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A Review: Adaptive Energy Supervisory Module for Optimized Energy Distribution in an Intelligent Microgrid Environment

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Abstract: *The growing adoption of renewable and sustainable energy sources such as solar and wind has highlighted the need to seamlessly integrate these into existing power systems to promote sustainable energy solutions. Microgrids play a crucial role in enhancing grid performance by mitigating power quality issues. By operating as active filtering units, they provide reactive power support, harmonic suppression, and load balancing at the Point of Common Coupling (PCC).*

One major challenge with standalone DC microgrids is maintaining reliability, which can be addressed by interconnecting them with the main utility grid. In this context, an Artificial Intelligence-based Icosϕ Control Algorithm is introduced to optimize power sharing and enhance power quality in smart microgrid environments. This control strategy is designed to intelligently respond to uncertainties such as dynamic load changes, varying battery charge levels in microgrids, and fluctuations in electricity tariffs, which depend on the availability of renewable power.

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.

Keywords: renewable and sustainable energy

I. INTRODUCTION

A stable and secure energy supply is the lifeblood of modern society, ensuring our comfort, health, and economic well-being. Concerns about dwindling resources and aging infrastructure cast a shadow over the future of our electricity supply, jeopardizing its security, reliability, and quality.

With the rise of renewables, growing consumer demand for control, intensifying climate concerns, and fluctuating economic landscapes, future grids need solutions for these evolving realities. As a result, the concept of Smart Grids emerged—integrating advanced technologies for monitoring, control, communication, and automated fault management. These systems utilize intelligent products and services to enhance efficiency and reliability. At the core of Smart Grids lie microgrids, which serve as fundamental units enabling decentralized and flexible energy management. Microgrids are small-scale power systems built with local, low-voltage electricity lines. They use various sources like solar panels and wind turbines to generate clean energy, store it in batteries, and power homes and businesses [1]. They can even operate independently if the main power grid goes down. Depending on their setup and needs, microgrids can operate in two modes: grid-connected, utilizing the main grid for additional power or support, or island mode, functioning autonomously when disconnected from the larger system. Optimal management and coordination of micro sources within the network empower them to deliver tangible benefits like increased resilience, improved power quality, and optimized energy flow, positively impacting overall system performance. Microgrids act as in- tegration platforms within local distribution networks, combining distributed energy resources (DERs) like microgeneration units, storage devices, and controllable loads. This integrated sys- tem enables efficient and

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localized energy management. Microgrids must operate effectively in two distinct states: grid-connected mode for normal functioning and islanded mode for inde- pendent operation during grid outages. Achieving long-term islanded operation in microgrids necessitates either significant storage size and high microgenerator capacity to ensure continu- ous power supply to all loads or a high degree of demand flexibility within the system. Partial islanding of specific, high-priority loads within a microgrid enhances its overall reliability dur- ing grid outages. This targeted approach optimizes resource allocation and ensures critical infrastructure remains operational.

Microgrids generally fall into two categories: AC and DC types. Their performance is significantly influencedby environmental factors, making their output variable and unpredictable. For instance, solar energy generation is heavily reliant on factors such as solar irradiance and ambient temperature [2]. This variability means that when microgrids are connected to the main grid, it becomes essential for prosumers to have an accurate understanding of their expected energy output. In this context, power forecasting becomes a critical tool. Rather than merely relying on microgrids for active power contribution, incorporating forecasting methods can lead to more cost-effective operation for both utilities and microgrid owners, ensuring better energy planning and management.

