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Micro Grid Integration of Distributed Power Generation Optimal Operating Methods

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Abstract: - Microgrids, as localized energy systems comprising distributed power generation sources, offer resilience, flexibility, and efficiency to the modern power grid. Integrating various distributed energy resources (DERs) within microgrids poses challenges in optimizing their operation to ensure reliable and cost-effective energy supply. This paper presents a comprehensive review and analysis of optimal operating methods for the integration of distributed power generation within microgrids.The study explores various aspects of microgrid operation, including optimal dispatch strategies, demand-side management techniques, energy storage utilization, and renewable energy source integration. It investigates the application of advanced optimization algorithms, such as linear programming, mixed-integer linear programming, and metaheuristic algorithms, to address the complex optimization problems inherent in microgrid operation. Furthermore, the paper examines the role of smart grid technologies, advanced control systems, and communication infrastructure in facilitating the efficient operation of microgrids with distributed power generation. It discusses the importance of real-time monitoring, data analytics, and predictive modeling for enhancing decision-making processes and optimizing microgrid performance.

Keywords: Microgrid, distributed energy resources (DERs), optimal dispatch strategies, demand-side management, energy storage, renewable energy integration, optimization algorithms

Introduction

Devices that store power and are linked to the grid are known as distributed energy resources (DER), and their acronym stands for "distributed energy storage" (DES). The DER system may be monitored and coordinated inside a smart grid via the use of interface devices. In contrast to centralised plants like thermal, nuclear, hydroelectric, and large-scale solar farms, distributed energy resource (DER) systems are decentralised, flexible, and situated close to the load centres they serve, so they do not require electricity to transmit over longer

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distances[1][2]. The DER system has a maximum capacity of 10 MW. A distributed energy resource (DER) system is similar to a hybrid power system in that it uses a combination of generating and storage devices. One improvement or replacement for traditional power grids is distributed energy resource systems. The cost of capital per kilowatt-hour is often greater in hybrid power systems. In contrast to traditional power plants, microgrids are smaller, more localised networks that are both contemporary and efficient[3][4]. Several microgrids are linked to the main grid and may be removed if needed. By running in island mode, it mitigates problems with central grid instability. Typically, a low voltage ac grid known as a microgrid is set up by the community that it is meant to serve. Microgrids often use diesel generators. A microgrid's protection and control grow more complex as it integrates several distributed power producers. Because it allows energy carrier substitution, microgrids have the critical attribute of meeting many end-user demands, including cooling, heating, and electric power. Because of this, the use of unwanted for heating and cooling boosts the effectiveness[5][6]. During the time it takes to go from grid-connected to island-mode operation, a microgrid can manage. Part of the distributed power generating system is shown schematically in Figure 1. Interactions between a main grid and a microgrid might potentially provide supplementary services. Power generated by the microgrid, both reactive and real, must meet the needs of individual loads while operating in standalone mode.[7]

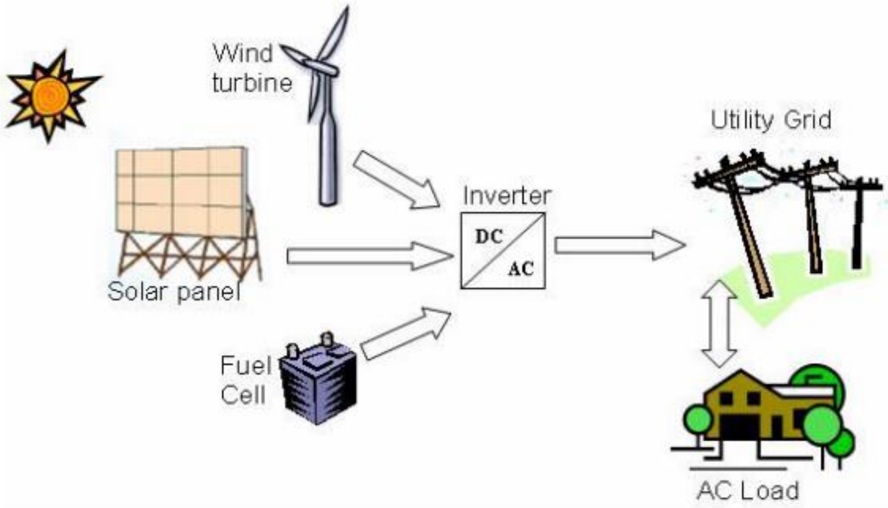

Figure 1. Schematic diagram of a distributed power generation.

