



Mastering the art of smart microgrid performance management

Rajani S Hardas¹, Dr. Vijayalaxmi Biradar², Dr. Manoj R Tarambale³

¹ Research Scholar, Department of Electrical Engineering, Kalinga University, Raipur, Chhattisgarh, India

² Research Guide, Department of Electrical Engineering, Kalinga University, Raipur, Chhattisgarh, India

³ Research Co Guide, Electrical Engineering, PVG's and GKP (W) IOM, Pune, Maharashtra, India

Abstract

"Mastering the Art of Smart Microgrid Performance Management" seeks to optimize the efficiency, reliability, and sustainability of modern microgrids by analyzing state-of-the-art strategies and technologies. In order to keep operations resilient and energy secure, microgrid performance management is becoming more important due to the increasing integration of renewable energy sources, electric cars, and distributed energy resources. Improved system flexibility, demand-supply balance, and loss reduction are all outcomes of intelligent control systems, real-time data analytics, and predictive algorithms, as shown in this study. It delves into how microgrids' ability to self-heal, identify defects, and make adaptive decisions is aided by solutions including the Internet of Things (IoT), artificial intelligence (AI), and machine learning. Further topics covered include the need for standardized performance metrics, interoperability of heterogeneous components, and cyber-physical security. It provides case studies and practical approaches to help operators, lawmakers, and academics optimize microgrid value in different contexts. According to the research, demand response systems, grid-to-microgrid connectivity, and coordinated energy storage use are crucial for sustainability in the long run. By learning about smart microgrid performance management, stakeholders may minimize operational costs, increase resilience to grid interruptions, and collect cleaner energy, paving the way for a more intelligent, environmentally friendly, and reliable energy future.

Keywords: Smart microgrid, performance management, renewable integration, energy

Introduction

Worldwide, electrical power systems are getting more complicated and tedious to keep up with the ever-increasing energy consumption. Furthermore, the size of these systems is increasing. In the conventional power system, a centralized authority is in control. Energy Management Systems, housed in the Energy Control Centers, are responsible for providing highly intricate control and decision-making infrastructure. The bulk power grid has seen significant technical development during the past hundred years (Ferrarini, L. 2020). The power grid is constantly being upgraded with new technologies, such as higher voltage equipment, more efficient and environmentally friendly generating sources, and better computerized monitoring, protection, control, and grid management techniques for planning, real-time operations, maintenance, and energy-efficient load management. Furthermore, there are flexible alternating current and high voltage direct current transmission systems. Higher voltage equipment, high voltage direct current transmission systems, and flexible alternating current transmission systems are all examples of such technology. Nevertheless, with the continued depletion of conventional energy sources and the ever-increasing demand for electrical power, preserving the power balance is becoming more challenging. Because of this, the systems are operating dangerously near to their stability limits, which makes them unreliable (Short, M. 2021).

A generation and load prediction model is needed to support the system in order to achieve proper demand response management and energy marketing. This is in addition to thinking about how to connect more distributed, locally available energy sources to the main grid, which could

increase alternative generation (Guerrero, J. (2018). Conventional energy sources are inadequate, and people are becoming more aware of the negative effects on the environment and the high carbon footprint of these sources. Another significant breakthrough that has provided electric power technology with extra momentum is the introduction and subsequent usage of power system deregulation in the twentieth century. This was accomplished by moving away from the utility company paradigm that relies on vertical integration (Agelidis, V. G. 2017).

