IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 3, July 2025
Impact Factor: 7.67

Boost Converter-Based Maximum Power Point Tracking of Solar Panels Using the P&O Algorithm

Pankaj Moyal[1], Rajnish[2], Ravinder Singh[3]
M.Tech. Scholar, Department of EE[1]
Assistant Professor, Department of EE[2,3]
BRCM College of Engineering and Technology, Bahal (Bhiwani), India

Abstract: *The study delves into the coordinated operation of wind and solar-based microgrids connected to the main grid, emphasizing intelligent power flow control to alleviate grid stress and elevate power quality. A simulated model of a smart grid with multiple renewable-integrated microgrids is developed, incorporating dynamic tariff mechanisms and efficient energy distribution for better performance. The results validate the potential of combining ANN-based forecasting with IoT-enabled smart monitoring for managing power in multiple microgrids. This setup also lays the groundwork for future participation in energy trading. The final hardware prototype, equipped with the AI-based Icosϕ control logic, successfully operates under nonlinear load conditions, demonstrating the practical applicability of the proposed system.*

Keywords*:* renewable energy sources, artificial neural network, feed forward neural network, internet of things, energy trading

I. INTRODUCTION

To address power quality issues, various filtering methods have been employed over time. Initially, both passive and active filters were used; however, studies have shown that active filters offer superior compensation performance compared to passive ones. In this context, the Voltage Source Inverter (VSI), which manages power exchange between the microgrid and the utility grid, has been further enhanced to also operate as an active filter, thereby improving its overall effectiveness in mitigating disturbances and maintaining power quality [1]. A three-phase rectifier introduces harmonics, distorting and destabilizing the power source current. A grid-connected microgrid can function as a shunt active filter, mitigating these distortions. Utilizing its DC-link voltage, the microgrid injects compensating currents based on a modified Icosϕ controller and hysteresis switching. Integrating microgrids to the grid can be improved by using an artificial intelligence-based "Icosϕ" algorithm, which controls reference signals for compensation and controls the flow of power between the grid and microgrids. This idea has been introduced in the concept of Smart Park [2]. Smart Parks is a concept where, instead of any microgrid, an electric vehicle charging center/RES-based smart park achieves ancillary services exchange in addition to real power exchange with the grid, making use of parked electric vehicle battery bank as a support to the storage system of the charging station's parking lot, A modified Icosϕ control algorithm is utilized for calculating the reference current, offering a more intelligent approach to power compensation. This algorithm operates in three distinct modes, determined by the gain factor "k." In the first mode, the system provides comprehensive compensation including voltage stabilization, active power support, and harmonic suppression. The second mode—compensative charging—simultaneously manages energy storage and compensation. In the third mode, surplus energy stored from renewable sources is sold, allowing for revenue generation[3].

Modern power systems continue to rely on filtering mechanisms for power quality improvement. While passive and active filters were both widely used in the past, active filters have proven to offer superior dynamic response and accuracy. The **Voltage Source Inverter (VSI)**, traditionally responsible for regulating power flow between the utility grid and the microgrid, has been enhanced to function as an active filter. Among various filtering control strategies, the

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 3, July 2025
Impact Factor: 7.67

enhanced Icosϕ algorithm stands out for its adaptability. It adjusts the compensation current in real-time by considering factors like source current fluctuations, grid pricing, and the microgrid's battery **State of Charge (SoC)**. This intelligent control not only optimizes energy sharing but also ensures improved power quality, making microgrid integration more robust and efficient[4].

In today's highly interconnected world, the **Internet of Things (IoT)** plays a transformative role in advancing power systems. IoT technologies enable real-time communication between grid components, facilitating dynamic power routing, preference adjustments, and operational automation[5]. As the adoption of **Renewable Energy Source (RES)**-based microgrids grows in pursuit of a low-carbon future, predictive systems and smart control protocols become vital for their optimal operation[6].

Artificial Neural Networks (ANNs) can be employed for forecasting renewable energy generation from solar or wind-powered microgrids. This predictive capability supports intelligent decision-making, including preventive maintenance planning, without interrupting the power supply. Moreover, integrating IoT data streams from these RES-based microgrids enables real-time logging of environmental and operational parameters. This data not only enhances ANN model accuracy but also supports dynamic electricity pricing and automated switching between microgrids, thereby improving overall grid intelligence and resilience[7].

II. SCOPE OF THE WORK

A prototype of a smart microgrid system with five different smart microgrids has been developed at the Amrita i-GEM research centre for intelligent electric grid and emobility (Figure 1). This smart microgrid system includes a commercial microgrid, residential microgrid, indus- trial microgrid, microgrid for electric vehicle charging facility and a microgrid for academic institution/ university campus.

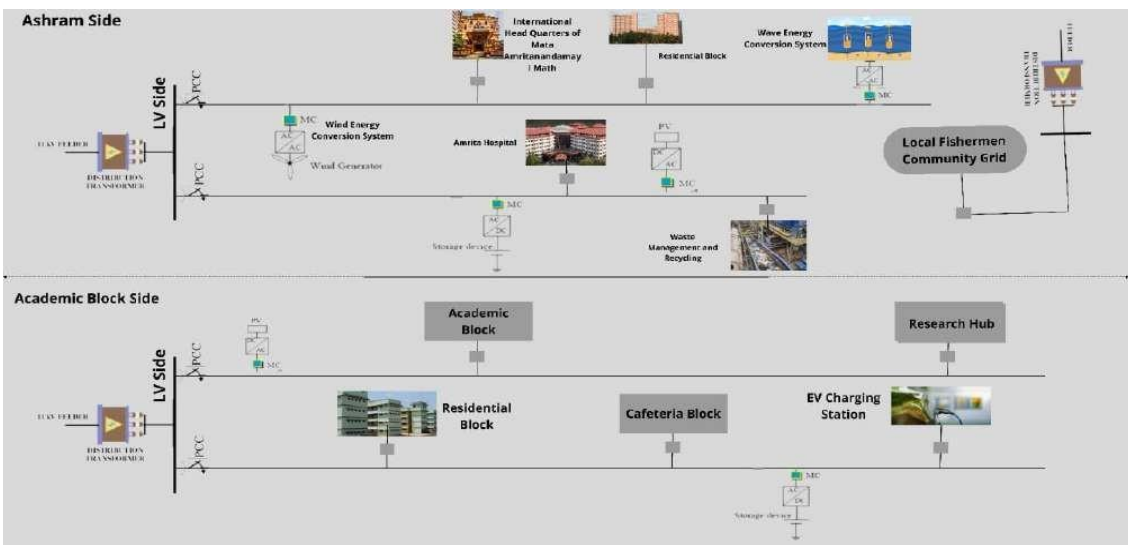

Figure 1: Smart Grid System with Different Microgrids

This research project centers on the design, analysis, and demonstration of key functionalities expected in an advanced smart microgrid system. The study addresses features such as self-healing capabilities, cyber-physical resilience, peer-to-peer energy trading, smart metering with automated data collection, detailed load profiling, and intelligent power flow optimization across interconnected microgrids and the main utility grid. Additional aspects include the strategic selection and integration of suitable energy storage solutions, as well as the development of the necessary instrumentation and control systems to support these advanced functionalities. The prototype developed during this work is also envisioned for real-world deployment. The proposed implementation site comprises multiple microgrids located within the Amrita Vishwa Vidyapeetham (Amritapuri Campus) and the adjacent Amritapuri Ashram (Mata Amritanandamayi Math), where the full capabilities of the smart microgrid

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 5, Issue 3, July 2025 Impact Factor: 7.67

model can be tested. A major focus of this research is the development of an intelligent control mechanism that enables efficient active power distribution between microgrids and between microgrids and the utility grid, while simultaneously improving overall power quality within the system.

