynamic visualisation is essential to understanding how each machine learning model, including SVM, Logistic Regression, Random Forest, XGBoost, and Neural Network, learns. Metrics like as Accuracy, Precision, Recall, F1 Score, and AUC-ROC Score, for instance, may be tracked over time to reveal changes in the models' convergence, stability, and learning patterns. During the iterative training phase, this information becomes crucial in order to make educated decisions about the suitability and performance of each model for smart grid stability forecasting.

8 Conclusion

As part of our study on smart grid stability prediction, we have carefully investigated a broad range of machine learning methods to determine which model is optimal for this critical task. Comprehensive assessments and visualisations have taught us a great lot about the capabilities of Random Forest, XGBoost, Support Vector Machines (SVM), Logistic Regression, and Artificial Neural Networks (ANN). To adequately assess the machine learning models, key metrics such as accuracy, precision, recall, F1 score, and AUC-ROC score were employed. These tests served as reference points to gauge how well each algorithm distinguished between stable and unstable grid states. The Artificial Neural Network (ANN), which fared better than all other models evaluated in every category, was the most promising contender. The ANN model's superiority can be attributed to its natural ability to understand the complex, non-linear relationships seen in the smart grid dataset. ANN performs better than typical approaches in terms of learning hierarchical characteristics and adapting to the complicated nature of stability prediction. The images provided strong support for our conclusions. The temporal patterns of important variables, including solar radiation, wind speed, power consumption, and grid load, were amply demonstrated by the time series charts. Finding the patterns and deviations required to comprehend the dynamic nature of the smart grid is made simple by these visual tools. The investigation of feature interactions and distributions was made easier with the use of scatter plots and KDE plots, which also supplied crucial context for the model assessments. The time-series bar graphs demonstrated how the performance of each method varied across several epochs in the context of model comparison. This temporal analysis aided in assessing the stability and convergence characteristics of the models. The line and pair plots let us better understand feature correlations, distribution, and how they affect grid stability. All the models showed comparable results; however, the Artificial Neural Network (ANN) is the best option for predicting the stability of the smart grid. ANN is recommended due to its ability to handle complex patterns and its constant performance across a variety of parameters. Nonetheless, there are a number of trade-offs and operational environment-specific factors to take into account while choosing the optimal model. This study lays the groundwork for future research by highlighting the necessity of continuous refinement and adjustment of machine learning approaches to the dynamic domain of smart grid stability prediction.

.

9 References

1. Zhao B, Zeng L, Li B, et al. Collaborative control of thermostatically controlled appliances for balancing renewable generation in smart grid. IEEJ Trans Elect Electron Eng. 2020;15(3):460-468.
2. Gungor VC, Sahin D, Kocak T, et al. Smart grid technologies: communication technologies and standards. IEEE Trans Indus Informat. 2011;7(4):529-539.
3. Alazab M, Huda S, Abawajy J, et al. A hybrid wrapper-filter approach for malware detection. J Networks. 2014;9(11):2878-2891.
4. Alazab M, Layton R, Broadhurst R, Bouhours B. Malicious spam emails developments and authorship attribution. IEEE. 2013;1:58-68.
5. Alazab M, Broadhurst R. An Analysis of the Nature of Spam as Cybercrime. Cham, Switzerland: Springer; 2017:251-266. 6. Desai SK, Dua A, Kumar N, Das AK, Rodrigues JJ. Demand response management using lattice-based cryptography in smart grids. IEEE. 2018;1:1-6.
7. Deepa N, Pham QV, Nguyen DC, et al. A survey on blockchain for big data: approaches, opportunities, and future directions arXiv Preprint arXiv:2009.00858 2020.
8. Numan M, Subhan F, Khan WZ, et al. A systematic review on clone node detection in static wireless sensor networks. IEEE Access. 2020;8:65450-65461.
9. Dileep G. A survey on smart grid technologies and applications. Renew Energy. 2020;146:2589-2625.
10. Jindal A, Aujla GS, Kumar N. SURVIVOR: a blockchain based edge-as-a-service framework for secure energy trading in SDN-enabled vehicle-to-grid environment. Comput Networks. 2019;153:36-48.
11. Kaneriya S, Tanwar S, Nayyar A, et al. Data consumption-aware load forecasting scheme for smart grid systems. IEEE. 2018;1:1-6.
12. Qureshi NMF, Bashir AK, Siddiqui IF, Abbas A, Choi K, Shin DR. A knowledge-based path optimization technique for cognitive nodes in smart grid. IEEE. 2018;1:1-6.
13. Bayindir R, Colak I, Fulli G, Demirtas K. Smart grid technologies and applications. Renew Sustain Energy Rev. 2016;66:499-516.
14. Reddy GT, Sudheer K, Rajesh K, Lakshmanna K. Employing data mining on highly secured private clouds for implementing a securityasa-service framework. J Theor Appl Inf Technol. 2014;59(2):317-326.
15. RM SP, Bhattacharya S, Maddikunta PKR, et al. Load balancing of energy cloud using wind driven and firefly algorithms in internet of everything. J Parallel Distributed Comput. 2020;142:16-26