Renewable Energy Sources

1. Solar Power Generation

Solar energy is one of the most accessible, long-term, and environmentally benign forms of electricity on our planet. The land and oceans absorb around 89 petawatts (PW) of the 174 PW of solar energy that reaches Earth. This is the total amount of energy that the Earth receives from the sun.

$$E = 3.6 * (10^{-9}) * S * h * r^2 \quad (1.1)$$

where "S" stands for the solar constant in $m (1.1) 2 \sim W$, "h" for time in hours, and "r" for the earth's radius in kilometers. The photovoltaic (PV) system's main objective is to transform the energy from the sun into usable electricity. This is achieved by converting light photons into electrical energy using semiconductor devices known as solar cells. Around half a volt is the electric potential that a photovoltaic (PV) cell produces. To improve the voltage and current ratings and boost power output, many PV cells are linked in both series and parallel topologies. When designing photovoltaic (PV) systems, single-crystal silicon is the semiconductor material of choice. Still, polycrystalline silicon, gallium arsenide (GaAs), and cadmium telluride (CdTe) are among the many other

module options that are out there. The quantity of energy generated is exactly proportional to the intensity of the solar radiation. Power production is highest during bright days and drastically lowered during overcast or nocturnal conditions. As a function of irradiance, the following formula may be used to calculate the electrical output:

$$E_m = A\eta I * PR \quad (kWh) \quad (1.2)$$

The link between the electrical energy generated (E_m), yield efficiency (η), solar irradiation (I), performance ratio (PR), and solar panel area (A) is represented by the equation. The generated power is also non-linear because of the irradiance's non-linearity.

2. Generation of electricity with wind power

Power plants frequently make use of wind energy since it is abundant, clean, and relatively silent. Figure 1.1 shows that according to the research conducted by the Global Wind Energy Council, wind power production is on the rise and is projected to reach 650 gigawatts of installed capacity by 2020. The produced power is obviously non-linear due to the non-linear character of wind velocity, even if the kinetic energy of the wind is transformed into electrical energy. One way to represent the connection between wind speed and produced power is as follows:

$$P_m = \frac{1}{2} \rho C_p A v^3 (W) \quad (1.3)$$

In this context, 'ρ' denotes the density of the wind, 'Cp' implies the coefficient of generated power, 'A' denotes area, and 'v' denotes the wind velocity, which is given in meters per second. The efficiency of wind turbines is highly dependent on the speed of the wind. Since wind speed is very non-linear, the produced wind power exhibits noticeable fluctuations. In order to provide a consistent voltage and frequency for alternating current (AC) power, the rectified output voltage is sent to a common DC bus using DC-DC converter modules. Combining the rectifier circuit with an MPPT boost converter allows for the most efficient energy conversion possible.

3. Active-Reactive Power Sharing for Voltage, Frequency and Harmonics Control

It is possible to influence the power system's characteristics via the transmission line's and the distribution side's active and reactive power exchange. Control strategies can be refined to enhance grid performance and change the power factor at the point-of-common coupling (PCC) by injecting or absorbing active power from the grid or distributed energy resources (DER) to maintain a steady load.

4. Power Quality Control in Microgrid

Currently, it is rather difficult to convert electrical energy from various renewable sources and generate electricity through microgrid systems while keeping power quality within an acceptable range. Voltage sag/swell, power factor, frequency, imbalance, and voltage variation are all factors that might impact it. This will be dictated by the state of distributed energy resources (DERs) and the characteristics of the local needs.

5. Demand Side Management (DSM)

The creation of sustainable urban areas and human societies in the age of smart grids depends on Demand Side Management (DSM). When thinking about ways to save energy, it's important to take into account things like rising demand, vital resources, lax rules, power capacities, and electrical networks. The various DSM techniques are shown in Figure 1.2. A modernized take on the old grid, the smart grid has bidirectional energy transfer, as well as two-way communication and control. This makes it possible to include a wide range of new features and apps. The U.S. National Institute of Standards and Technology (NIST) supply this definition. The smart grid has state-of-the-art sensors, robust communication infrastructure, and powerful computing capabilities. It can fix itself automatically, is easy to operate, and is very vigilant against cyber and physical dangers. Demand Side Management (DSM) includes Home Energy Management Systems (HEMS), which allow customers to track and manage their equipment' power use in order to lower their electricity bills. At present, domestic electricity consumption accounts for around 30% of the global total. The optimization of HEMS schedules is a stochastic challenge.