This can be made more effective and profitable using an efficient control algorithm since the microgrids have to operate in grid-connected mode and standby mode. There are many technical challenges in the integration of a smart microgrid system with different types of microgrids. The relevance of this research work lies in integrating multiple microgrids with the grid under different complex source and load conditions by introducing knowledge-based coordinated control. The knowledge base ensures proper power sharing and weather forecasting based on the power availability of a smart microgrid system with improved power quality and reliability.

III. RESEARCH OBJECTIVES

The primary aim of this study is to design and implement an intelligent control system that enhances both power flow efficiency and power quality within a smart microgrid framework. This involves considering the dynamic behavior of Distributed Energy Resources (DERs), energy storage systems, weather-based forecasts, and real-time operating conditions.

IV. MOTIVATION FOR RESEARCH

The rapidly rising demand for electricity in today's world is accelerating the depletion of conventional, nonrenewable energy sources. This pressing issue has driven a global shift toward greater reliance on renewable energy technologies such as solar and wind power. These renewable sources offer a sustainable, dependable, and widely available alternative to traditional energy. However, the inherent variability of renewables—affected by factors like geographic location, weather conditions, and terrain—poses a significant challenge in accurately forecasting their availability[8]. Having reliable predictions of renewable energy generation at specific sites is crucial for effective energy management and economic planning.

Furthermore, power quality concerns become particularly critical when integrating nonlinear loads with the grid. The concept of connecting multiple microgrids to the main grid offers an opportunity to operate these units flexibly based on local power generation, load requirements, battery state of charge, and dynamic tariff structures. This research is motivated by the need to overcome the complexities involved in seamlessly integrating diverse microgrids within an existing smart grid framework. The goal is to develop intelligent power quality enhancement methods and optimized power flow management strategies that ensure efficient, reliable, and cost-effective utilization of distributed renewable energy sources.

V. INTRODUCTION

Efficient Power Sharing and Enhancement of Power Quality in a Smart Microgrid Using an Intelligent Integrated Controller

Increasing concerns over the depletion of primary energy resources and the aging condition of current electrical transmission and distribution infrastructure present significant challenges to ensuring a reliable, secure, and high-quality power supply. In India, the surge in energy demand has intensified the strain on nonrenewable energy reserves, highlighting the urgent need to integrate renewable energy sources into the main power grid. India has positioned itself as a global frontrunner in renewable energy deployment, with substantial progress in biomass, solar, wind, hydropower, and other emerging technologies. The adoption of these clean energy sources is driving innovation within the modern electric power sector. A smart grid, characterized by its advanced intelligence and communication capabilities, plays a vital role in mitigating power quality issues by interconnecting multiple microgrids with the main grid and enabling effective monitoring and management. These interconnected microgrids enhance the stability and reliability of individual units, fostering better overall grid performance. To address environmental concerns and support efficient energy management, the implementation of self-sustaining smart grid technologies is essential.

One common approach to enhancing power quality within the grid involves using filters, either passive or active. Although passive filters are widely used, their large size and limited performance have shifted preference towards active filters, despite the latter's higher costs [9]. Since the early 2000s, the integration of photovoltaic (PV) and wind energy systems as active filters in utility grids has gained increasing research attention worldwide [10]. Extensive studies have explored methods to boost the active filtering efficiency of smart grids integrated with microgrids. Among the control algorithms applied to Shunt Active Filters (SAFs) [11] are the Instantaneous Reactive Power Theory (IRPT) [12], Synchronous Reference Frame Theory (SRFT) [13], Icosϕ [14] method, and the Improved Linear Sinusoidal Tracer (ILST) [15]. When these algorithms are utilized to control Voltage Source Inverters (VSI) in grid-connected systems, they effectively eliminate source-side current harmonics and provide reactive power compensation, thereby enhancing power quality and grid stability [16].

1.Smart Microgrids

As per India's Model Smart Grid Regulations [17], a "smart microgrid" is described as an intelligent electrical distribution system that links loads, distributed energy resources, and storage within distinct electrical boundaries. This interconnection allows the system to function as a unified controllable entity with the main grid [18]. According to the CEA estimate, India would have 74.306 GW of solar energy capacity overall by the end of January 2024. Similarly,

44.96 GW of wind energy might be generated in the nation overall. According to the January 2024 edition of the monthly government report, India added 988 MW of new solar capabilities. The wind energy capacity is also increased by 233 MW. [19].

MGs are small-scale power stations with power ranging from 100 kW that can operate in grid-connected and islanded modes, with high energy security, reliability, storage size, and economics for demand-side and load-side management [20]. They are capable of local control via automated mechanisms, and by inspecting and responding to problems, self-recovery of the power sector is possible. India's electric sector, with solar and wind RESs, in combination with smart grid systems, has been transformed to return excess energy back to local microgrids and thus generate cost savings. Smart microgrids are self-sufficient and can serve a local community without relying on central power grids, but they also have the ability to integrate with the grid. In [21], grid-tied solar PV is explored using a Kalman filter-based controller that minimizes the harmonics. The management of a hybrid photovoltaic system and battery storage for power flow control is examined with an artificial neural network in [22]. The growth of the smart grid has increased the opportunities for improving the demand response of consumers. In [23], intelligent techniques for optimum scheduling of electrical energy are considered. Based on similar investigations made on electrical systems, intelligent controller- based smart grid systems with multiple MGs integrating with the grid without disturbing the quality of power will be a necessity for future generations. Figure 3.1 shows a smart microgrid with solar PV and wind as RESs. PV systems have two types of configurations- on-grid and off- grid systems [24]. The off-grid system requires charged controllers for charging and discharging batteries and inverters for converting the solar PV-generated DC to AC on the consumer side. In an on-grid PV system, the output power of the PV is fed directly into the grid, which does not require a battery for storage. Wind energy systems can be used with other energy sources for better power management due to the intermittent nature of RESs. Wind systems can have predictable uncertainties based on location, time of day, the charge status of the battery, load variations, etc.; besides, there are unpredictable uncertainties such as weather conditions. Some of the predictable uncertainties are considered along with the solar PV source and wind energy source[25].

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 3, July 2025
Impact Factor: 7.67

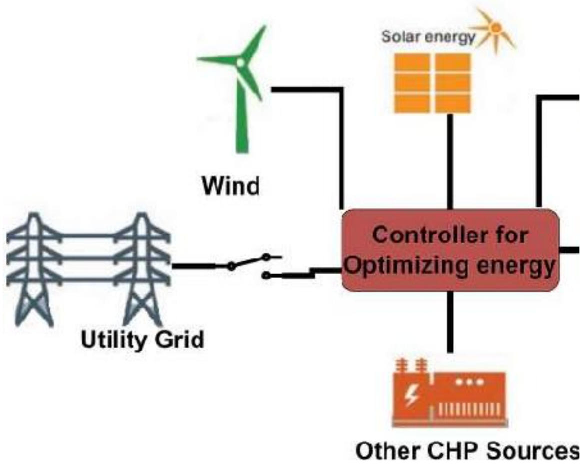

Figure 3.1: Smart microgrid with solar PV and wind as RES.