Microgrid

A microgrid typically consists of loads, an energy storage system, and distributed generation (DG) units.Since the majority of power networks nowadays utilise alternating current (AC), this kind of microgrid was first presented. A residential neighbourhood or other small section of an existing AC grid may be transformed into an AC microgrid by installing enough DG and an isolating switch at the grid interface to allow for islanding [8][9]. Commercial and residential structures, as well as new area developments in rural regions, are more suited for DC microgrid deployments. Current AC systems typically use three phases and need at least three wires—negative, positive, and ground—to function, therefore the idea of DC microgrids might work for these types of setups. However, installing power electronic converters and upgrading a lot of equipment would be necessary to transform an existing system into a DC microgrid [10]. A key consideration when choosing between AC and DC microgrids is the amount of converters needed, which varies with the kind of DG and the loads connected to the system. Powering motors equipped with variable speed drives, light-emitting diode loads, and uninterruptible power supply systems from alternating current (AC) systems incurs several energy-wasting conversions [11]. Renewable energy sources are defined as those that can regenerate and continue to provide energy indefinitely. Energy sources such as solar, geothermal, wind, hydropower, and tidal wave fall under this category.

Microgrid Difficulties It is important to consider the many operational issues brought about by microgrids and the consolidation of DER units when designing the control and protection system. So, it's obvious that the existing degree of dependability is losing its effectiveness. The potential advantages of DG units, or Distributed Generation, are therefore fully used. Some difficulties derive from false assumptions that are relevant to traditional distribution networks, while others are the result of stability problems that were previously only apparent in transmission systems. The following obstacles exist for microgrid protection and control[12].

(a) Issues of Stability When the interface of the control system of DG units takes place it can create local oscillations. It requires a detailed small-disturbance stability analysis. When a grid-connected solar photovoltaic system moves to island mode of operation, this transition activity makes the system temporarily unstable[13]. Recently it has been studied that the DC-microgrid requires significantly simpler control system, more efficiently distribute energy and having a higher current carrying capacity for same line ratings.

(b) Bi-Directional Power Flow The integration of distributed power generation with low voltage distribution network may lead to reverse power flow which creates obstacles in protection coordination, undesirable power flow patterns, distribution of fault current and control of voltage.

Low Inertia Bulk power generating stations where a large number of synchronous generators are connected together shows high inertia as compared to low voltage distribution microgrid. Especially when a DG unit is interfaced with a significant share of power electronic devices, this phenomenon is clearer. In the lack of proper control mechanism, the inertia of low voltage microgrid may lead to high-frequency deviations in standalone operation[14].

(d) Modeling Microgrid models are needed to be revised because may characteristics in low voltage distribution grid such as primarily inductive transmission lines, the prevalence of three-phase balanced conditions, and constant-power loads are not valid.

(e) Uncertainties In isolated microgrids, the load profile and weather forecasting make the coordination in critical demand-supply more challenging. In a bulk power system, the number of the load is more as compared to isolated microgrids and available energy resources are not highly correlated. Therefore uncertainties are less.

Optimal Strategies of Microgrid Integration

In this paper, we looked at how distributed power generation could work best inside a microgrid, considering things like efficiency, performance ratio, power loss from voltage ripple, PV module degradation, energy payback time, and battery charging and discharging. Unpredictability in the distribution system output could result from distributed power generation, such grid integrated solar power [15]. The energy storage technology that uses batteries can convert between real and reactive power in milliseconds. Batteries have a special quality that makes them ideal for energy storage systems; these systems are more resilient to issues like instability in voltage, frequency, and ramp rate. Developing mathematical models of solar energy is tough since it is strongly dependent on weather conditions. However, such situations may be characterised by case studies, experimental settings, and intelligent techniques. To find out how a solar PV system that is linked to a microgrid may work best, we analysed data from case studies, conducted experiments, and used intelligent methods [16].[17]

Performance Analysis Of Solar Photovoltaic System

Power output and efficiency are affected by three factors: soiling loss, global irradiation, and temperature. The objective of this endeavour is to track the efficiency of the PV system in connection to time of day (TOH), average temperature, and global irradiation for a whole day. Extensive research has demonstrated the SPV's effectiveness in a wide range of geographical and environmental settings [18]. Solar cells made on thin film were more flexible than those made of crystalline silicon.