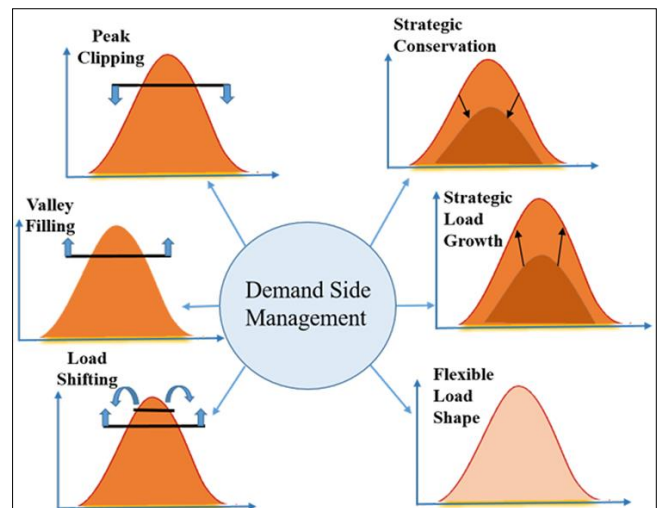


Fig 1: Different ways of Demand side management.

Consumer demand, power price, and the dynamics of renewable energy sources are all very variable and difficult to anticipate. Energy storage and load scheduling are practical ways for customers to lower their power bills. The energy scheduling and control decisions are further complicated by factors such as the restricted optimum period, interaction with energy storage devices, and the limited capacity of the batteries.

6. IoT based HEMS

Intelligent home gadgets with built-in communication capabilities form what is known as the Home Energy Management System (HEMS). When combined, these tools provide for a very efficient setting for controlling energy use. The IoT, or Internet of Things, is quickly becoming the de facto standard for controlling and communicating with a wide variety of devices connected to a LAN or HAN. Figure 1.3 shows the block diagram of the HEMS that is based on the IoT. The environment is made up of the following essential components:

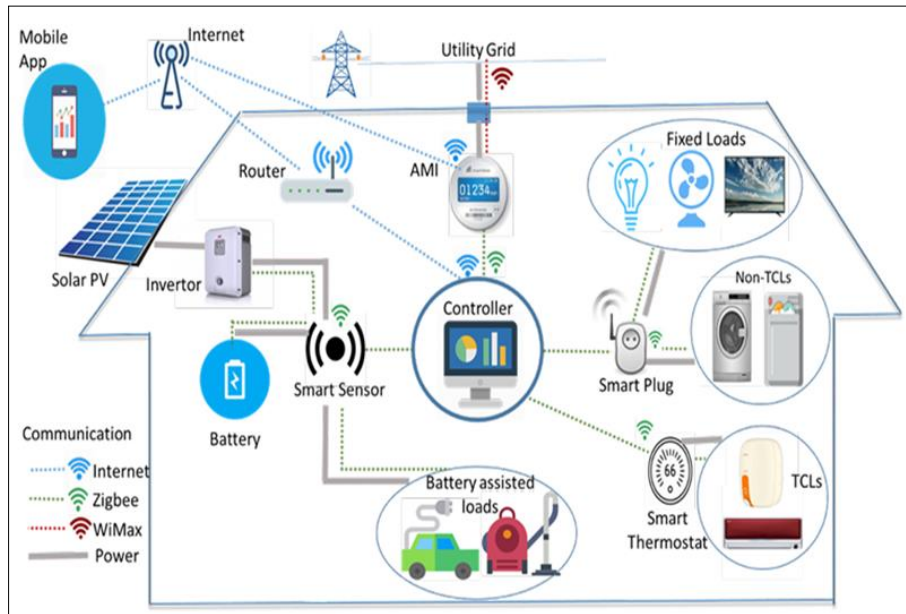


Fig 2: IoT based Smart Home

7. Smart Appliances

With the use of the Internet of Things (IoT), smart appliances may connect with other smart devices, such as smartphones and tablets, so that homeowners can manage and access their appliances from anywhere. These home appliances may communicate wirelessly with the smart meter, allowing them to immediately respond to changes in power supply and dynamic tariff, thereby reducing energy use. Many factors influence customers' decisions to buy smart home goods, and this article explores them all. The following are the elements to think about:

- the practicality of the appliance.
- the level of customer happiness.
- the potential for cost savings; and
- the convenience of control.