(SPV) systems into the grid demands strategies to address their power output's inherent uncertainty and variability, necessitating sophisticated management and control mechanisms. Solar output variability forecasting is critical in optimizing the planning and modeling of SPV plants. We can optimize energy dispatch, grid integration, and overall system performance by accurately predicting power generation. Accurate solar power forecasting provides valuable insights for optimizing the design and operation of solar photovoltaic plants. This information is critical for grid operators to balance electricity demand and supply, ensuring grid stability and reliable power delivery [3]. The increasing use of various power electronic converters has led to a noticeable decline in overall power quality. The prevalence of non-linear loads in today's power systems, including rectifiers, converters, and motor drives, introduces complexities due to their non-sinusoidal current draw, impacting grid stability and power quality [4]. The proliferation of nonlinear loads, such as AC-to-DC converters and variable-speed drives, injects harmonic currents into the power grid. These harmonics distort the sinusoidal waveform, leading to various power quality problems like voltage fluctuations, heating, and equipment failures. Non-linear loads like LED lights and adjustable speed drives are the primary source of harmonic distortion in power distribution systems, impacting voltage quality and potentially harming equipment. Non-linear loads produce harmonic currents that are injected back into the electrical network at the Point of Common Coupling (PCC). These harmonics can interact with other connected equipment, leading to voltage waveform distortion and a decline in overall power quality. The resulting distorted current causes fluctuations in the voltage profile, which in turn affects both the microgrids linked to the main grid and any sensitive loads dependent on stable power conditions.

Microgrids represent a promising solution for modern power systems, particularly in supporting the widespread adoption of Distributed Energy Resources (DERs) and Renewable Energy Sources (RES). The integration of renewables into the main power grid has become increasingly essential to meet the surging demand for electricity. For example, in October 2021, India experienced a significant power shortage of approximately 1,201 million units—the most severe in over five years—primarily due to a shortfall in coal supplies for thermal power plants. Furthermore, India's commitment to reducing carbon emissions and achieving net-zero targets in the coming decades underscores the urgency of transitioning from fossil fuels to sustainable energy alternatives[45]. In this scenario, distributed generation systems, particularly microgrids, hold the potential to support this transition and play a critical role in shaping the smart grid infrastructure of the future. Moreover, The increasing market acceptance and penetration of DER technologies necessitates further investigation into their integration, control, and optimal operation within microgrid frameworks[6]. This focus arises from the need to effectively manage and leverage the distributed nature of these resources for enhanced sys- tem performance. The development of microgrids utilizing distributed generation, particularly from renewable sources, poses a significant opportunity to reshape how we approach rural electrification, both in established grids and areas lacking centralized infrastructure[7].

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II. 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.

III. LITERATURE REVIEW

A stable and accessible power supply acts as the backbone of economic progress. Electricity un- derpins growth across diverse sectors, from powering factories and farms to supporting schools and healthcare systems. As economies boom, energy needs escalate, as seen by the projected rise in peak electricity demand to 283GW(13th plan) by 2022, as envisaged in the 18th Electric Power Survey(EPS) report of the Central Electricity Authority(CEA). This underscores the critical role of the electricity industry in meeting these growing demands.

India's rich tapestry of renewable resources, including solar, wind, and others, presents a strategic solution to address its multifaceted energy challenges. By effectively harnessing this potential, the country can achieve long-term energy security, energy affordability, and climate change mitigation, paving the way for a sustainable future. As per the CEA report on Jan 31st, 2024, the RES is 136570.09MW, which constitutes 31.94%, which includes solar, wind, Biomass, etc. Beyond renewables, during the same time frame, India has also added 210969.51MW, which constitutes 49.34%, Hydro with 46928.17MW, which is 10.98%, and thermal and nuclear sources, as shown in figure 2.1. [9] as shown in Figure 1.

The surge in RE sources and distributed generation demands innovative ap- proaches to operate and manage the electricity grid. Power electronics play a critical role in integrating these diverse resources and ensuring continued reliability and quality of power supply. As applications become more interconnected, the use and development of this tech- nology are rapidly expanding [10]. Grid integration of PV systems and wind systems or any RES is accomplished through the inverter, which converts DC power generated from the RES

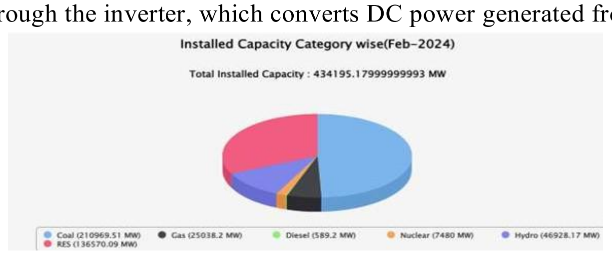

Figure 1: Installed Capacity[9]

An inverter plays a crucial role in converting power from renewable energy sources into alternating current (AC)[11], which is the standard form of electricity used to operate most electrical devices in the grid-connected system.. Smart microgrids are on the horizon, offering flexible power solutions that can operate independently or connect to the main grid. These intelligent systems will ensure stable power flow, manage voltage fluctuations, filter out unwanted electricity, and even store energy, ultimately providing everyone with a more reliable and efficient power supply. [12].