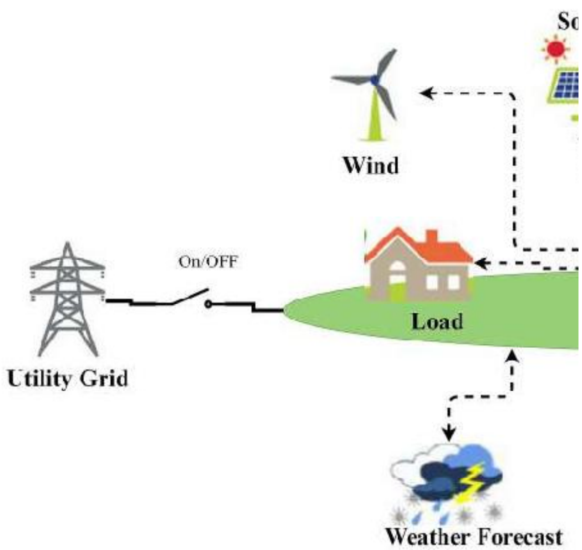

Figure 3.2: A Smart microgrid system.

2. Smart Microgrid Systems

A smart microgrid system can be considered as a smart grid system with multiple smart microgrids linked together by an efficient controller, which can be integrated with the grid or operated independently, as depicted in Figure 3.2. The smart microgrid system comprises various renewable and non-renewable energy sources, as well as residential, commercial, and industrial load centers attached to the different smart microgrids or to the main grid. Real-time management of electric power systems calls for statistical analysis of the collected consumers' energy usage data, along with weather forecasts for different RESs using data analytics and AI techniques.

The AI-based controller processes information from the power consumers, together with other modules such as tariff control [86] and power flow management. Predicting the avail- ability of renewable energy sources is difficult in the near future. This problem affects the optimal exploitation of green energy resources. Therefore, reliable weather forecasting is es- sential for renewable energy management and its economics. Artificial Intelligent systems can be applied for weather forecasting and power flow management in a smart microgrid system. Power quality concerns are prevalent in the grid, primarily attributed to diverse linear and non- linear loads. The emergence of harmonic currents from nonlinear loads significantly contributes to power quality issues, serving as the primary origin of harmonic

DOI: 10.48175/IJARSCT-28521

distortion within power dis- tribution systems. These harmonic currents, generated by nonlinear loads, are reintroduced into the power system via the point of common coupling. The distorted supply current distorts the supply voltage profile. This distorted voltage, in turn, affects the microgrid connected to the main grid.

This research focuses on the development of a smart microgrid system with multiple RES- based MGs integrated with the electrical power grid. The SAF control mechanism conceived here is based on the Icosϕ algorithm. This algorithm was upgraded using an FLC and rendered intelligent by accounting for diverse parameters [87] regarding the main power grid, microgrid, source current, and load demand. This concept is extensible to any number of microgrids for the management of power flow targeted to enhance power quality. The feed-in tariff value suggested by the microgrid can be more economical, which means the tariff can be based on the microgrid's power availability and load demand. Tariff-based power flow management is emphasized here, in which each microgrid is capable of predicting its power generation pro- file along with intelligent power flow management and power quality improvement. Here, the microgrid with solar PV and wind energy has its energy availability forecasted using an ANN controller. Each microgrid (the prosumers) has an intelligent controller for power flow man- agement. The forecasted power of the microgrid and the load demand are the inputs to the FLC-based intelligent controller. The proposed smart microgrid system has intelligence incor- porated into power forecasting, power flow management with tariff control, and power quality improvement. A detailed analysis of the simulation and hardware model of the proposed FLC- based intelligent controller for active power-sharing and reduction of power quality problems under the worst condition of an unbalanced nonlinear load is discussed in detail in this chapter. The SPV system with maximum power point tracking and power quality improvement is tested in Matlab/Simulink. The test system consists of a 25kW solar array connected to a 415V, 50Hz grid feeding a 10kW load at the point of coupling.

For real-time monitoring of the power flow in a smart microgrid system, the data visualiza- tion can be done in an IoT platform. As the world around us is getting increasingly connected, IoT serves to be a big step in this direction in making future power systems more analytical and intelligent. IoT enables grids to communicate with each other, adjust their preferences, allow routing of power, and much more. An IoT-based controller is used to control the microgrids for participating in trading, taking into account the electricity pricing of solar-powered and wind-powered microgrids. These parameters are sent to the IoT platform as telemetry data, and the controller executes the trading based on these parameters. The real-time IoT-enabled signal is generated depending on the electricity pricing of the microgrid participating in energy trading. The microgrid controller takes this data from the IoT platform depending on the real-time tariff and thus enables the microgrid to take part in the bidding.

3. Smart Microgrid with Solar PV as RES coupled with grid

Traditional energy sources face two difficulties: a scarcity of fuel and an increase in pollution. These systems create environmental problems and are major sources of greenhouse gases and global warming. An alternative to conventional sources is SPV, which is sustainable, environ- mentally friendly, and has no physical limits. The price of PV modules was, in the past, a major contribution to the cost of these systems, but now, the worldwide government policies aimed at increasing the deployment of PV systems have reduced the cost. However, due to its intermittent nature, it cannot be used directly to feed loads. To solve this problem, a grid- connected PV system can be used. There are a number of potential challenges in integrating SPV into the grid, which include the extraction of maximum power and power quality issues due to the power electronic interface. The proper control of SPV injects power in phase with the grid and eliminates power quality issues in the system.

However, because of the numerous nonlinear loads in distributed systems, power quality issues continue to plague the grid. Controlling the SPV interfacing inverter so that it can feed the extracted energy while also reducing the power quality issues of the AC distribution system brought on by diverse loads would be an efficient option. An important issue attracting academic interest globally is the use of grid-interfaced PV systems with active filters. There has been a lot of research done to enhance the grid-connected PV systems' maximum power point tracking and active filtering abilities. P&O and INC Algorithms are the most used MPPT algorithms. In P&O with rapidly changing atmospheric conditions, the MPP oscillates. The INC method has better tracking capabilities, and a modified INC algorithm that uses variable iteration step sizes can increase accuracy even more. The use of passive or active filters is one solution to grid power quality problems.

