A Review of Decentralized Energy Management Strategies for Microgrids and Optimization Approaches

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Abstract - In recent decades, there has been a growing interest in microgrids, localized, independent energy systems operating independently or in conjunction with the utility power grid. Microgrids are a vital area of study in the power sector because of their unique characteristics, such as using renewable energy resources and eliminating the need for power transmission. Energy management of microgrids is an inevitable research paradigm due to the intermittent nature of distributed generation resources and the need to improvise the microgrid's economic feasibility. Recent literature reviews the various facets of EMS and the optimization techniques used in the EMS framework for microgrids-specific Energy Management Systems (EMS). The paper focuses on various optimization techniques used for energy management, evaluates the factors affecting the performance of the algorithms, and proposes the enhancement of the optimization algorithm. Further, the paper suggests an improvised version of the optimization algorithm to enhance the convergence and focus on the cost-effectiveness of the Energy management system.

Key Words: microgrids, EMS

1.INTRODUCTION

A. Overview

The increasing price of goods like nourishment, transportation, and power could have adverse impacts on the natural world if they are produced using only conventional methods as the world's population continues to rise. Fossil fuels (such as gases and petroleum) accounted for roughly 64% of the world's electricity production, renewables 26% (2018), such as hydroelectric power, winds, plant matter, and sunlight), and nuclear power plants (10%) accounted for 10%. Using fossil fuels has resulted in unprecedented levels of carbon dioxide emissions [1]. In light of the critical need to combat global warming, numerous programs have been launched to stimulate the development of renewable energy sources.

Renewable energy sources are plentiful and relatively easy to access; however, due to their sporadic natural world, novel approaches are needed to optimize their use. Using such assets as decentralized generators is crucial for lowering greenhouse gas emissions and minimizing energy losses in the grid. Microgrids arrive into play in this context, as they allow for dependable local manufacturing by converting used areas into factories. Loss of transmission [2] in distribution and transport systems is just one of the many issues that can be addressed by switching to a microgrid from a traditional electrical grid. The importance of an Energy Management System (EMS) for ensuring its effective execution, as it allows for maximum control. The management system employs optimization strategies with the twin goals of decreasing monthly bills for customers and decreasing emissions of greenhouse gases without compromising convenience for end users. The necessity of distributed, multiple-source energy generation gives rise to the idea of microgrids. Many nations now use renewable energy sources to power their economies. Through the end of 2020, the global total for renewable energy production had increased to 2839 GW, according to the Renewable energy sources 2021 Worldwide Status Update [3]. The worldwide growth of renewable power capacity has been severely hampered by the COVID-19 crisis. Regardless of this, the IEA predicts that the number of renewable power setups worldwide is going to increase in 2021 as opposed to 2020. The primary reason is that the majority of the initiatives that were put on hold due to the unforeseen COVID-19 crisis are finally going live [4]. To combat ecological exhaustion, the microgrid idea was developed to harness distributed energy to renewable energy sources (RES), including wind and photovoltaic (PV). Three primary advantages of microgrid infrastructure have been identified and established: (a) physical (and cyber) dependability; (b) ecological sustainability (in terms of the environment); and (c) financial (in terms of cost optimization and efficiency).

B. Microgrids: Advancing Efficiency, Resilience, and Sustainability in Power Distribution Systems

In recent decades, microgrids have improved power grid efficiency, reliability, and longevity. Microgrids have become a pledging norm due to rising electricity consumption, renewable energy collaboration, and the need for flexible, self-governing energy sources. A microgrid is a distributed energy infrastructure [1] that serves a limited region and can operate independently or with the larger electrical grid. It uses batteries, wind, PV, and microgenerators.

Microgrids balance power production and demand in a building, campus, or neighborhood. Microgrids integrate and regulate multiple energy sources, providing many benefits. Their main purpose is to improve power grid reliability by increasing energy production and storage capacity. [2] This quality is crucial in disaster-prone or remote areas without access to the power grid. Even without the grid, microgrids can power their communities. Microgrids help reduce greenhouse gas emissions by integrating clean energy sources into energy assets. Microgrids can reduce grid strain by controlling peak demand, improving energy efficiency, and generating clean energy using shared Energy Resources (DERs). Load optimization and voltage regulation balance local supply and demand to improve power quality and stability. Microgrids boost energy autonomy and financial gains. [5] Microgrid users use less power from the grid and may save money by generating electricity on-site.