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Grid Integration of Microgrids

Microgrids are essentially small-scale power systems with multiple distributed generators like solar panels connected to the larger grid through inverters. This allows them to work in- dependently or integrate seamlessly with the main system, promoting renewable energy and enhancing grid stability. Distributed Generation (DG) offers various benefits, including pollu- tion reduction, high energy utilization rate, flexible installation, and low power transmission losses [13], as depicted in Figure 2. Within a microgrid, DER units serve multiple purposes, The management of real and reactive power flow between the microgrid and the distribution system includes providing electricity during periods when intermittent renewable generation is unavailable and supporting local loads during islanded operation. In situations where energy storage is not used, rapid response through the inverter interface becomes crucial for power generation[14]. Inverter control strategies generally fall into two categories: power quality (PQ) control and power-sharing control. PQ control typically involves the distributed generation (DG) unit supplying all available power to the microgrid, often operating at unity power factor. Power-sharing control within an islanded microgrid can vary from fully centralized systems to fully decentralized approaches[15]. The use of multi-agent systems has proven effective for microgrid management, as it reduces communication requirements and computational complexity[16].

Several challenges arise when integrating distributed energy resources into the grid, particularly concerning power quality and stability. Technical issues include power fluctuations, energy storage considerations, protection mechanisms, optimal siting of renewable energy sources (RES), and islanding detection. Specifically, wind energy systems face uncertainties in wind speed prediction, limited forecasting accuracy, voltage regulation difficulties, and stability concerns. Solar energy, while advantageous for its low cost, environmental benefits, flexible installation options, and lack of reactive power consumption, also presents challenges such as high installation expenses, unpredictable solar irradiance, and power variability caused by changing sunlight conditions[17].

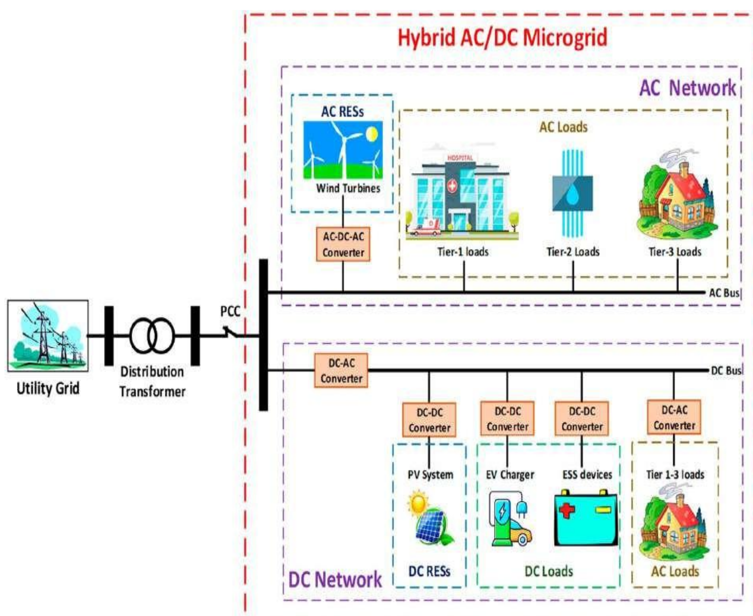

Figure 2: Grid integration of Microgrids[3]