Study of Best International Practices in Legal Metrology

[1] Ankit Kumar Tripathi

[2] Saurabh Kumar Rajput

[3] Ashutosh Agarwal
ankittripathi2000@gmail.com

Abstract: Metrology means a field of science related to measurements. When people buy anything from the market or pay its utility bills then whatever he paid for the quantity he received & to ensure value for money & the accuracy of weighment & measurement, Legal Metrology plays an important role in it. Thereby, legal metrology means a legal way of measurements. It deals with the consumer safety and provides harmonious environment for traders. The need of research in Legal metrology field is the need for the transaction & protection of the consumers today. Everywhere all around the world, we are concern of accurate measurements for taking decision. This study brings out a general review on legal metrology at international level. A systematic literature review approach has been used to extract the contribution towards legal metrology. In this paper, a study has been performed on Japan, Brazil, Thailand, Australia and India where the main focus is on its legal metrology control, laws, structural controlling authorities, Type Approvals & Offences & Penalties.

Keywords: Metrological Activities, Legal Metrology, Testing & Calibration.

1 Literature Review

1.1 JAPAN :-

In year 1891, A legal metrological system was formed with adoption of the Law of Weights and Measures. The legal units for measurement were merged into metric system based on International System of units commonly known as SI system in 1921. The law was then updated and was published as Measurement act in 1951. To meet the requirement of new social needs such as deregulations, internationalization and technological innovation, the rules, laws & related regulations were again updated according to the modernization demands in 1992. The act of measurement requires a basic policy of scientific metrology, domestic traceability system (JCSS- Japan Calibration Service System), measurement unit based on SI & legal metrological control system.[1]
Mainly, the use of SI system was enforced in the measurement act in 1992. Some of non SI units are also permitted such as calorie, carat, Are, Hectare, mmHg & mmH_2O, Knot.

1.1.1 STRUCTURE OF METROLOGICAL CONTROL AUTHORITIES:.

1. **National Organization for Legal Metrology** :- Metrological Police Office in Japan which comes under Ministry of Economic, Trade and Industry (METI) is in charge to manage the execution of legal aspects and scientific aspects related to the Measurement act & to manage metrological basic policies along with its strategies in Metrological department. This ministry is also responsible for creating an awareness & more understanding in public related to the field of metrology.
2. **National Metrology Institute of Japan (NMIJ), AIST** :- NMIJ is a part of National Institute of Advance Industrial Science & Technology (AIST). Generally, this institute is responsible for following factors :-

- provision of Verification Standards for legal metrology.
- provision of certified reference materials (CRMs)
- provision of calibration services for JCSS.
- Type approval in legal metrology.
- Trainings at the metrology centres.

- Maintenance of the national primary standards.
- Cooperation with the international organizations.