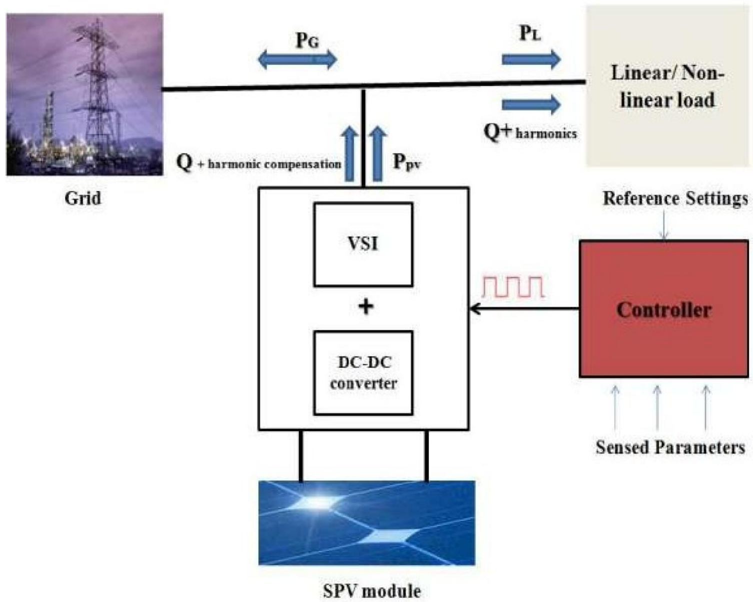

Figure 3.3: Grid Connected PV system

Despite their higher price, active filters are more appealing due to the bulk and resonance problems with passive filters. An effective solution would be to control the SPV interfacing inverter in such a way that it can perform as an active filter, also mitigating the power quality problems of ac distribution system caused by nonlinear and unbalanced loads, as shown in Figure 3.3. The control of the SPV system to act as an active filter includes two loops. The outer loop tracks the maximum power point of the solar array under varying irradiance conditions, and the inner loop modulates the inverter current to feed real power as well as provide reactive power compensation and harmonic elimination to the local loads of the SPV system. Grid-connected SPV systems can be single-stage or two-stage, based on the implementation of the control. A lot of research is done in the area of single-stage SPV systems in which the solar array is interfaced into the grid through a single interfacing inverter. The two control loops are realized in a single power conversion stage, which makes the control more complex. Also, it is necessary to limit the voltage of the PV array within the operating range for proper operation of the system, which will limit the MPPT capability of the single-stage SPV system. In two-stage systems, the two loops are implemented in two different power converter stages. MPPT and power quality improvement are independent, which makes the total system control less complex and more reliable. The power loss due to environmental changes is found to be zero in the single-stage system. In this research work, the scope of using a two-stage SPV system as the active filter is explored.

4. Power Sharing and Power Quality Improvement in the Smart Microgrid with Solar PV as RES Coupled with Grid

The objective is to develop a controller for a Grid-connected PV system to act as SAF. The control is implemented in two different stages. The outer loop for MPPT is implemented in the first stage of the boost converter to track the maximum power point of the PV array. The inner loop modulates the current of the interfacing inverter to feed the maximum power available from the PV modules and provide reactive power compensation and harmonic elimination of the local linear/nonlinear loads at the coupling point. SPV, which is green, environment friendly, and unlimited in nature, is a sustainable alternative to conventional sources. The concept of integration of microgrids based on renewable energy sources into the grid is considered. This is a

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 3, July 2025
Impact Factor: 7.67

competitive alternative to conventional grid extension. There are many potential challenges in integrating SPV into the grid, which include proper power sharing and reduction of power quality issues due to the presence of nonlinear loads in the distribution system. Active filters,
basically voltage source inverters, overcome this drawback using proper active filter algorithms. Here, the first step is to develop an integrated controller for grid integration of microgrid 1 with SPV as RES. As shown in Figure 3.3, the solar array is connected through the power electronic interface. P_{pv} is the real power from the SPV, P_G is the real power flow in the grid, P_L is the real power required by the load, and Q is the reactive compensation required by the load. The DC-DC boost converter is controlled using a variable step incremental conductance algorithm to track the maximum power point of the SPV during varying irradiance conditions. The power available at the output of the boost converter (DC link) is converted to AC through VSI. The system is controlled such that the output power from the PV feeds the loads at PCC, and extra power is fed to the grid. If, due to reduced irradiance, the power output from PV is not sufficient to feed the load at PCC, then the deficient power is taken from the grid. The loads connected at the PCC may include linear/nonlinear loads. Reactive power compensation and harmonic elimination are also incorporated in the VSI-SAF algorithm.
When utilizing a fixed step size for adjusting the duty ratio, it's essential to effectively balance the tradeoff between dynamics and steady-state oscillations. To address these chal- lenges, a modified INC MPPT algorithm with a variable step size can be employed. The step size is automatically adjusted based on the specific characteristics of the PV array. When the operating point is far from the MPP, the step size is increased, enabling rapid tracking. Conversely, when the operating point is near the MPP, the step size is decreased, minimiz- ing oscillations and enhancing efficiency. The flowchart of the variable step INC algorithm is depicted in Figure 3.4.

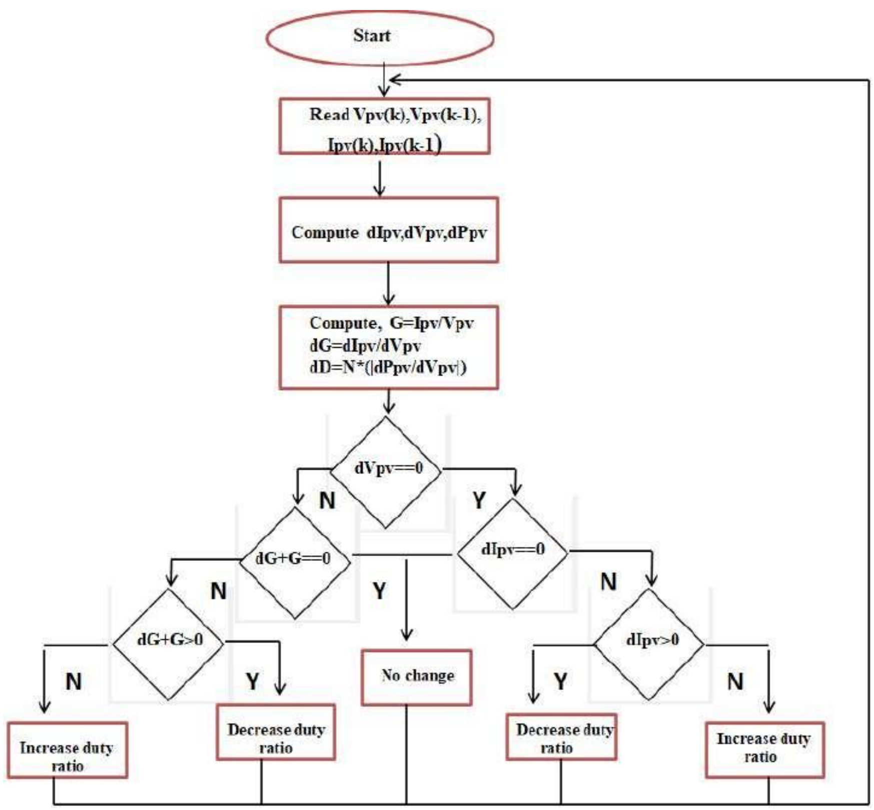

Figure 3.4: Incremental Conductance Algorithm

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 5, Issue 3, July 2025 Impact Factor: 7.67