Microgrids combine localized, renewable energy sources, intelligent control systems, and grid independence to provide reliable power. Unlike relying on a distant power plant, micro- grids generate electricity locally, ensuring uninterrupted power even during major grid outages, boosting energy security for the community. Microgrid technology addresses three crucial soci- etal needs: ensuring uninterrupted power flow (including in cyberattacks), minimizing environ- mental impact through renewable energy integration, and optimizing costs for efficient energy use. DG, or distributed generation, refers to generating electricity near where it's consumed, unlike traditional power plants located far away. DG brings generation closer to homes and businesses than big, centralized power plants. This cuts out the middleman (expensive power lines) and reduces energy losses, making it more efficient and cheaper. Distributed genera- tors exhibit lower generation costs, enhanced reliability, and improved security compared to traditional centralized plants. This is due to reduced transmission and distribution infrastruc- ture needs, redundancy within the distributed system, and potential isolation from wider grid vulnerabilities. Distributed generation excels at minimizing generation costs through localized production. Its inherent reliability and reliance on renewable resources also ensure sustain- able energy delivery to specific loads. The decentralized nature of distributed generation offers an inherent benefit in terms of cybersecurity. Unlike a single, large power plant prone to widespread attacks, multiple, smaller generators present smaller targets, making it more dif- ficult for hackers to cause major disruptions. Microgrids offer a perfect solution for regions with underdeveloped transmission infrastructure like remote villages. These self-contained "is- landed" systems provide reliable power generation and distribution independently of the main grid. Microgrids with conventional grid architecture (generation, distribution, transmission,control) are classified as scaled-down models of the actual grid system. This similarity facili- tates integration with the larger grid when needed while enabling independent operation.

Active Filters and Active Filter algorithms

Thyristor's and other form of semiconductor plugs or switches are frequently utilized to control AC power in applications such as adjustable speed drives (ASDs), furnaces, and computer power supplies. Despite their effectiveness, these solid of state converters introduce harmonic and reactive power components as nonlinear loads into the AC mains, leading to potential issues in three-phase systems, such as imbalance and excessive neutral currents. These introduced harmonics, reac- tive power demands, imbalance, and excessive neutral currents have the potential to diminish system efficiency and negatively impact power factor [18]. Extensive studies quantify the chal- lenges of nonlinear loads like adjustable speed drives and computer power supplies in AC power networks. These loads contribute to harmonics, reactive power burden, and imbalances, reduc- ing system efficiency and poor power factor. Traditionally, passive L-C filters and capacitors were employed for mitigation, but their effectiveness diminishes. The rise of "harmonic pollution" in power grids has spurred engineers to develop innovative solutions. Active filters (AFs) or Active Power Line Conditioners (APLCs) offer approaches to tackle quality issues, ensuring a robust and efficient grid. These active filters can also operate as voltage source inverters (VSIs), enabling effective regulation of power exchange between the microgrid and the main utility grid, [19].

Unlike fixed passive filters, active filters offer a dynamic and versatile solution. They can filter out harmful harmonics, stabilize voltage fluctuations, balance loads across phases, op- timize reactive power, and even reduce flickers in one compact package. [20]. Contemporary active filters outperform traditional passive filters in terms of filtering performance, physical size, and versatility in application [21]. As the demand for effective harmonic mitigation rises, there is a growing emphasis on refining the hardware and software components of active power filters to achieve optimal performance [22]. Non-linear loads tend to extract substantial harmonic and reactive power components from the utility grid, which significantly deteriorates power quality. To address these challenges, various filtering solutions are employed[23]. Among passive, active, and hybrid filter configurations, active filters have demonstrated superior performance due to their adaptability and precision. Passive filters, on the other hand, are often bulky and difficult to tune effectively. A wide range of active filter systems have been explored, categorized by converter design, system configuration, and grid type. Central to the effectiveness of active filters is the control mechanism, which typically operates in three distinct stages. In the initial stage, sensing devices such as potential transformers (PTs), current transformers (CTs), or Hall effect sensors are used to extract measurement signals. The second stage processes these signals to determine the appropriate compensation response. The final stage involves generating control pulses using methods like pulse width modulation (PWM), hysteresis control, or sliding mode control to drive the switching devices[24]. The primary contributors to power quality degradation are non-linear loads—devices that utilize power electronics, such as modern electrical and electronic equipment. These loads generate harmonic currents that, when transmitted through the network, distort voltage waveforms at the load bus, leading to irregular and non-sinusoidal voltage profiles. Voltage waveforms can become highly distorted and rich in harmonics due to non-linear loads, which pose a serious challenge to power quality. One effective way to counter this issue is through the use of Flexible AC Transmission Systems (FACTS), incorporating both active and passive filters installed at the load end. Active filters outperform passive ones in terms of filtering efficiency and compactness. Unlike passive filters, which rely on components such as capacitors, inductors, or resistors and tend to be bulkier, active filters offer a range of advanced functionalities. These include harmonic suppression, mitigation of voltage flicker, and power factor improvement through reactive power compensation—collectively known as power conditioning. While pure active filters are mainly used for comprehensive power conditioning of non-linear loads, hybrid active filters are primarily applied for harmonic reduction. However, the major limitation of FACTS devices remains their high cost, which restricts widespread adoption[25].