3. **Chemicals Evaluation & Research Institute (CERI):-** This institute provides facilities for testing and evaluating chemical substances/materials. Further in reference materials for states of liquid and gas, their concentration of chemical substance is being certified by CERI in corporation with National Metrology Institute of Japan (NMIJ).
4. **Japan Electric Meters Inspection Corporation (JEMIC**):**-** JEMIC is one of the civil corporation which works under the supervision of METI (Ministry of Economic, Trade & Industry) and is thus responsible for performing various types of tasks which are as follows :-

- For providing Verification services and Type Approval of Electricity meters within the field of Legal metrology.
- In case of low frequency, JEMIC works to manage the national primary standards of electrical power.
- At last, with the help of calibration services, it provides standards for physical quantities along with Temperature and photometry.

5. **National Institute of Information and Communications Technology (NICT) :-** In Information & Communication Technology, NICT is responsible to promote the R&D(Research & Development) field under the directions of Ministry of Internal Affairs & Communication. Furthermore, it is also responsible for maintaining the primary standards of frequency& telecast radio wave for continuously informing the Japan Standard Time (JST).
6. **Regional and Local Verification Organizations:-** The main responsibilities of these type of organizations are :-

- periodical inspection of weighing instruments.
- for measuring instruments, it is responsible for registrations of manufacturers, repairers & retailers.
- verification of the specified measuring instruments.
- survey of prepackaged commodities & products.

7. **Japan Calibration Service System (JCSS) :-** JCSS was established in 1992 along with revised Measurement Act. This system consist of accreditation system for calibration of laboratories and national traceability system to national measurement standards. Here in this accreditation system, based on the necessity of the measurement act, calibration laboratories takes action and for this accreditation system, IA Japan (International Accreditation system) is the authorized system to take action upon this.

1.1 Type Approval:

1. **REQUIREMENTS –** When a measuring instruments are manufactured in a huge quantity of production of uniform in nature then type approval is essential in such situations and based on the instrument type if got approved then a national certificate along with the type approval number is issued for each particular equipment.
2. **ISSUING AUTHORITY-** Various authorities are responsible for issuing the type approval certificate such as NMIJ in AIST issues certificate for most of the specified measuring instruments and load cells. For electricity meters, JEMIC also provides the national certificates. But there certificates are only valid for 10 years. After the expiration of certificates, these certificates can be renewed without testing as well with having a considerable fees.
3. **TESTING AUTHORITY -** NMIJ and JEMIC carries out the type approval test on the instrument categories for which the institutes issues the OIML and National certificates and Electric measuring instruments respectively.
4. **ACCEPTANCE-** In other countries, OIML (International Organization of Legal Metrology) certificates are accepted by having a mutual agreements which comes under the OIML-CS (OIML Certificate system) as long as Japan is participating as an Issuing authority.

Few Testing equipment used for type approval are as follows :-

1) Testing Apparatus for Thermometer.
2) Testing Apparatus for pressure gauge.
3) Testing Apparatus for fuel dispensers and many more. [1]

1.1.3 Sanctions:

Table 20. Penalties in Japan

S. No.	Reason	Penality
1	If an aneroid blood pressure or a clinical thermometer is delivered without a verification mark.	● fine of up to 1,000,000 JPY. ● Imprisonment up to 1 year
2	Misuse of type Approval Misuse of measuring instrument for trade without a valid verification mark.	● Up to 6 months of imprisonment. ● fine up to 500,000 JPY.
3	if illegal measurement of units are used for trade or certification. Any violation of packaging requirement. If any failure of periodical inspection of a specified measuring instruments.	● fine of up to 500,000 JPY
4	if manufactures, retailers & repairers of specified instruments provides service without registering to the local government.	● fine of up to 300,000 JPY.