The main aim of the control is to inject active power in synchronization with the grid and eliminate power quality problems. The pulses for controlling the VSI are obtained by comparing the reference source currents with the actual source currents in a PWM generator.
The desired value of source currents without PV would be the active current required for the load at PCC with reactive and harmonic parts supplied by the filter. Since the PV is capable of supplying active power at the dc link of the VSI acting as a filter, the magnitude of per phase reference source current will be the active component of load current minus the active current from the PV system.
The integration of Renewable Energy Sources (RES) into the existing power grid has become increasingly essential in the current energy landscape, especially to supplement the main grid and effectively address the continuously rising electricity demand. With growing urbanization, industrialization, and digitalization, the pressure on centralized power generation systems is escalating rapidly. For instance, in October 2021, India experienced a significant power supply deficit amounting to 1,201 million units. This was the highest shortfall recorded in the previous five and a half years and was primarily attributed to a critical shortage of coal, which severely impacted the functioning of thermal power plants. Such instances highlight the vulnerability of relying heavily on fossil fuel-based energy systems.
Moreover, India has made ambitious international commitments to mitigate climate change by reducing carbon emissions and achieving net-zero carbon emissions in the coming decades. These pledges underscore the urgent need to transition away from conventional thermal power generation and embrace cleaner, more sustainable alternatives. Renewable energy sources such as solar, wind, and small hydro are now seen as indispensable components of future energy planning.
In light of these developments, the integration of distributed generation systems—such as rooftop solar panels, small wind turbines, and biogas plants—has become a promising solution. Furthermore, the deployment of microgrids, which can operate independently or in conjunction with the main grid, is gaining traction as a means to enhance energy resilience, ensure reliability, and enable efficient energy management. These microgrids are expected to play a pivotal role in the evolution of smart grid technologies, ultimately leading to the realization of a decentralized, intelligent, and sustainable power system for the future.

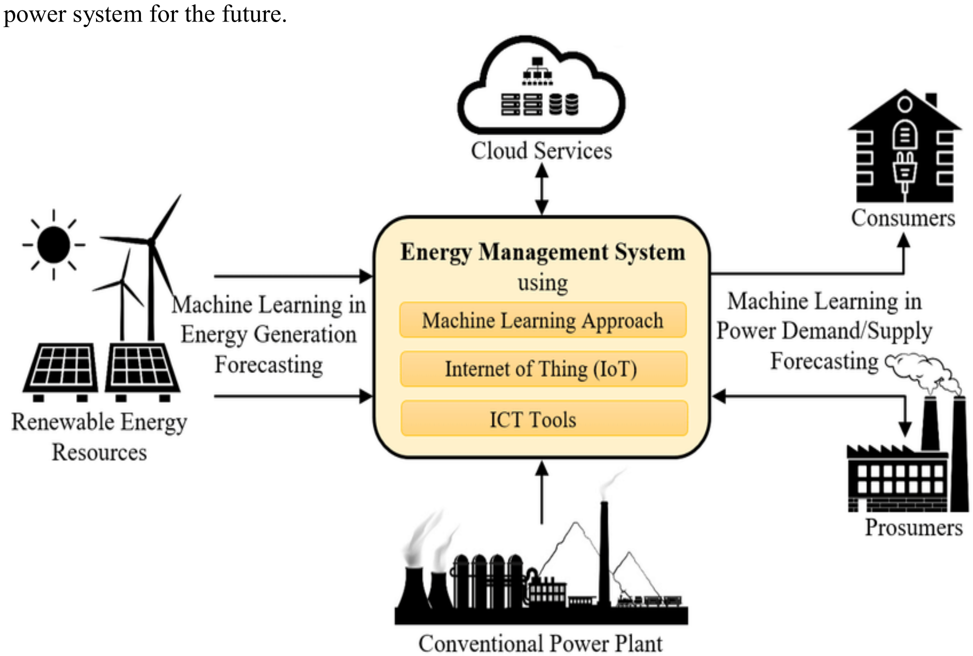

Fig. 1. Power system management using machine learning & internet of things approach.

RES has numerous benefits; they are perpetual sources of energy and pose zero threat to the environment, which is why it has managed to gather a lot of attention in the energy industry for the past years. The only major downside of RES is its intermittent nature, which dubbed this entire class of energy sources unreliable and inconsistent and therefore, not a viable or popular choice. The issue of the unreliable nature of RES can be solved by a Battery Energy Storage System (BESS) or proper power forecasting to ascertain the power output values for varying climatic conditions. Moreover, power system management using machine learning & internet of things approach is a dynamic topic of discussion these days as shown in Fig. 1 [1].

With the increasing usage of RES as microgrids for a cleaner future, certain predictions and protocols need to be set for its efficient operation and in this paper, the different aspects of smart grid and its associated modernisation is strategically reviewed with an objective of grid integration using appropriate power forecasting techniques and optimal power sharing mechanisms. The paper is arranged in such a way that

Section II presents a detailed review on power forecasting, power sharing, grid integration and real time grid monitoring, followed by the conclusion and the work's future scopes given in Section III.

A REVIEW ON POWER FORECASTING, POWER SHARING, GRID INTEGRATION & REAL TIME GRID MONITORING

Real Time Grid Monitoring, Assessment, Control & Modernization

M. Litwin et al. (2020) proposed a method of approach for active synchronization of the micro-grid and the utility grid. Renewable energy sources are spread around a multitude of places which in turn is closer to the consumers. Microgrids introduce new ways to continue the supply of power even if there are fault or energy inadequacies. Microgrids can be disconnected and reconnected to the utility grid without interruption to the supply. For the reconnection, there is a need for the power sources to be synchronized. Unsynchronized operation can cause damage to micro-grid units and blackouts. There are certain requirements for microgrid reconnection of the utility grid, such as magnitude of voltage from both microgrid and utility grid needs to match with a maximum error of 10%. Other synchronization methods discussed include passive synchronization, open transition synchronization and active synchronization. It was proposed to have a synchronization data sender and synchronization data controller on the utility grid and micro grid with a Global Positioning System (GPS) signal compensating for the network delay. Droop control method is used, which will provide real and reactive balance in microgrid and phase and frequency compensation [2].

The impact of energy challenges soon is highlighted, and a proposal is made to address the same by the Power Electronics & Systems (PEAS) technology-based grid modernization scheme [3]. Power grids when integrated with distributed energy resources are supposed to ensure stability checks in terms of fault isolation, voltage management, frequency regulation, and the technology serves to play a key role in ensuring the same when the grids are getting modernized. The challenges to improve metering infrastructure, control techniques, reliability, security, etc. points towards the requirement of a mechanism which could ensure an autonomous control and continuity of service, integration and resiliency, grid compatibility and inter-operability, power flow control, smart network devices connectivity, etc. Furthermore, the pace of grid integration targets customer flexibility by keeping a modern grid-based business outlook [2]. B. Falahati et al. (2013) proposes the requirement of a multiple-state Markov chain model based smart monitoring system, for evaluating power system to enhance its reliability [4].