Decentralized and regional energy trade allows microgrid consumers to increase energy efficiency, sell excess electricity, and possibly create new revenue streams. However, implementing microgrids requires a thorough investigation of resource allocation improvement and establishing energy part interoperability, which is the main technical challenges. Economics covers many topics, including cost-effectiveness, financial modelling, and tariff organization. Microgrids require regulatory framework changes [1]. This requires adequate energy reimbursement, opportunity grid relationships, and operational standards. DERs and controlled loads allow microgrids to operate in grid-connected or islanded modes. This is crucial to incorporating renewable DERs while minimizing transmission losses. Distributed energy resources (DERs) on the transmission side, such as Tesla Powerwall battery systems, wind turbines, and solar plants, allow simultaneous power flow [6]. This turns a power grid into a microgrid that runs solely on DERs and exports excess power to the grid. A microgrid can cover a smart home or a smart city.

C. Advantages and Challenges

1. Advantages

Energy management systems improve microgrids' efficiency and sustainability. Energy management improves microgrid DER use. Energy management systems may improve DERs by organizing power production, preservation, and use. This method saves energy and improves system performance. Savings and less power grid dependence result. Energy management systems strengthen microgrids. These networks track and control power availability and demand in real-time to maintain a consistent and reliable power supply. [1] Energy management systems can operate microgrids autonomously during grid outages. The microgrid restores essential loads faster by operating independently. This feature will benefit disaster-prone areas or those without a reliable power grid. Microgrid energy management systems enable renewable energy sources. Microgrids are becoming the ideal foundation for PV Wind and other clean energy installations. Coordinating renewable energy's short-term availability with microgrid systems' energy management needs to optimize consumption [2]. Traditional energy production's greenhouse gas emissions are reduced by such technology. Energy independence and cost savings are possible with microgrid energy management strategies. Native power production, storage, and consumption are enabled by microgrid power source oversight. This reduces their grid dependence and increases their energy independence. Energy management systems can improve utilization patterns and reduce peak demand costs by implementing load balancing and demand-side response strategies [7]. Residents can profit from selling excess power to neighboring microgrids or the main grid with integrated energy management systems [8].

2. Challenges

Microgrid structures still face an important research obstacle when it comes to load scheduling. The challenge is to allocate and schedule traffic in a microgrid in such a way as to maximize energy use and minimize running costs. The challenge grows more challenging owing to the changing load trends, fluctuating demand for energy, as well as having to support a wide variety of appliances. The difficulty resides in designing sophisticated scheduling methods capable of coping with these nuances and achieving optimal load balancing in light of multiple goals and restrictions. Improving energy management and increasing the overall effectiveness of microgrid actions would result in solving this problem.

Precise load demand estimation is an additional field of microgrid study that is still being explored. The ability to accurately predict future load demand is critical for the allocation of resources and effective energy utilization. Load prediction for demand in microgrids, however, is notoriously difficult because of the many variables at play, including weather, utilization trends, and customer behavior. Load Forecasting Demand is already complicated, as well as renewable energy sources' sporadic natural world only makes things worse. Scientists are hard at work creating cutting-edge forecasting models that can account for these unknowns and deliver accurate load predictions. Microgrids face significant difficulties due to the unpredictability of renewable energy sources. Because of their irregular natural world and reliance on surroundings, RES like PV and wind present challenges when integrated into microgrids. Microgrid durability and dependable functioning may be compromised by these unknowns. To lessen the effects of RES unpredictability, scientists are investigating a wide range of methods, from improved instruments for forecasting to ESS and smarter controls. The adaptability and longevity of microgrid systems could be improved with the development of trustworthy techniques to deal with these unpredictability issues. Along with that, it becomes a challenge to control the load using an appropriate controller.