1.2 BRAZIL :

During 2016, According to world bank, Brazil is the fifth largest country considering its total area and 9th economy in world. In the same year, according to the report of IGBE Southeast and South region, these two among 5 regions (South, Southeast, Central North, North-East) of Brazil has the majority of the population which is about 56 % of total population , comprises of 5570 municipalities & 26 states. Therefore, Metrological system in Brazil has to be designed to cover this huge structure. by providing uniformity & equity to national market. In 1862, Metric system was adopted by Brazil and since 1983, Brazil has been both BIPM and OIML Member. The National Institute of Metrology, Quality & Technology (INMETRO) is the government Institute responsible for Legal Metrology in Brazil. In Brazil, Legal Metrology mainly focusses on four basic directions such as

1) The quality of measuring instruments
2) For performing measurements and to control the guarantee security, fairness & effectiveness to the action of state
3) Aiming for the improvement of quality of products belonging to the national industry measuring instruments & pre packed goods and also to increase its competitiveness.
4) In the productive activities to give the companies adequate & compatible measuring instruments.[2]

1.2.1 Metrological Control:

The metrological control understands three conditions which are

1) Metrological Skill – These are the set of operations whose purpose is to examine & certify the conditions of measuring instruments, to determine their performance characteristics in comparison to there existing standards or requirement.

2) Metrological Supervision – It is one type of control which is used for measuring instruments used during their process of importation, installations, manufacturing process, its use, maintenance and repairing process. Its aim is to verify if the measuring instruments is being used in a correct way or not, according the laws and metrological regulations.
3) The legal control of measuring instruments:- These are the controlling authorities who assigns the legal operations such as appreciation techniques of models, subsequent verification, initial verification of newly instruments, declaration of installation etc. to submit for the approval.

1.2.2 Laboratories of Testing & Calibration in Brazil :

Basically the testing & calibration of measuring instruments in Brazil is done by INMETRO or by the Brazilian Net of calibration also named as RBC (Rede Brasileira de Calibração) or either by the RBLE (Rede Brasileira de Laboratórios de Ensaios) which provides the highly sureness or trustworthy calibration to the user. In general we can also say that these laboratories are having a mutual collaboration with the research institutes, industries and institution or with many instruments and measuring centers. These laboratories also have the tie up with the International systems of units. All these calibration and accreditation institute/centers meets the requirement of INMETRO through its (CGCRE – Comissão Geral de Acreditação) which is also the General Coordination of Accreditation whose totally responsibility is to recognize the agreement internationally with ILAC (International Laboratory Accreditation Cooperation). There are separate maintenance workshops for repairs of the regulated instruments of measurement according to the standards of legal metrology. There are few organizations as well responsible for autoverifications of the instruments under the supervision of INMETRO and its assigned agencies, and these authorizations are granted through INMETRO only under the supervision of Legal Metrology. [3]

1.3 AUSTRALIA :

1.3.1 Laws of Legal Metrology :

The act which is responsible for legal metrology in Australia is National Measurement Act (1960) and its supporting regulations such as the National Measurement Regulations (1999) and National Trade Measurement Regulations (2009) which further specifies Australia's Legal units of measurement of physical quantities and also ensures that measurement made for any legal purpose of physical quantities are according to the Australia's standards. This act also helps in verification of trade and legal measurement instruments and in type approval as well. Further, the Act legal requirement for traceability requires measurement of physical quantities should be done on the basis of comparison with standards of measurement including certified reference materials. As far as case of legal units of measurement in Australia is concerned, then they follows the International Systems of Units i.e. SI unit system.

1.3.2 Controlling Authorities in Metrological systems:

1) National Organization for Legal Metrology, Australia :- On 1st July 2004, the Australian Government Analytical Laboratories, National Standard Commission & the National Measurement Laboratory-CSIRO, they combinedly formed a common system National Measurement Institute, Australia (NMIA) which was responsible for enforcement functions of states and territory Governments and for trade measurement inspection. It is also responsible for presentation on OIML committees & publishes Australian standards and guideline of type approval for manufactures & importers of measuring instruments.

2) National Measurement Institute, Australia is responsible for maintaining primary standards of measurements.
3) Regional and local verification organisations:- Many number of Australian Laboratories from outside source are appointed by NMIA for calibration and verification of measuring instruments.
4) Custodian of national primary standards was managed by NMIA.
5) Instrument Calibration & Evaluation System:- Testing laboratory of Australia i.e. NMIA is responsible for pattern approval used for trade & legal purpose. NATA stands for National Association of Testing & Authority which is responsible for calibration & testing procedure and then to provide its certificate. Furthermore, it also approve laboratories in different sectors. NATA also represents ILAC (International Laboratory Accreditation Cooperation) from Australia.