Testing of the solar cells was place in the dry Indian environment using dust collection on three different types of silicon surfaces: polycrystalline silicon with an epoxy coating, monocrystalline silicon with a glass surface, and an amorphous silicon panel with glass. Following 1.1 hours of testing, scientists found that compared to the polycrystalline module, the amorphous one showed less performance degradation [2]. There have been several studies on PV performance, but dust deposition or soiling is by far the most important. Whenever there is a change in the intensity or quality of the incoming irradiance, dust, whether organic or inorganic, may influence the properties of solar irradiance that hit PV modules. This, in turn, can impact the performance of PV output. Consider the site carefully while deciding how often and what kind of cleaning to do [3]. Cleaning after two or three weeks was strongly recommended in a study that did not account for cleansing rain. A cost-benefit analysis should be conducted by every system that wishes to determine its cleaning schedule requirements [4]. Researchers have studied the impacts of irradiance, ambient temperature, humidity, precipitation, and other meteorological factors by simulating a PV system that is linked to the grid. The INSEL software, which stands for integrated simulation environment language, was used to perform the study and model. Over the last 20 years, there has been a rise in the average performance ratio of new PV systems in warm climates, moving from 0.65 to 0.85 [10].

Renewable energy sources must be further expanded and made more widely available to meet the ever-increasing need for electricity. The attractiveness of solar power generation lies in the fact that it enables the massive and continuous creation of energy without the emission of carbon dioxide. The performance ratio for solar photovoltaic systems installed on rooftops was 0.75 and for those put on ground it was 0.8, according to statistics provided by Environment Canada [8]. A performance ratio (PR) for the solar plant has been calculated by reporting the effects of average temperature, time of hour (TOH), and sun irradiation on the plant's power production and efficiency. The following is one method for calculating the performance ratio (PR), which may be used to assess the efficiency of a solar system:

$PR\% = Ps \times 100 / 1 \times A \times Es$…………………………(1)

Ps is the total amount of output energy (kWh) of the system. ‘I’ represent for irradiance (kWh/m2), ‘A’ shows the area of the array, the efficiency of the module is represented by ‘Es’. When normalizing with respect to irradiance, the influence of losses is quantified on the rated output

Fuzzy Logic Controlled Battery Energy Storage System

Energy efficiency improvements are becoming more and more important in the fight against environmental challenges and for lowering overall energy usage. The only way for humans to stay alive on this planet is to harness renewable energy sources, since traditional energy sources are running out at a rapid pace and pollution levels are rising at an alarming rate. The latest trend is to use energy that is part of a sharing system, which has several advantages, such as great potential, controllability, and flexibility [19]. With the help of battery energy storage systems (BESS), the integration of DER with the distribution grid becomes less complicated. One or more dispersed generating units that may be operated independently or linked to the utility grid make up a microgrid, a small power system [20].

Reliable and adaptable power on a smaller scale is provided by the microgrid. In order to avoid power outages, it is linked to both the utility grid and units of the local generating system. A microgrid may serve anything from a single household to a whole town. Renewable and alternative energy sources are gaining popularity as generating and distribution businesses battle it out in the market. To lessen the burden on transmission power and keep energy costs down, this study devised the best scheduling solutions for the BESS function. In the event that the renewable energy situation is uncertain, the actual power resource may be maintained with the help of the battery energy storage system. We have completed the fuzzy logic control strategy for an optimum power flow in a grid-tied renewable power generating arrangement utilising MATLAB/SIMULINK in the power system block set. The planned approach successfully reduces the primary resource needed to manage the output power of renewable energy sources. Electricity from photovoltaic cells (PV), batteries, loads, secondary sources, and state of charge (SOC) are all fuzzy variables that have been studied in a Simulink model. For the purpose of charging and discharging the battery, MATLAB code has been created. Both tabular and graphical representations of the results of the study of the system model are available.

Need for Batteries

The issue of renewable energy sources being unpredictable is addressed by battery energy storage systems. Some vital loads will continue to get power from the battery during grid outages; otherwise, money would be lost due to disconnection. Using batteries to power peak-hour loads helps businesses save money on their power bills. The utility level uses the battery to power the grid's auxiliary services. The usage of batteries is being encouraged by state governments, who are now regulating laws for self-consumption.

Battery Model

A decrease in DG yield and the subsequent implementation of load peeling are symptoms of a power imbalance. The capacity to isolate the microgrid from a larger system and provide very reliable electrical power is provided by the on-site generating sources. As a byproduct, heat from generators like microturbines might be used for restricted course heating, enabling a versatile trade-off between the demands for electricity and heat. In light of the disaster that struck India on July 30 and 31, 2012, microgrids are being seriously studied. Over half of India's population and over 9 percent of the world's population—620 million people—were impacted by this blackout in 22 states throughout the country's northeast, east, and north.