Several control strategies are used for active filtering, such as the Icosϕ algorithm[26], synchronous detection algorithm, DC bus voltage control, instantaneous power theory (p–q theory), and synchronous reference frame theory[27]. These algorithms are responsible for generating the reference compensation current required in shunt active filters. The overall responsiveness and precision of the filter are highly dependent on the chosen algorithm. In shunt configurations, the output is a current reference signal, whereas series filters produce voltage-based compensation signals[28].

When operating in grid-connected mode, microgrids support the main utility grid by supplying additional power to meet the demand. This is achieved through a hierarchical control framework involving both central and distributed controllers, which coordinate various microgrid units. Incorporating intelligent energy management systems and decision-making techniques into microgrids enhances overall system efficiency, stability, and reliability.

Active power filters rely on sophisticated control strategies to effectively compensate for unwanted currents and improve power quality. These strategies, like algorithms, determine the filter's accuracy and response time, impacting its overall performance and stability. In resource- constrained environments, efficient calculation methods are crucial for optimizing the control circuit size and maximizing functionality. [29]. The effectiveness of an active filter largely depends on the control algorithm used, as it directly influences both the accuracy and response time of the system. To ensure the compactness and efficiency of the control circuitry, the algorithm should involve minimal computational steps[30]. Control methods that operate in the frequency domain, such as those based on Fourier transforms—including Recursive Discrete Fourier Transform (RDFT) and Kalman filtering—tend to be computationally intensive. In contrast, time-domain approaches rely on the instantaneous values of electrical signals and are therefore less demanding in terms of processing requirements. As a result, time-domain techniques are commonly preferred for controlling active filters[31].

Among the prominent control methods used for three-phase shunt active filtering are instantaneous power (p–q) theory, synchronous detection algorithm, DC bus voltage control strategy, synchronous reference frame theory, and the Icosϕ algorithm. These approaches offer various advantages depending on the application and system dynamics.

The Smart Park concept, which integrates intelligent energy flow and power quality management, is illustrated in Figure 3. In such systems, bidirectional three-phase converters are governed by an enhanced version of the Icosϕ control algorithm to enable efficient power exchange and support dynamic grid conditions.

Smart Parks can employ shunt active filters to compensate for reactive power and eliminate harmonics by ensuring that the filter current opposes the harmonics in the source current. These systems operate in three primary modes: compensation, compensative charging, and the selling of stored energy generated from renewable sources. The operational behavior of the system is governed by the gain factor, denoted as "k". By leveraging Smart Parks for reactive power compensation, the dependency on expensive FACTS . devices such as STATCOM can be significantly reduced.

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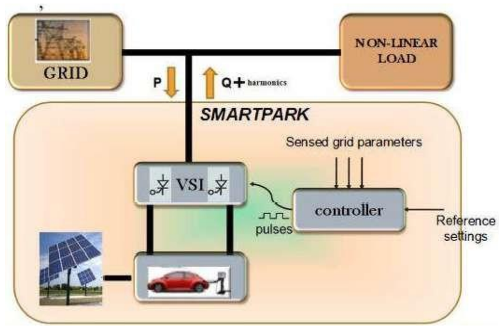

Figure 3: Block diagram of Smart Park connected to the grid.