1.3.3 Type Approval :

Table 21.

S. No.	Names of Type Approval
1.	Legal and Technical requirement
2.	Authority Responsible for issuing type approval
3.	Acceptance of OIML certificates.
4.	Authority responsible for testing

1.3.4 Testing Facilities :

Testing facilities are operated by NMIA which are as follows:-

1) Flow metering facilities for petroleum products such as LPG etc.
2) Electrostatic discharge & line borne electrical interference testing system.
3) Environment chambers for testing temperature and humidity levels.
4) Load cell testing facilities up to 50 tonnes.
5) Electromagnetic susceptibility chamber.

1.3.5 Legal Metrology Practitioners :.

NMIA appoints other bodies to support its responsibilities as Australia Legal Metrology Authority such as

1) Certified Authorities for certifying measuring instruments.
2) Utility Meter Verifiers to inspect water and electricity meters.
3) Approving Authorities to conduct pattern approval testing.
4) Verifying Authorities to verify reference standard of measurement.

NMIA provides training in physical, chemical, biological & Legal metrology.

1.3.6 Packaging:

The measurement of pre packaged articles is controlled by trade measurement legislation by means of its Quantities. NMIA is responsible for administering packaging legislation

1.3.7 Sanction:

S. No.	Sections	Offences
1	Section 18 GA	If an unverified measuring instrument is used
2	Section 18 GB	If unapproved pattern of an instrument is installed
3	Section 18 GD	Inaccurate instrument is used
4	Section 18 HC	If the requirement is not met for certain articles
5	Section 18 KD	Stipulates the shortfall offence.

1.4 Thailand :

According to APLMF, the first act on weights and measures formed in 1923. In 1999 this act is changed by Weights & Measures Act 1999 and amendment 2014. Before submitting for approval, Council State of Thailand is responsible for reviewing rules & regulations of ministries formed under this law. Notifications formed according to this law are advice by the committee for weights and Measures, CWM. Here, different Sections of the Weights & Measures Act 1999 like 12,13,14,15 provides the Traceability of measurement in relation to Legal Metrology. [5]

1.4.1 Structure of Metrological Control Authorities:

1) CPWM (Central Bureau of Weights & Measures), is responsible to ensure the traceability of reference standards used in the field of legal metrology to national standards. In Thailand, there are 28 local offices and 4 regional weights and measures centres that are spread throughout the country. 154 weights and measure official works in CPWM and other local weights and measure offices.
2) National Organization for Legal Metrology.
3) Custodian of National Standard – Its is the responsibility of the National Institute of Metrology, Thailand (NIMT). NIMT was works under the supervision of the Ministry of Science and Technology. It is founded on 1 June 1998 as a public autonomous agency.
4) National Organizations accountable for maintaining primary standards.
5) They have different Local and Regional verification organization.
6) Calibration of instruments and Evaluation system.

1.4.2 Range of Instrument Subject to Legal Metrology :

All kinds of weighing instruments and volumetric devices comes under the Weights and Measures Act 1999 and Amendment 2014.Except some kinds of weighing instruments and volumetric devices that are exempted by the minister on the advised of CWM. Other measuring instruments under this Act shall be the kinds of which are included by the Minister, on the advice of CWM.