The impact of smart distribution grid technologies over the power quality performance within a grid interconnected system is reviewed [5]. Feeder reconfiguration and demand side management are significant application-based factors in power quality analysis, in which variations and imbalances in supply voltage, flickering in voltages and frequency, harmonic distortions, etc. contributes to power quality issues in automatic or manual feeder reconfiguration with frequent switching, large load recovery period, disruptions in communication networks, etc. Mapping the adversity of various smart grid-based applications over power quality concerns point towards the need for a set of changes in operating standards and regulations, be it an improvement in data collection, control methods, equipment compatibility, harmonic, or transient compensation, etc. S. Rahman et al. (2020) proposes an assessment technique to obtain the expected voltage stability characteristics of a power grid with high penetration of large solar Photovoltaic (PV) systems [6]. This work primarily revolves around an approach involving Monte-Carlo simulation, where, to ensure proper understanding and scalability; the grid voltage stability indicators of real and reactive power loss, reactive power margin, critical eigen value, etc. are to be considered. The applicability of the framework was ensured with proper time consumption and through testing strategies at different penetration levels in a PV system. Thus, the

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 3, July 2025
Impact Factor: 7.67

proposed novel grid voltage stability analysis approach ensured that there wouldn't be a huge impact of varying penetration levels affecting voltage stability, provided the PV system has to be fixed. A secure framework to read isolated smart grid devices, which assists in the regulation of smart grid activities, keeping the real time hardware constraints under consideration is detailed [7].

In the grid connected energy system, since the major components are enclosed within the system, a better predictive analysis could be made regarding the possible faults that might occur within the system, where the drive topology is used for power delivery from the renewable energy systems. Alternative Model-Creating Technique, Two Parameters Based Alpha Model Technique and Proposed Fuzzy Fault Tree Based Technique are the three major reliability assessment techniques for grid connected energy systems, which approaches to an assessment based on good distribution with an increased system size. For improving the system reliability and balancing the associated fluctuations, so as to obtain the desired output from the drive operated system, an intelligent control strategy of an advanced control system using the fuzzy logic control through model predictive control schemes [8]. The concepts, design principles and engineering practices required for the development of a Smart Micro Energy Grid, using an intelligent energy management system, that could support the economic, environmental and safety criteria for the same, in order to accommodate micro grids, distributed generation systems, and associated storage and distribution infrastructures is detailed. The need for a self-optimum-approaching dispatch and control strategy necessitates the need for the development of an efficient and flexible micro energy grid and to facilitate the same, an integrated energy system approach could be taken into account by considering different classes of energy networks as an energy hub [9].

Distributed dynamic pricing that could be implemented in smart grids for Plug-in Hybrid Electric Vehicles (PHEV) are the major focus [10]. Intelligent pricing schemes are proposed by categorizing home price and roaming price. EVs' charge at home will be on home price and if it's charging outside its premise, it will be on roaming price. If the EV is charging using foreign grid, the excess energy of that microgrid to which it is connected will be provided to grid, after providing the electricity to its residential users. The Plug in Vehicles are registered to a particular microgrid, which charge their batteries in home or in parking during office hours. An algorithm is proposed for the micro grid, which gets information regarding the total supply; and its output will be home price and roaming price. Calculating real time pricing and roaming pricing using equations is done and this pricing is broadcasted with the customers.

Power Forecasting & Power Sharing in Smart Grid
System via Artificial Neural Network (ANN)

The neural network acts as a black box taking in a set of inputs and depending on the internal layers and functionality, it will intelligently provide the adequate estimated output. ANN is used to learn the erratic behavior of solar irradiance and is used to simulate and predict its non-linear behavior with power. Neural networks are trained under different climatic situations and fuzzy logic is used to define sky conditions into three different fuzzy sets- sunny, rainy, cloudy. The algorithm proposed by this model is as follows- time will be checked to see if it fits in the defined range primarily, after which it will be classified based on the fuzzy sets of three different sky conditions followed by temperature [11]. ANN is employed in wind power forecasting as its input parameters such as wind speed, air density, temperature, blade angle, etc. affects the power being generated, where the actual nature of the relationship is not known and is complex. A Feed-Forward Neural Network (FNN) is used to train historical climatic data to test and predict the corresponding set of power. In addition, non-linear regression was carried out to predict future time series values with the knowledge of the past values and this was in turn compared with the previous results to ascertain the effectiveness of the proposed method. Numerical Research Analysis and Nonlinear Auto-Regressive Exogenous models were used for the same [12]. A general schematic for ANN based power forecasting is shown in Fig. 2 [13].

DOI: 10.48175/IJARSCT-28521

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 3, July 2025
Impact Factor: 7.67

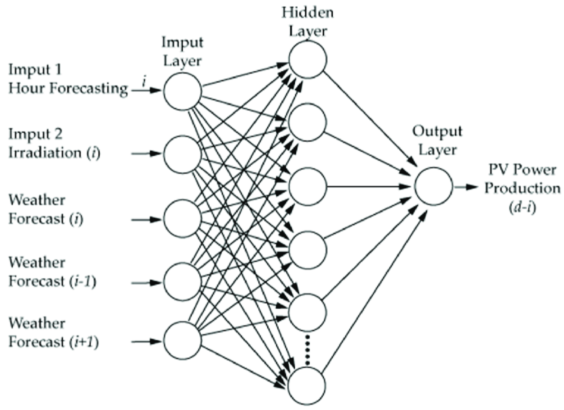

Fig. 2. ANN based power forecasting.

Eseye et al. (2016) proposed a feed-forward artificial neural network method with a backpropagation algorithm. The data used for training the neural network was obtained from the historical wind speed and wind power data collected over a period of one year from Supervisory Control & Data Acquisition records. The backpropagation algorithm used is Levenberg-Marquardt backpropagation supervised training algorithm, which resembles the feedback of a closed-loop system as the input is fed to the neural network and is then compared with the target features. The difference between the two is defined using an error vector which is fed to the backpropagation training algorithm; and based on its weight and bias, adjustments take place [14].

The forecast of the electricity load demand is done as electricity is difficult to store and also because the future estimations of the electricity demand can be made. In this proposed method, a feed forward neural network is used, which is trained using the Levenberg-Marquardt algorithm and then trained again using the radial basis function [15]. The model is able to accurately predict the day-ahead peak load and it was also observed that the results from the ANN model trained using the Levenberg-Marquardt algorithm are better than those obtained using the radial basis function. Electricity price forecasting is another important factor and both soft or hard forecasting methods are available to implement the same. Neural networks are faster to implement and take less computation, showing accurate results and good performance.

K. Bhaskar et al. (2012) proposed a method, which is split into two stages [16]. Firstly, wavelet transforms are applied to the wind series and Adaptive Wavelet Neural Network is applied to these decomposed wind speed values. This enables the prediction of wind speed values, for over a day ahead in advance. In the second stage, feed forward neural network is used to establish the non-linear relationship between the inputs and the outputs and helps in mapping the forecasted wind speeds to its corresponding wind power as output, thereby enabling the prediction of the desired wind power from the forecasted wind speed values. In this method, a Numerical Weather Prediction model that can predict wind power up to 72hr is proposed. This method has a lower average Mean Absolute Error for 30hr-ahead prediction when compared to other existing methods; and a significant improvement of over 60% in Multi Resolution Analysis based Adaptive Wavelet Neural Network with respect to New Reference and Persistence benchmark models.

The process of current injection from Distributed Energy Resources integrated with a grid is largely controlled by the inverters but result in unstable point of common coupling which could adversely affect the grid control and stability [17]. These disruptions are to be eliminated from the system by means of a controller, which in this work is a Filtered Tracking Error based controller. The controller could be designed by dynamically tracking the error from the concept of filtered error notions, with a Lyapunov function-based stability analysis.