Privacy, control, and the capacity to work with other smart appliances are major considerations for consumers when making purchases. According to reference, operating household appliances with an IoT-based system successfully addresses interoperability issues and greatly enhances user engagement with smart appliances.

8. Advance Metering Infrastructure (AMI)

By enabling two-way communication between the utility grid and smart meters installed at consumer premises, AMI is a vital technology that enables customers to actively engage in the electricity consumer market. It also collects and transfers data, remotely monitors systems, ensures the privacy and security of client information, and presents dynamic tariff information, all of which are essential in IoT-enabled HEMS. In terms of consumer lifestyle disclosure, AMI poses a number of security risks due to the detailed information it has about customers' data consumption behaviors. Concerns about data modification or theft, power theft, cyber and physical attacks, and other similar threats are growing among utility businesses and law enforcement groups. These attacks and security issues have been covered extensively in the literature. Several important methods for configuration have been proposed in the literature to provide privacy and security during AMI-utility secure connection. But claims about the algorithms' security, computational burden, and complexity are still up for discussion.

Table 1: Communication Technologies for Smart Home

Technology	Spectrum	Data rate	Coverage range	Applications	Limitation
WiFi	2.4 GHz	11 Mbps	100 m	Monitoring and controlling	Security, Interference
Zigbee	2.4 GHz	250 Kbps	30-50 m	AMI	Low data rate, short range
WiMAX	3.5GHz	Upto75Mbps	10-50Km	AMI, Demand response	Not widespread
5G	1-6 GHz	Upto10Gbps	1000 feet	AMI, Demand response	Cyber security

9. Smart Thermostat

The term "smart home plug" refers to an electrical device that may transform regular household appliances into smart ones. By studying the energy usage patterns of linked household devices, it may establish their exact category. Connecting to a wireless home network is made possible by this device's inbuilt wireless communication protocols. Users may keep tabs on their energy use and control any electronics hooked up to the smart plug from anywhere in the world thanks to this feature. The article has dealt with the topic of smart plug security. One example of a smart

plug is the TP-Link Hs110, another is the Centralite ZigBee plug-in, and still another is the iDevices smart plug.

10. Load Profile of Smart Appliances

The energy and power requirements of smart appliances may be monitored by the smart meter thanks to the sensors that come standard with these devices. Saving energy expenses and optimizing resource management are both made possible by analyzing the energy consumption patterns of various smart home equipment. This data offers significant insight into consumer load patterns. The creation

of accurate and efficient load control algorithms also relies heavily on it. A load profile depicts the link between energy consumption and time for smart home equipment, commencing at the beginning of operation and ending at its end. Two separate approaches are available for creating appliance load profiles: smart meters and consumer surveys.

11. Aim and Objectives

Methods for Performance-Aware Management of Smart Microgrid Systems are the focus of this research.

- To design and investigate the Techniques for Performance Aware Management of Smart Microgrid System.
- To propose the multi-stakeholder approach for improving the performance of smart microgrid system.
- To develop a novel optimization-based load distribution management mechanism to proportionally allocate locally available energy to the customers.
- To model, simulate, and evaluate the proposed models with existing methods.

12. Need and Scope of the Study

When you're trying to figure out a study subject, you can end up with a bunch of fresh inquiries along different dimensions. Possible future research directions include predicting competitors' bidding behavior using their past bidding data and investigating innovative bidding methods grounded in game theory. You can achieve both of these goals by analyzing data from past bids. To further refine the SSSB energy trading model's clearance price determination process, it may be necessary to construct an electrical market with bidding on both sides. A fair quantity of weight age might be provided to the seller and the customer in this way. It is possible that smart appliances, which can be programmed and dimmed, may be more effective in managing energy use in a smart home.