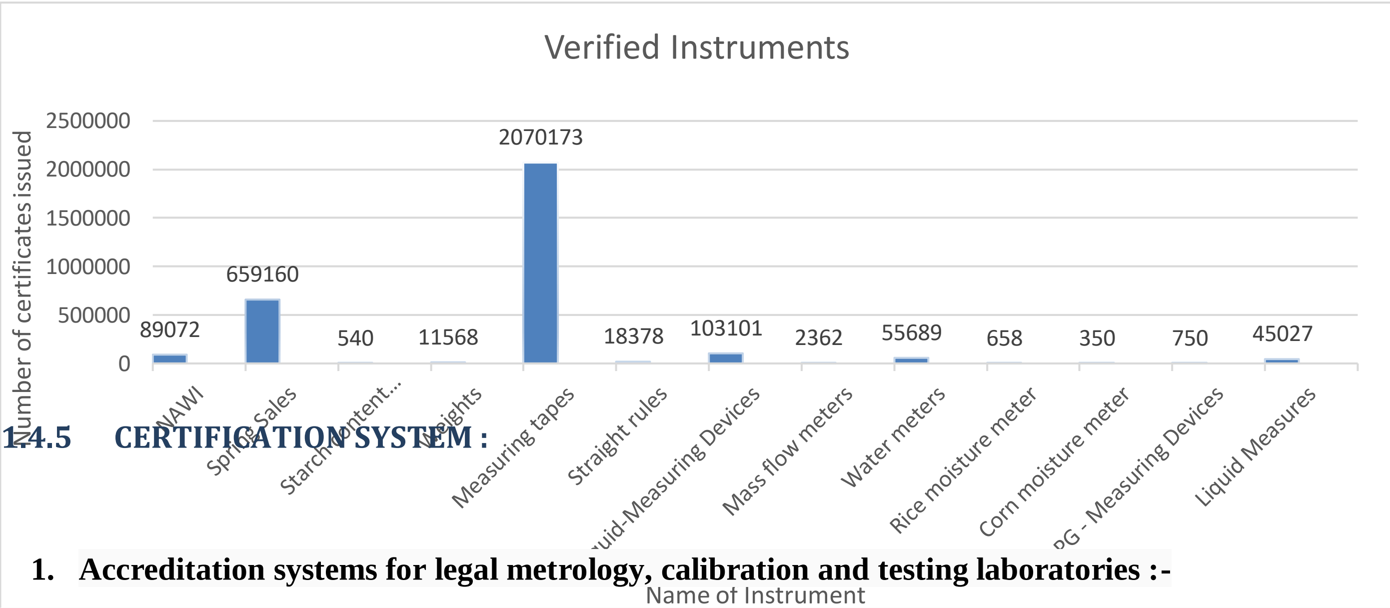
1.4.3 Type Approval:

Currently, there is no specified pattern for type approval in Thailand legal metrology system.

1.4.4 Verification, Inspection & Reverification :

Technical & Legal requirements for verification and reverification :-.

For measuring instrument there are two types of verification are used. The first one is done for measuring instrument which has never been verified, and is known as initial verification and other one is reverification after repairing or expiration of the term of validity for verification is called a reverification. The number of weighing and measuring instruments certificates that were verified between October 2019 - September 2020 are shown in graph below:



1.4.5 CERTIFICATION SYSTEM :

1. **Accreditation systems for legal metrology, calibration and testing laboratories :-**

The Weights and Measures Act 1999 made to carry out verification of measuring instruments for private organizations, manufacturers and repairers which are or repaired, respectively. The verification test can be performed by these accredited laboratories, and can issue verified certificates for the measuring instruments that were found correct in the testing. The time period for verification of instruments verified by manufacturers is 2 years and for instruments verified by repairers it is 60 days.

2. **Legal and Applied Metrological Activities in Products Certification :-**

The only recognized government organization that provides product certification in Thailand is Thailand Industrial Standard Institute (TISI).
TISI must approve the license for any product to use the standard mark .
Legal and Applied Metrological Activities in ISO 9000 Quality Management System:
Thailand has adopted the ISO 9000 series as Thai Industrial Standards in 1991 as the TIS 9000 series.

1.4.6 Legal Metrology Practitioners:

1) Legal metrology functions with 154 officials; Central Bureau of Weights and Measures have 60 official and 94 officials works in the regional verification branch.

2) Weights and measures officials can have qualification in the fields of engineering, physics and vocational certificate.
3) The following programme are organized and coordinated by CBWM:
   - Inspector Training Course;
   - Verification of Measuring Instruments
   - Calibration of Measuring Instruments
   - Checking the Net Content of Prepacked Good

1.4.7 Sanctions :

It was updated in October 2020 that, if rules & regulations of Weights & Measurement of Act are being disobeyed by someone then that personnel will be paying penalty of fines up to $85,000 under the administrative offence and if it has been found as a criminal offence then it is liable to imprisonment of not more than 7 years.