Microgrids are decentralised power systems that include one or more distributed generation resources and have the capability to separate from the larger power grid and function autonomously. The idea has gained traction because to the rising use of distributed generation resources including solar, fuel cells, wind, and combined heat and power plants. These resources may run constantly or intermittently, apart from the main electrical grid, to meet the local demand, provided they are appropriately sized and designed. If there are disruptions to the main grid, microgrids may enhance the reliability of their local systems by intentionally islanding without impacting grid integrity. Because of the growing need for generating expended capacity, DG utilisation has been on the rise. To address power shortages, DG resources might be seen as an alternative to building new conventional power plants, taking into account the financial concerns and right-of-way difficulties related to electrical energy production and transmission. The need to manage and coordinate many resources and the loads they produce gave rise to the microgrid idea, which has been made possible by improvements in the controllability and dependability of DG resources.

Microturbines, fuel cells, photovoltaics, and internal combustion engines with permanent magnet generators are the most significant DG technologies for microgrid applications. Microgrids are generally compensated for by increased energy competence, decreased operational and transmission costs, less carbon footprint, and improved power quality and availability to end users through advanced control techniques. In particular, microgrids integrate renewable energy resources. Nevertheless, there are a lot of obstacles to overcome when putting the microgrid idea into practice, such as managing the cost of management, islanding, energy conversion, and controlling a large number of distributed energy resources. The DC microgrid offers more benefits than its AC counterpart when it comes to possible improvements in power system performance. These include the ability to better integrate distributed energy resources and energy storage systems, as well as to isolate power system disruptions from the power island. But DC systems come with their own share of problems, namely synchronisation and power system safety via fault detection and isolation [96]. Energy from the sun, in the form of radiation, is sent to Earth. The intensity of the radiation that the Sun emits to Earth remains relatively constant towards its outer edge. Using the average yearly distance between the sun and Earth, the global solar constant calculates the amount of energy that the Earth receives from the sun per unit of time. Typically, with a 1% margin of error, the universal solar constant is assumed to be 1367 W/m2.

In most cases, a power conversion system, a monitoring and control system, and batteries are the main parts of a battery energy storage system. The building blocks of cell batteries are modules made up of interconnected cells, which are in turn linked into packs. An external tank stores the electrolytes that flow through a reaction stack in a flow battery. To guarantee optimal performance and safety, a battery management system would often include a monitoring and control system. The monitoring and control system ensures that the individual cells are not overcharged and that charging and discharging are controlled. For a battery energy storage system to function safely and to achieve its full potential, this is crucial. The intended control strategy for the energy storage system that uses batteries has been modelled in the MATLAB simulink environment. Table 1 displays the parameters of the system model. Also shown is the system's dynamic performance.

S.N	Parameter	Rating
1	Grid voltage	3-phase,415 Volt,50Hz

2	transformer rating	100 kVA,415 Volt,50Hz
3	Resistance Inductance Capacitance	0.345-0.4864 Ω 0.9837-4,1255mH 14.74-7.751

With an emphasis on solar photovoltaic systems in India, this article discusses the best operational tactics for integrating dispersed power production with the current distribution infrastructure. Optimal scheduling of microgrid, estimation of energy payback time, air pollution mitigation potential, performance under different radiant flux, impact of climatic factors, power loss comparison in single stage and double stage, degradation factor, and performance ratio are all thoroughly examined in this paper[4][8]. This article presents the major results gained from the following studies. The performance ratio is a location-independent metric for evaluating solar plant quality. This is another name for a plant's quality factor. A performance ratio of 0.7 to 0.8 is typical. A greater performance ratio indicates that the plant is operating more efficiently. A previous problem is indicated if the plant's performance ratio deviates considerably in comparison to a reference value [8].

Environmental variables, such as PV module temperature, solar irradiation, power dissipation, and whether or not the measuring gauge (such as the Sunny Sensor Box) is in the shadow or dirty, all have an impact on the performance ratio. A solar photovoltaic power plant's performance ratio may be enhanced by including a tracking mechanism within the array. This mechanism allows the panels to rotate in relation to the sun, ensuring that they always face the sun for maximum irradiance and, therefore, power output.