Solar and Wind Power- An overview

To effectively harness the highest possible energy output from a solar photovoltaic (PV) array, numerous Maximum Power Point Tracking (MPPT) techniques have been developed. One widely used approach is the Incremental Conductance (INC) method [32], which operates by comparing the incremental conductance (dI/dV) of the PV system with its instantaneous conductance. This enables the system to determine whether the operating voltage should increase or decrease to reach the maximum power point (MPP). However, the INC method is relatively computationally intensive due to the need to monitor both voltage and current variations and the complexity of its algorithm. The calculated incremental conductance directly impacts the derivative of power with respect to voltage (dP/dV), thereby influencing the tracking accuracy of the MPP.

Another notable technique is Ripple Correlation Control (RCC) [33], which utilizes the natural oscillations in power and inductor current of the DC-DC converter to determine the MPP through correlation methods.

Beyond traditional techniques, advanced soft computing approaches have gained traction in recent years. These include machine learning [34], artificial neural networks (ANNs), fuzzy logic controllers (FLC) [35], adaptive neuro-fuzzy inference systems (ANFIS) [36], and genetic algorithms. While these methods show promise for optimizing MPP detection, they require specialized knowledge of soft computing and entail the use of complex algorithmic frameworks. Additionally, their accuracy depends heavily on the quality of training data and the learning ability of the respective models.

IV. MAIN CONCLUSIONS OF THIS RESEARCH WORK

A prototype of a smart microgrid system with five different smart microgrids has been developed at the Amrita i-GEM research center for the intelligent electric grid and emobility. Out of the various features of the research in the proposed smart microgrid system, self-healing, cyber resilience, peer-to-peer energy trading, etc., are considered. In this research thesis, an AI- based Icosϕ controller is developed to enhance power quality and share power between multiple microgrids and renewable energy sources. The prototype developed here is also proposed on a real site for implementation purposes. The proposed site for the smart microgrid system includes different microgrids within the Amrita University campus and Amritapuri Ashram campus (Mata Amritanandamayi Math), which incorporates all the said features of the smart microgrid system.

Even though many factors could be considered when developing the proposed controller, in this research, power sharing and power quality improvement are only two factors considered. Under all conditions of the system operation, we have not tested and validated the proposed model (Unstable, power failure, unbalanced load, etc). The collection of solar power DC output power and wind power output has been a big challenge in the process, but that has been solved by analyzing the site. Small hydropower (SHP) and biomass energy sources contribute significantly to renewable energy and are less impacted by weather fluctuations making them a more reliable and steadier source of energy, but it is not considered in this research.

REFERENCES

[1] Sharmin, Ruhi & Chowdhury, Sayeed & Abedin, Farihal & Rahman, Kazi. (2021). Implementation of MPPT Technique of Solar Module with Supervised Machine Learning.

[2] Reddy, D. & Satyanarayana, S. & Ganesh, V.. (2018). Design of Hybrid Solar Wind Energy System in a Microgrid with MPPT Techiques. International Journal of Electrical and Computer Engineering. 81. 730-740. 10.11591/ijece.v8i2.pp730-740.

[3] N. Alamir, O. Abdel-Rahim, M. Ismeil, M. Orabi and R. Kennel, "Fixed Frequency Predictive MPPT for Phase-Shift Modulated LLC Resonant Micro-Inverter," 2018 20th European Conference on Power Electronics and Applications (EPE'18 ECCE Europe), 2018, pp. P.1-P.9.

[4] L. Zhang, S. S. Yu, T. Fernando, H. H. Iu and K. P. Wong, "An online maximum power point capturing technique for high-efficiency power generation of solar photovoltaic systems," in Journal of Modern Power Systems and Clean Energy, vol. 7, no. 2, pp. 357-368, March 2019, doi: 10.1007/s40565-018-0440-2.

[5] S. Khadidja, M. Mountassar and B. M'hamed, "Comparative study of incremental conductance and perturb & observe MPPT methods for photovoltaic system," 2017 International Conference on Green Energy Conversion Systems (GECS), 2017, pp. 1-6, doi: 10.1109/GECS.2017.8066230.

[6] R. B. Bollipo, S. Mikkili and P. K. Bonthagorla, "Hybrid, optimal, intelligent and classical PV MPPT techniques: A review," in CSEE Journal of Power and Energy Systems, vol. 7, no. 1, pp. 9-33, Jan. 2021, doi: 10.17775/CSEEJPES.2019.02720.