D. Decentralized Energy Management Strategies for Microgrids: Balancing Efficiency, Privacy, and Scalability

A microgrid's power flows are controlled by its EMS, which adjusts power imported/exported from/to the primary grid, transportable DERs, and manageable loads based on real-time and predicted market, era, and load data. Microgrid energy administration is often framed as an irregular optimization problem due to its complexity. Combined integer computer programming ordered exponential computer programming, particle swarm optimization (PSO), neural networks, and others have been proposed to solve this problem. Centralized methods are unscalable because they depend on the MGCC's computing power. A centralized EMS needs the MGCC to collect optimization inputs from DERs (production costs, constraints) and loads (client tastes, limitations). However, multiple DERs may be controlled by different companies, and all may want to keep their data private. Clients may hesitate to share data due to privacy concerns. Microgrid management has many distributed methods. The author proposes decentralizing the asymmetrical duty problem [2]. Dual breakdown creates a distributed EMS and the concave formulation maintains microgrid demand and supply ratios. Distributed maximizes DER processes using a cumulative increase/multiplicative reduce system. Current dispersed methods oversimplify by assuming total demand equals total supply. The fundamental distribution of the power system, electrical flow [3] (e.g., Kirchhoff's law), and barriers (e.g., voltage tolerances) are ignored. All power plants and loads are connected to one bus. These algorithms may produce useless plans because they may not meet the above criteria. Multiple DR studies have focused on distribution systems. Microgrids address supply and demand-side administration, but no research has examined the benefits of integrating distribution systems with distributed energy administration.

Having a firm grasp on these fundamental elements is crucial for developing effective and long-lasting strategies for energy management. In addition, an in-depth examination of optimization techniques with an eye toward their application in microgrid energy management contexts is provided in this paper. Without optimization methods, microgrids cannot provide adequate energy management. These strategies aim to optimize the performance of DERs, batteries, and grid conversations in order to maximize system availability, especially reduce operational costs, lessen the system's environmental impact, and increase the use of RES.

2. Literature Review

A. Overview

In this section, the author examines the nature, function, and classifications of Micro Grid Energy management. For effective and long-lasting energy management strategies, it is essential to have a firm grasp of these foundational elements. In addition, this section offers an in-depth analysis of optimization methods with an eye on how they can be used in microgrid energy management settings. Ideal energy management in microgrids is impossible without the use of techniques for optimization. These approaches seek to maximize system availability, decrease operational costs, lessen the system's environmental impact, and increase the use of RES by optimizing the functioning of DERs, batteries, and grid conversations. This section provides a thorough analysis of the many optimization strategies that have been implemented in the field of microgrid energy management. The advantages, drawbacks, and applicability of both established and cutting-edge optimization algorithms are discussed, with a focus on their application in microgrids.

B. Various Grid Structures

There are different types of grids based on various factors. Here are some commonly recognized types of grids in the context of energy management systems:

1. Conventional Grid

Large-scale power plants will be managed by the rail network's control center. The TSO receives consumption data from the distribution network operators and transformer stations. Because the quantity of power generated by decentralized sources cannot be controlled and must be predicted independently, network operators view it as a negative load [9]. Power outages can occur when distributed generation in one area of the grid exceeds local demand.

2. Micro Grid

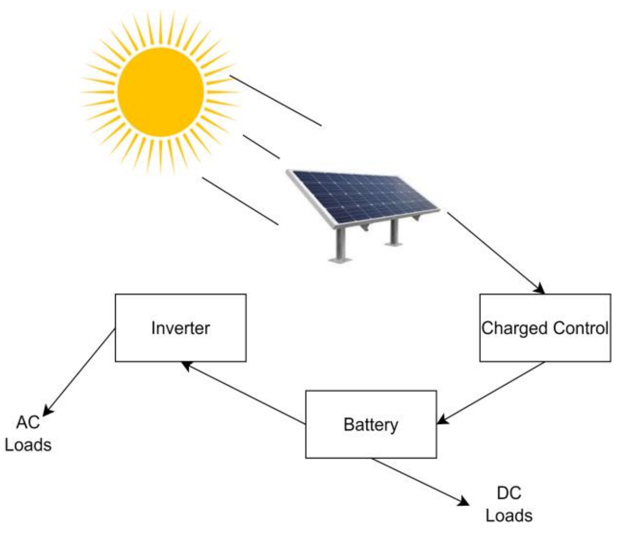

Fig -1: Producing Power through PV System Energy

Microgrids are localized energy systems that work with or without the power grid. Control systems and energy management software connect DERs like solar panels (Fig. 1), wind turbines, batteries, and generators [10]. A microgrid supplies power to a community, university campus, military base, or industrial facility. It works grid-connected and islanded. Grid-connected microgrids draw power from the grid and export excess electricity. The microgrid can operate autonomously in islanded mode to provide power during grid outages or emergencies [10]. Microgrids improve energy management. They can integrate and efficiently use renewable energy sources, reducing greenhouse gas emissions and fossil fuel use. Microgrids improve energy efficiency, cost, and independence by optimizing energy generation, storage, and consumption locally. They reduce power disruptions and provide emergency backup power to improve grid resilience.