Improved efficiency is necessary for the grid-connected solar photovoltaic power plant to function at its best. Power loss occurs in both single-stage and double-stage grid-connected solar PV systems due to ripple in the voltage at twice the line frequency. Total power loss is almost identical in single-stage and two-stage grid-connected solar photovoltaic systems, but the former has the benefit of using less equipment, such as a boost converter, according to a comparison of the two types of systems [6]. The advantages of a single-stage grid-connected solar PV system in a dc distribution system are its greater efficiency, lower cost, better layout, size, and practicability. Adding a battery to a single-or double-stage grid-connected solar photovoltaic system drastically lowers the harmonic content, but it also raises the overall cost of the system. Particulate matter and other forms of pollution may reduce the efficiency of solar photovoltaic arrays. Between 0.55 and 0.95 percent per year is the deterioration rate [11].

In order to feed the alternating current (AC) electricity produced by a solar photovoltaic (PV) plant into the grid, a solar PV inverter is an essential piece of equipment. If infrared scanning and monitoring are done correctly, issues may be identified and fixed before inverters fail, which might lead to a loss of megawatt output. Properly cleaning the panel so it could receive maximum irradiance is said to boost the efficiency of the solar photovoltaic power plant. Eliminating weeds may reduce the shading impact and increase efficiency. Maintaining a constant flow of electricity to microgrid loads requires battery energy storage managed by a fuzzy system [7]. Some delicate equipment need a constant power source. Using a battery energy storage system may minimise the cost of energy production and lessen customers' dependence on the main grid. Fuzzy control has optimised the charging and discharging of a grid-connected battery energy storage system, which has resulted to an improvement in the battery's output power, power given to the load, and battery state of charge. If we want to enhance power quality, dependability, technical performance, and minimise greenhouse gas emissions while avoiding the use of finite fossil fuels, we need to connect a microgrid that stores energy in batteries and is managed by a fuzzy system to the main grid. Consequently, a battery with more capacity than what the microgrid requires should be installed. To extend the life, make sure the discharge depth doesn't go up by more than half. Further reduction in labour and improvement in longevity may be achieved by proper maintenance, automation, and battery management [9].

Reduced energy payback time and less air pollution should be the goals of optimally operating distributed power production linked to microgrid. Distributed power production, as opposed to power facilities that rely on fossil fuels, may alleviate a lot of environmental issues. Reducing the energy payback period is possible via optimal plant installation, which allows the plant to receive maximum irradiance and, thus, generate maximum power.

The EPBT decreases when the cost of grid power rises. We need a more robust incentive programme that includes net metering, tax credits, and refunds.

A greater performance ratio, reduced power loss owing to voltage ripple, and a lower degradation factor of the solar photovoltaic module would allow distributed power production linked to microgrid to work efficiently. This system is ideal because it uses a battery energy storage system and uses a fuzzy control system to regulate the charging and discharging of the battery. The investment in a solar power plant's construction will provide a return on energy consumption far sooner than the plant's expected lifespan. Using distributed power production to tackle the anticipated energy crisis in the near future might help alleviate global warming, the world's most pressing challenge. Therefore, this paper's study findings suggest that microgrids linked to distributed power production will be crucial in meeting the world's and emerging nations' future energy demands, particularly those of India, which have a massive power need. In addition to being eco-friendly, these microgrid-connected distributed power generating systems will provide reliable, low-cost energy. The world's energy dilemma has no solution other than distributed power production linked to microgrids. A worldwide energy crisis may ensue in the not-too-distant future since the known reserves of fossil fuels are finite and are being used at an alarming rate. Rooftop or ground-mounted, linked or independent, distributed power production, including solar photovoltaic systems, are all possible. Installing these microgrid-connected distributed power generation systems close to load centres reduces transmission costs, increases efficiency, and lowers the cross-sectional area of conductors, all of which contribute to lower electricity prices.

Conclusion

As we delve into different facets of microgrid operation—such as the best ways to dispatch power, how to manage demand, how to use energy storage, and how to integrate renewable energy sources—it becomes clear that sophisticated optimisation algorithms are essential for navigating these challenges. Optimising microgrids via distributed power production has proven to be a challenging task, however linear programming, mixed-integer linear programming, and metaheuristic algorithms are useful tools for the job. Modern power networks may be made more resilient, flexible, and efficient by integrating distributed power production into microgrids. This integration, however, is not without its obstacles. In order to overcome these obstacles and make the most of the benefits that microgrid integration brings, this article has offered a thorough evaluation and analysis of optimum operating approaches.

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