[7] S. Mohanty, B. Subudhi and P. K. Ray, "A Grey Wolf-Assisted Perturb & Observe MPPT Algorithm for a PV System," in IEEE Transactions on Energy Conversion, vol. 32, no. 1, pp. 340-347, March 2017, doi: 10.1109/TEC.2016.2633722.

[8] A Belkaid, U. Colak and K. Kayisli, "A comprehensive study of different photovoltaic peak power tracking methods," 2017 IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA), 2017, pp. 1073-1079, doi: 10.1109/ICRERA.2017.8191221.

[9] B P. Nayak and A. Shaw, "Design of MPPT controllers and PV cells using MATLAB Simulink and their analysis," 2017 International Conference on Nascent Technologies in Engineering (ICNTE), 2017, pp. 1-6, doi: 10.1109/ICNTE.2017.7947932.

[10] S. Bhattacharyya, D. S. Kumar P, S. Samanta and S. Mishra, "Steady Output and Fast Tracking MPPT (SOFT-MPPT) for P&O and InC Algorithms," in IEEE Transactions on Sustainable Energy, vol. 12, no. 1, pp. 293-302, Jan. 2021, doi: 10.1109/TSTE.2020.2991768.

[11] A Mohapatra, B. Nayak and C. Saiprakash, "Adaptive Perturb & Observe MPPT for PV System with Experimental Validation," 2019 IEEE International Conference on Sustainable Energy Technologies and Systems (ICSETS), 2019, pp. 257-261, doi: 10.1109/ICSETS.2019.8744819.

[12] R. John, S. S. Mohammed and R. Zachariah, "Variable step size Perturb and observe MPPT algorithm for standalone solar photovoltaic system," 2017 IEEE International Conference on Intelligent Techniques in Control, Optimization and Signal Processing (INCOS), 2017, pp. 1-6, doi: 10.1109/ITCOSP.2017.8303163.

[13] K. Jain, M. Gupta and A. Kumar Bohre, "Implementation and Comparative Analysis of P&O and INC MPPT Method for PV System," 2018 8th IEEE India International Conference on Power Electronics (IICPE), 2018, pp. 1-6, doi: 10.1109/IICPE.2018.8709519.

[14] U. Jayashree, R. H. P. Nightingale and S. Divya, "Implementation of basic MPPT techniques for zeta converter," 2017 Third International Conference on Science Technology Engineering & Management (ICONSTEM), 2017, pp. 601-604, doi: 10.1109/ICONSTEM.2017.8261393.

[15] M. R. Javed, A. Waleed, U. S. Virk and S. Z. ul Hassan, "Comparison of the Adaptive Neural-Fuzzy Interface System (ANFIS) based Solar Maximum Power Point Tracking (MPPT) with other Solar MPPT Methods," 2020 IEEE 23rd International Multitopic Conference (INMIC), 2020, pp. 1-5, doi: 10.1109/INMIC50486.2020.9318178.

[16] R. Benkercha, S. Moulahoum and I. Colak, "Modelling of Fuzzy Logic Controller of a Maximum Power Point Tracker Based on Artificial Neural Network," 2017 16th IEEE International Conference on Machine Learning and Applications (ICMLA), 2017, pp. 485-492, doi: 10.1109/ICMLA.2017.0-114.

[17] M. Kermadi, Z. Salam, J. Ahmed and E. M. Berkouk, "An Effective Hybrid Maximum Power Point Tracker of Photovoltaic Arrays for Complex Partial Shading Conditions," in IEEE Transactions on Industrial Electronics, vol. 66, no. 9, pp. 6990-7000, Sept. 2019, doi: 10.1109/TIE.2018.2877202.

[18] Y. Xue, S. Sun, J. Fei and H. Wu, "A new piecewise adaptive step MPPT algorithm for PV systems," 2017 12th IEEE Conference on Industrial Electronics and Applications (ICIEA), 2017, pp. 1652-1656, doi: 10.1109/ICIEA.2017.8283104.

[19] M. Krishnan M. and K. R. Bharath, "A Novel Sensorless Hybrid MPPT Method Based on FOCV Measurement and P&O MPPT Technique for Solar PV Applications," 2019 International Conference on Advances in Computing and Communication Engineering (ICACCE), 2019, pp. 1-5, doi: 10.1109/ICACCE46606.2019.9079953.