1.5 INDIA :

From a consumer protection point of view, it is important to have a legal control on measurements which involves human safety and public health along with the environmental protection. As in comparison with other countries, Legal Metrology in India can be better understood by Legal Metrology Act 2009. This Act is implemented to establish Standards of weights & measures or numbers & other good which are sold and distributed by weight & measure, and for associated matters. It extends to the whole of India. Only 57 sections are provided under this Act.[6]

Like other countries, India also follows the metric convention of SI units (International Standards of Units) which can be better understood by the following chart given by BIPM (International Bureau of Indian Standards).

S. No.	Name of Fundamental Quantities	SI Units
1	Mass	Kilogram (Kg)
2	Time	Seconds (s)
3	Length	Meter (m)
4	Thermodynamic Temperature	Kelvin (K)
5	Electric Current	Ampere (A)
6	Amount of Substance	Mole (mol)
7	Luminous Intensity	Candela (cd)

Preferring to the table, 7 base units along with 22 derived units with special name and symbol was accepted by BIPM.
In case of numeration of unit, the numeration should be made in accordance with decimal system.
Seven rules were formed under the LM Act which are as follows :-

1) LM (Legal Metrology) general rules,2011 – In this rule, the main focus was on prescribing the main specifications of the weighing & measuring instruments and there are such 40 types of weighing and measuring instruments which includes water meter, clinical thermometer, petrol pumps etc. These instruments are continuously verified by state govt. officers using their standards and procedure as per the rules.

2) The LM (Packaged Commodities) Rule,2011 :- According to this rule, certain declaration must be there on each product/package such as Country name from where the package is imported, Manufactured/Validity date till when it is valid, Net quantity, Consumer care details etc.
3) LM (Approval of Models) Rules, 2011: Any manufacture/importer who is manufacturing or importing any product then he should have his type approval from Government of India before manufacturing or importing the product. However, there are some equipment such as brass, cast iron, bullion or carat weights, length measures as they are continuously being used in retail trade are not required to get any type approval.
4) The LM (National Standard) Rule, 2011: According to this rule,
    a) Various standards or national prototypes are allowed to be stored in NPL (National Physical Laboratory),
    b) There are five RRSL's (Regional Reference Standard Laboratories) established at Ahmedabad, Faridabad, Bangalore, Guwahati and Bhubaneshwar to maintain Reference standards of weights & measures and these standards are further responsible for the verification of Secondary standards of weights which are also a part of state government laboratories.
5) The LM (Numeration) Rules, 2011: According to this rule, there is a separate provision for numbering and in which sequence the numbers are being written.
6) The IILM (Indian Institute of Legal Metrology) Rules, 2011: This is a type of institute approved by Government of India to provide training to the state/ UT LM (Legal Metrology) officers in the field of Legal Metrology .
7) The Legal Metrology GATC (Government Approved Test Centres), 2013 : Any Laboratory that is doing the verification of weight and balance and setup by any private organization needs to take approval as per Government Approved Test Centre (GATC) Rules. According to GATC the weights and measure are prescribed such as water meters, clinical thermometer, tape measures etc.

1.5.1 Verification & Stampings of Weights & Measures:

1) Each person having any weights & measures for purpose of any transaction or for protection used by him should be verified at such place.
2) The central government and state government should notify GATCs (Government Approved Test Centres) on such terms & conditions or on a payment of such fee may be prescribed.
3) The central government may prescribed the kinds of weights & measures for verification done through GATCs.
4) The GATCs might appoint some persons having relevant qualification & experience for verification of weights & measures.

1.5.2 Requirement of Legal Metrology :

A legal metrology usually provides the following :-

1) Metrological, Technical control of measuring instruments coving all the requirements.
2) Legal measurement & physical representation of units.
3) Maintenance & custody of measurement standards.
4) Metrological control of manufacture, repair, import and control of pre-packaged commodities.