C. Information Technology (IT) Based Optimization Techniques in Smart Grid Environment

Under a smart grid environment, distributed generation needs to have a flexible operation framework to get better system reliability and backup generation and to provide voltage support and reactive power to the grid

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 5, Issue 3, July 2025 Impact Factor: 7.67

interconnected mode. Distributed generators can support the grid voltage and if controlled to do so, this needs to be done when there is voltage sag and disturbances. Control scheme of Internal Model Control is adopted to design tracking and rejection
performances independently. Synchronization is required during reconnection, which happens after blackouts; and for this, small frequency deviations in voltage command can be made to minimize phase shift with the multiple voltages [18]. The different smart grid features of demand side management, micro-grid management, load shifting, dynamic pricing, cost- optimization, data storage, cyber-security, data security, and threat detection are discussed [19]. Microgrid management are proposed as useful solutions for demand side management. A proposal for a cost-optimization scheduling algorithm is used in an office environment. Cyber-security is one of the important considerations in a smart grid architecture and digital-ants framework identifies a cyber-attack in the smart grid. Automatic theft and threat detection mechanisms are proposed for reliable power supply to the end-users, such that the status of the customers is modelled as unity when they are honest. Cloud-based security applications are proposed for cost-effective security mechanisms in the smart grid. The system architecture in [20] consists of smart plug, demand response server, demand response controller and user interface. These operate on a three-layer architecture. Smart plug is the monitoring unit, and it sends the communication data to the Demand Response Server. It contains the database and saves the logs from various devices and other data associated with the smart plug devices. The Demand Response Controller uses the data from server and acts based on the data received. In the Prototype developed, for message exchange, a well-defined protocol is used, and an initialization message is sent during initialization of the device. The communication is carried out using User Datagram Protocol and all the data is stored in the database of controller.

Distributed optimization, specifically consensus-based algorithms, is used here for Energy Trading [21], designed with directed network concept because, undirected network requires two-way inter agent communication and it will increase the cost for implementation. A power distribution network model is made where directed graphs and entries in graph incidence matrix are used as the components. A Multi Agent System communication weight matrix is used for the agents in buses. A topology for a communication in the network is defined using a weight set matrix. It is proposed to use consensus-based distribution solution for the distributed optimization. Simplified convex function is incremental cost is made by reformulating the cost function. A scalable and distributed IoT platform has been developed where the platform architecture consists of sensors and actuators, IoT server, User Interface (UI), etc. [22].

Data management unit and database storage is another part of the IoT server which has all the software modules, which will store the sensor data and other configurations [23]. There's a configurator unit and database for unit specific configurations. A secure access manager is maintained for managing privacy and data protection. A study on grid connected/islanding in micro grids which has a storage device for energy is also done in detail. The proposed control method joins the feature set of existing droop control and V/F control, which nullifies its shortcomings. A Phase Locked Loop is used, which analyses grid voltage and makes a sinusoidal signal with the same frequency, phase, and amplitude of unity. An operation scheme
is set up for the Single Throw Switch closing and opening. For the improved V/F control, it uses voltage and current double closed loop quasi-PR control strategy. The suitability of an open-source software, Quantum Geographic Information System (QGIS), owing to its advantage of data storing from a chosen residential grid of choice, in order to visualize the same in a real time environment is discussed [24]. The data to be layered include load demand, supply, load consumption, user profile, running status of accompanied appliances, details of supply from distributed sources, etc. with and without demand curve optimization. The demand side management, upon the employment of the visualization techniques could effectively optimize the supply, demand, and consumption within a power system, instead of surfing through the server's data pool. It provides an idea about the role of Geographic Information System tools in data visualization and management in smart grid technologies.

A. Majee et al. (2017) discussed the development of an automated Central Protection Centre based on the notion of Internet of Things with an aim to constantly monitor the grid for fault detection and its associated rectification. The Central protection centre which is the main control centre responsible for all relay connections corresponding to microgrid reconfiguration and has the sole duty of microgrid protection. An online data monitoring and the adoption of an adaptive protection scheme effectively aids in fault clearances. The hardware interface employed must ensure minimum disconnections within the grid while clearing faults, which was ensured by the shortest path algorithm, namely Dijkstra's algorithm [25].

VI. CONCLUSION

This paper had made an assessment over the concepts of power forecasting, power sharing, grid integration, real time grid monitoring, IT based grid optimization techniques, etc. to reach out to the conclusion that RES as microgrids could aid to a great extent in enabling grid modernization via optimal strategies on power forecasting and power sharing by the employment of accurate grid improvement facilities like QGIS, PEAS technologies, etc. in order to meet the necessary power quality requirements.

The wide and unique benefits on integrating distributed RES to a grid could pave way for target and incentive-based alignment via upscaling of renewable energy generation. The challenges of operation and planning could be tackled to a great extent by power forecasting methodologies and the procuring flexibility aims for power sharing within the system. Moreover, the potential constraints to reliability could be tackled effectively during the process by appropriate power system planning strategies, thereby facilitating a robust grid integrated approach.

REFERENCES

[1] Rahman, Md. Mijanur & Shakeri, Mohammad & Tiong, Sieh Kiong & Khatun, Fatema & Amin, Nowshad & Pasupuleti, Jagadeesh & Hasan, Mohammad. (2021). Prospective Methodologies in Hybrid Renewable Energy Systems for Energy Prediction Using Artificial Neural Networks. Sustainability. 13. 2393. 10.3390/su13042393.

[2] M. Litwin, D. Zieliński and K. Gopakumar, "Remote Micro-Grid Synchronization Without Measurements at the Point of Common Coupling," in IEEE Access, vol. 8, pp. 212753-212764, 2020, doi: 10.1109/ACCESS.2020.3040697.

[3] D. Tan and D. Novosel, "Energy challenge, power electronics & systems (PEAS) technology and grid modernization," in CPSS Transactions on Power Electronics and Applications, vol. 2, no. 1, pp. 3-11, 2017, doi: 10.24295/CPSSTPEA.2017.00002.

[4] B. Falahati, Y. Fu and M. J. Mousavi, "Reliability Modeling and Evaluation of Power Systems with Smart Monitoring," in IEEE Transactions on Smart Grid, vol. 4, no. 2, pp. 1087-1095, June 2013, doi: 10.1109/TSG.2013.2240023.

[5] M. H. J. Bollen et al., "Power Quality Concerns in Implementing Smart Distribution-Grid Applications," in IEEE Transactions on Smart Grid, vol. 8, no. 1, pp. 391-399, Jan. 2017, doi: 10.1109/TSG.2016.2596788.

[6] S. Rahman et al., "Analysis of Power Grid Voltage Stability with High Penetration of Solar PV Systems," 2020 IEEE Industry Applications Society Annual Meeting, 2020, pp. 1-8, doi: 10.1109/IAS44978.2020.9334716.

[7] K. Sha, N. Alatrash and Z. Wang, "A Secure and Efficient Framework to Read Isolated Smart Grid Devices," in IEEE Transactions on Smart Grid, vol. 8, no. 6, pp. 2519-2531, Nov. 2017, doi: 10.1109/TSG.2016.2526045.