[20] K., Vineeth & A., Asha. (2014). An efficient solar power converter with high MPP tracking accuracy for rural electrification. 2014 International Conference on Computation of Power, Energy, Information and Communication, ICCPEIC 2014. 383-389. 10.1109/ICCPEIC.2014.6915394.

[21] A A. Anu and R. Divya, "Multiple input DC-DC converters for solar cell power supply system and its maximum power point tracker," 2013 International Conference on Energy Efficient Technologies for Sustainability, 2013, pp. 287-290, doi: 10.1109/ICEETS.2013.6533397.

[22] L. S. Stanly, Divya R and M. G. Nair, "Grid connected solar photovoltaic system with Shunt Active Filtering capability under transient load conditions," 2015 International Conference on Technological Advancements in Power and Energy (TAP Energy), 2015, pp. 345-350, doi: 10.1109/TAPENERGY.2015.7229643.

[23] 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.

[24] K. Harini and Syama S., "Simulation and analysis of incremental conductance and Perturb and Observe MPPT with DC-DC converter topology for PV array," 2015 IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT), 2015, pp. 1-5, doi: 10.1109/ICECCT.2015.7225989.

[25] P. Sahu, A. Sharma and R. Dey, "Ripple Correlation Control Maximum Power Point Tracking for Battery Operated PV Systems: A Comparative analysis," 2020 IEEE International IOT, Electronics and Mechatronics Conference (IEMTRONICS), 2020, pp. 1-6, doi: 10.1109/IEMTRONICS51293.2020.9216414.

[26] Hirsch, Y. Parag, and J. Guerrero, "Microgrids: A review of technologies, key drivers, and outstanding issues," *Renewable and sustainable Energy reviews*, vol. 90, pp. 402–411, 2018.

[27] J. J. Justo, F. Mwasilu, J. Lee, and J.-W. Jung, "Ac-microgrids versus dc-microgrids with distributed energy resources: A review," *Renewable and sustainable energy reviews*, vol. 24,pp. 387–405, 2013.

[28] J. Singh, S. Prakash Singh, K. Shanker Verma, A. Iqbal, and B. Kumar, "Recent control techniques and management of ac microgrids: A critical review on issues, strategies, and future trends," *International Transactions on Electrical Energy Systems*, vol. 31, no. 11, p. e13035, 2021.

[29] Mikkili, Suresh, and A. K. Panda., "Power quality issues and solutions–review.," *Interna- tional Journal of Emerging Electric Power Systems 16*, vol. 4, pp. 357–384, March 2015.

[30] L. Morán, J. Dixon, and M. Torres, "Active power filters," in *Power electronics handbook*,pp. 1341–1379, Elsevier, 2018.

[31] V. Raveendran and M. G.Nair., "Smartpark as shunt active filter using modified icos con- troller," *POWER AND ENERGY SYSTEMS: TOWARDS SUSTAINABLE ENERGY*, pp. 1–6, March 2014.

[32] T. Ahmad and D. Zhang, "Using the internet of things in smart energy systems and networks," *Sustainable Cities and Society*, vol. 68, p. 102783, 2021.

[33] S. Energy, "Renewable energy for sustainable development in india: current status, future prospects, challenges, employment, and investment opportunities," 2019.

[34] "Central electricity authority, installed capacity, january 2024." ://cea.nic.in/dashboard/ ?lang=en. Accessed: 2024-03-25. J. M. Carrasco, L. G. Franquelo, J. T. Bialasiewicz, E. Galván, R. C. PortilloGuisado,

[35] M. M. Prats, J. I. León, and N. Moreno-Alfonso, "Power-electronic systems for the grid integration of renewable energy sources: A survey," *IEEE Transactions on Industrial Electronics*, vol. 53, no. 4, pp. 1002–1016, 2006.

[36] Mohamed, Eltawil, and Z. Zhengming, "Grid-connected photovoltaic power systems: Technical and potential problems—a review," *Renewable and Sustainable Energy Reviews*, vol. 14,p. 112–129, 2010