1.5.3Penalties:

There are 23 sections for penalties among few which are listed below-.

S.no.	Offences	Penalties
1	For use of non standard weight or measure	a) Fine of up to Rs 25000 b) for second and subsequent offence,

		imprisonment of about six months with fine.
2	For manufacture/sale of non standard weight or measure	a) fine of up to Rs 25000 for first offence. b) for second and subsequent offence, imprisonment of about three years with fine.
3	For alteration of weights & Measures	a)Fine of up to Rs 50000 for first offence. b) for second and subsequent offence, imprisonment of six months to 1 year.
4	For tampering with license	Fine of up to Rs 25000 along with imprisonment of one year, if needed.
5	For manufacturing Weights & Measures without license	a) Fine of up to Rs 20000 for first offence b) for second and subsequent offence, imprisonment of about one year with fine.
6	For giving false information or false return	a) Fine of up to Rs 5000 for first offence b) for second and subsequent offence, imprisonment of about six months with fine.

2 Conclusion

The study shows that the requirement of legal metrology in Japan, Brazil, Thailand, Australia and in India are more or less similar. There are different strategies to deal with the measurement and inspections We studied about the legal metrology rules being followed by these countries. Just like we observed that in Brazil, the system of legal metrology faces several issues in accordance to bring accurate results. Although to tackle these problems, INMETRO has done a lot in field of Information & Communication Technology tools and with the help of this, up to a few extent they succeeded as well. Further in Japan, we observerd that how structured legal metrology system they have. Like this, we further studied about Thailand legal metrological system and then at last the Legal Metrological system of India.

It may be recommended that National Metrological Institutes of other countries should come forward and share the information and data with other countries as well. These comparisons of various countries might help peoples to study and develop their best ideas related to Legal metrology and further contributing towards the harmonization at the international level. These type of studies allows us to gain knowledge through the use of consolidated methodology.

3 References

215. https://www.aplmf.org/japan.html
216. Pedro Paulo Almeida Silva , Maurício Réche , Maurício Evangelista da Silva. : THE LEGAL METROLOGY BRAZILIAN MODEL (2006)
217. Bruno Amado Rodrigues Filho, Alexandre Nixon Soratto. : An overview of Legal Metrology Activities in Brazil (January 2017)
218.
219. https://www.aplmf.org/australia.html
220. https://www.aplmf.org/thailand.html#:~:text=The%20Central%20Bureau%20of%20Weights,to%20the%20Ministry%20of%20Commerce.
221. Department of consumer affairs : https://consumeraffairs.nic.in/organisation-and-units/division/legal-metrology/overview#:~:text=The%20Legal%20Metrology%20Act%2C%202009%20is%20a%20single%20Act%20covering,weights%20and%20measures%20is%20required

ABOUT THE JOURNAL

The inaugural edition of the Multidisciplinary Innovations in Technology and Science Journal, launched by Madhav Institute of Technology and Science in Gwalior, embodies the spirit of progressive academia. With an eclectic blend of research spanning various disciplines, from engineering to life sciences, this journal heralds a new era of collaborative exploration. It showcases the culmination of rigorous inquiry and inventive thinking, presenting a mosaic of groundbreaking ideas and pioneering solutions. As a catalyst for cross-disciplinary dialogue and intellectual exchange, it paves the way for transformative advancements in both technology and science. This inaugural issue marks the dawn of an exciting journey towards innovation, promising to ignite curiosity, inspire discovery, and shape the future of scholarship.

MADHAV INSTITUTE OF TECH & SCIENCE
WORK IS WORSHIP
Estd. 1957

MITS

माधव प्रौद्योगिकी एवं विज्ञान संस्थान, ग्वालियर (म.प्र.), भारत

MADHAV INSTITUTE OF TECHNOLOGY & SCIENCE, GWALIOR (M.P.), INDIA

Deemed to be University

(Declared Under Distinct Category By Ministry Of Education, Government Of India)

NAAC ACCREDITED WITH A++ GRADE