[8] I. Akhtar, S. Kirmani and M. Jameel, "Reliability Assessment of Power System Considering the Impact of Renewable Energy Sources Integration Into Grid With Advanced Intelligent Strategies," in IEEE Access, vol. 9, pp. 32485-32497, 2021, doi: 10.1109/ACCESS.2021.3060892.

[9] S. Mei et al., "Paving the way to smart micro energy grid: concepts, design principles, and engineering practices," in CSEE Journal of Power and Energy Systems, vol. 3, no. 4, pp. 440-449, Dec. 2017, doi: 10.17775/CSEEJPES.2016.01930.

[10] A. Majee and O. V. Gnana Swathika, "IoT based reconfiguration of microgrids through an automated central protection centre," 2017 International Conference on Power and Embedded Drive Control (ICPEDC), 2017, pp. 93-97, doi: 10.1109/ICPEDC.2017.8081066.

[11] S.X. Chen, H.B. Gooi, M.Q. Wang. Solar radiation forecast based on fuzzy logic and neural networks, Renewable Energy, Volume 60, 2013, Pages 195-201, ISSN09601481https://doi.org/10.1016/j.renene.2013.05.011.

[12] Anirudh S Shekhawat. Wind Power Forecasting using Artificial Neural Networks, International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 3 Issue 4, April - 2014
[13] Brusco, G. & Burgio, Alessandro & Menniti, Daniele & Pinnarelli, A. & Sorrentino, Nicola & Vizza, Pasquale. (2017). Quantification of Forecast Error Costs of Photovoltaic Prosumers in Italy. Energies. 10. 1754. 10.3390/en10111754.
[14] Eseye, Abinet & Zhang, J. & Zheng, D. & Shiferaw, Dereje. (2016). Short-Term Wind Power Forecasting Using Artificial Neural Networks for Resource Scheduling in Microgrids. International Journal of Science and Engineering Applications. 5. 144-151. 10.7753/IJSEA0503.1005.
[15] Pandey, N., Kulshrestha, S.& Sharma, M. K. (2016). Analysis of Electrical Load Forecasting by using MATLAB tool box through Artificial Neural Network. IJCESR, 3(1), 135-141.
[16] K. Bhaskar and S. N. Singh, "AWNN-Assisted Wind Power Forecasting Using Feed-Forward Neural Network," in IEEE Transactions on Sustainable Energy, vol. 3, no. 2, pp. 306-315, April 2012, doi: 10.1109/TSTE.2011.2182215.
[17] X. Huang et al., "Robust Current Control of Grid-Tied Inverters for Renewable Energy Integration Under Non-Ideal Grid Conditions," in IEEE Transactions on Sustainable Energy, vol. 11, no. 1, pp. 477-488, Jan. 2020, doi: 10.1109/TSTE.2019.2895601.
[18] S. Misra, S. Bera and T. Ojha, "D2P: Distributed Dynamic Pricing Policyin Smart Grid for PHEVs Management," in IEEE Transactions on Parallel and Distributed Systems, vol. 26, no. 3, pp. 702-712, 1 March 2015, doi: 10.1109/TPDS.2014.2315195.
[19] A. Kahrobaeian and Y. A. I. Mohamed, "Interactive Distributed Generation Interface for Flexible Micro-Grid Operation in Smart Distribution Systems," in IEEE Transactions on Sustainable Energy, vol. 3, no. 2, pp. 295-305, April 2012, doi: 10.1109/TSTE.2011.2178045.
[20] S. Bera, S. Misra and J. J. P. C. Rodrigues, "Cloud Computing Applications for Smart Grid: A Survey," in IEEE Transactions on Parallel and Distributed Systems, vol. 26, no. 5, pp. 1477-1494, 1 May 2015, doi: 10.1109/TPDS.2014.2321378.
[21] A. K. Sultania, F. Mahfoudhi and J. Famaey, "Real-Time Demand Response Using NB-IoT," in IEEE Internet of Things Journal, vol. 7, no. 12, pp. 11863-11872, Dec. 2020, doi: 10.1109/JIOT.2020.3004390.
[22] M. H. Ullah and J. -D. Park, "Distributed Energy Trading in Smart Grid Over Directed Communication Network," in IEEE Transactions on Smart Grid, vol. 12, no. 4, pp. 3669-3672, July 2021, doi: 10.1109/TSG.2021.3067172.
[23] E. Spanò, L. Niccolini, S. D. Pascoli and G. Iannacconeluca, "Last- Meter Smart Grid Embedded in an Internet-of-Things Platform," in IEEE Transactions on Smart Grid, vol. 6, no. 1, pp. 468-476, Jan. 2015, doi: 10.1109/TSG.2014.2342796.
[24] K. Wang, Y. Ma, P. Ding, R. Mu and R. Sun, "Operation Control Strategy for Photovoltaic/Battery Micro-Grid," 2018 China International Conference on Electricity Distribution (CICED), 2018, pp. 821-824, doi: 10.1109/CICED.2018.8592593.
[25] Monika, D. Srinivasan and T. Reindl, "GIS as a tool for enhancing the optimization of demand side management in residential microgrid," 2015 IEEE Innovative Smart Grid Technologies - Asia (ISGT ASIA), 2015, pp. 1-6, doi: 10.1109/ISGT-Asia.2015.7387041.
[26] D. R. Nair, Devi S., M. G. Nair and K. Ilango, "Tariff based fuzzy logic controller for active power sharing between microgrid to grid with improved power quality," 2016 International Conference on Energy Efficient Technologies for Sustainability (ICEETS), 2016, pp. 406-409, doi: 10.1109/ICEETS.2016.7583789.
[27] M. Soman, Manitha P.V. and Ilango K., "Design and control of a soft switching grid connecting inverter using PI controller," 2016 Biennial International Conference on Power and Energy Systems: Towards Sustainable Energy (PESTSE), 2016, pp. 1-6, doi: 10.1109/PESTSE.2016.7516423.
[28] k. Sreeram, P. K. Preetha and P. Poornachandran, "Electric Vehicle Scenario in India: Roadmap, Challenges and Opportunities," 2019 IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT), 2019, pp. 1-7, doi: 10.1109/ICECCT.2019.8869479.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 5, Issue 3, July 2025 Impact Factor: 7.67

[29] D. R., G. N.P. and M. G. Nair, "ANN Based Solar Power Forecasting in a Smart Microgrid System for Power Flow Management," 2019 Innovations in Power and Advanced Computing Technologies (i-PACT), 2019, pp. 1-6, doi: 10.1109/i-PACT44901.2019.8960168.

[30] A. Varghese, L. R. Chandran and A. Rajendran, "Power flow control of solar PV based islanded low voltage DC microgrid with battery management system," 2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES), 2016, pp. 1-6, doi: 10.1109/ICPEICES.2016.7853407.

[31] A. Viswanathan, N. B. Sai Shibu, S. N. Rao and M. V. Ramesh, "Security Challenges in the Integration of IoT with WSN for Smart Grid Applications," 2017 IEEE International Conference on Computational Intelligence and Computing Research (ICCIC), 2017, pp. 1-4, doi: 10.1109/ICCIC.2017.8524233.