Conclusion

Finally, getting a handle on smart microgrid performance management is essential if we want to have an energy future that is efficient, dependable, and sustainable. Smart microgrids are complex energy systems that need cognitive decision-making tools, real-time analytics, and advanced control techniques for optimal administration. In order to dynamically balance supply and demand, maximize the consumption of renewable energy, and ensure operational stability even under variable conditions, operators can leverage artificial intelligence (AI), Internet of Things (IoT) connection, and predictive algorithms. To further increase resilience against grid disruptions and outages, it is recommended to integrate efficient energy storage utilization, strong demand response systems, and smooth grid-to-microgrid coordination. Unlocking the full potential of these systems requires addressing obstacles including interoperability, cyber-physical security, and the lack of common performance standards. Smart microgrid performance management has the potential to develop into a framework that is both highly flexible and self-optimizing with the help of ongoing innovation, public backing, and stakeholder engagement. In the end, becoming an expert in this field helps streamline operations, save money, and

hasten the shift to smarter, more decentralized energy infrastructures that are greener. In order to create a more sustainable and resilient power landscape, this comprehensive strategy will enable communities, industry, and utilities to fulfill increasing energy demands with minimal environmental repercussions.

References

1. Dao LA, Dehghani-Pilehvarani A, Markou A, Ferrarini L. A hierarchical distributed predictive control approach for microgrids energy management. arXiv preprint arXiv,2006, 00963.
2. Ahmethodzic L, Music M. Comprehensive review of trends in microgrid control. *Renewable Energy Focus*,2021;38:84–96.
3. Al-Saadi M, Al-Greer M, Short M. Strategies for controlling microgrid networks with energy storage systems: A review. *Energies*. 2021;14(21):7234.
4. Han H, Hou X, Yang J, *ET AL*. Review of power sharing control strategies for islanding operation of AC microgrids. *IEEE Trans Smart Grid*. 2020;7(1):200–15.
5. Han Y, Li H, Shen P, *ET AL*. Review of active and reactive power sharing strategies in hierarchical controlled microgrids. *IEEE Trans Power Electron*. 2017;32(3):2427–51.
6. Dragicevic T, Lu X, Vasquez JC, *ET AL*. DC microgrids–part II: A review of power architectures, applications, and standardization issues. *IEEE Trans Power Electron*,2016:31(5):3528–49.
7. Sahoo SK, Sinha AK, Kishore N. Control techniques in AC, DC, and hybrid AC–DC microgrid: A review. *IEEE J Emerg Sel Top Power Electron*,2018:6(2):738–59.
8. Hirsch A, Parag Y, Guerrero J. Microgrids: A review of technologies, key drivers, and outstanding issues. *Renew Sustain Energy Rev*,2018:90:402–11.
9. Marín LG, Sumner M, Muñoz-Carpintero D, Köbrich D, Pholboon S, Sáez D, Núñez A. Hierarchical energy management system for microgrid operation based on robust model predictive control. *Energies*,2019:12(23):4453.
10. Morstyn T, Hredzak B, Aguilera RP, Agelidis VG. Model predictive control for distributed microgrid battery energy storage systems. *ArXiv*, 2017.
11. She B, Li F, Cui H, Zhang J, Bo R. Fusion of model-free reinforcement learning with microgrid control: Review and vision. *ArXiv*, 2022.
12. Rozada S, Apostolopoulou D, Alonso E. Deep multi-agent reinforcement learning for cost efficient distributed load frequency control. *ArXiv*, 2020.
13. Chen D, Chen K, Li Z, Chu T, Yao R, Qiu F, Lin K. PowerNet: Multi-agent deep reinforcement learning for scalable powergrid control. *ArXiv*, 2020.
14. Dao LA, Dehghani-Pilehvarani A, Markou A, Ferrarini L. A hierarchical distributed predictive control approach for microgrids energy management. *ArXiv*, 2020.
15. Farhangi H. *Smart microgrids: Lessons from campus microgrid design and implementation*. CRC Press, 2016.