3. Smart Grid

Contemporary communication and information technology optimizes the production of electricity, distribution, and consumption in a smart grid. The power grid is smarter and more efficient. In a smart grid, energy producers, customers, and grid infrastructure have detectors, inches, and communication links [11]. These devices may share real-time information and respond to electricity demand and supply changes thanks to a robust communication network.

C. Various Sources of Energy Availability

The power grid is made up of many different systems of transmission and distribution which collaborate together to get electricity from generators to homes and businesses. With the advent of micro and nano-grid systems, the initial transmission technique has been refined over numerous iterations.

1. Micro Grid Generation

Microgrid generation is an integral part of an EMS, as it helps to maximize efficiency, decrease dependence on the main grid, and diversify energy sources. It paves the way for the incorporation of RES, which can help make the overall energy mix cleaner and more long-lasting. By functioning separately from the main grid, microgrids may offer power resiliency throughout grid interruptions and crises by guaranteeing uninterrupted electricity to vital facilities [12]. Furthermore, efficient demand reaction and load management techniques are made possible by microgrid power generation. Energy managers may regulate supply and demand, maximize efficiency, and cut costs by keeping tabs on and regulating microgrid electricity use. This decentralized method of energy production and management has the added benefits of improving grid stability, decreasing transmission losses, and easing pressure on the main grid.

2. DG

DG refers to the practice of producing electricity from a number of fewer generators connected to low-voltage or, less frequently, medium-voltage grids. Distributed generation is typically powered by energy from renewable sources, yet conventional generators can also be utilized. There has been an important uptick in this kind of production in recent years, and an autonomous power manufacturer is able to market its energy on power markets; various mechanisms exist based on the nation as a whole [13]. In addition to the political will to increase energy autonomy and reduce emissions of carbon dioxide and other contaminants, the growing importance of renewable energy in the global energy group is also a contributing factor in an upsurge in distributed generator use. All users and power system actors stand to gain from distributed generation.

Consumers can potentially reduce their electric bills by investing in on-site energy generation. Coordination among distributed generators and co-management of distribution systems throughout peak hours calls for more flexibility and, thus, expenditure on enhancing small-scale networks.

Since both manufacturers and consumers are so closely linked together, losses are kept to a minimum. Distanced consumption sites may also gain from distributed production if their electrical demands are too low to justify the construction of large power plants. Distributed generating machinery has the potential to enhance the reliability of the power supply to vital loads. Distributed generation is dependent on production in excess of demand, but sources of clean energy pose stability concerns due to their unreliable nature. The excessive voltage on the local grid and the inability to reliably predict future electricity demand also contribute to customers' annoyance. Distributed power plants provide vitality beneath safeguards, and can in certain instances cause them to fail on their own. The solution to these problems involves distributed microgrids that incorporate renewable energy engines, storage of energy, and small power plants. These distributed generators could be used by microgrids to provide energy reserves that can be utilized to satisfy periodic interest at less money than managing the marketplace.

D. *Typical DGs used in Micro-Grid*

Microgrids allow multiple power sources. Their most efficient use requires two things: (a) the ability to manage the necessary power without much generator maintenance, and (b) economic reliability compared to standard sources or the main grid connection. Wind power is the best choice because it is renewable and widely available. Wind turbines are expected to generate 593 TWh of electricity worldwide this year, second only to hydropower. Residential turbines near supply points can generate hundreds to thousands of watts, while offshore turbines can generate several megawatts and stand tens of meters tall. Wind energy has unlimited potential [14]. Air currents caused by the sun's uneven heating of Earth's surface cause this phenomenon. New climatic zones and global wind patterns result. Heat is transported from the equator to the poles because the polar regions lack energy. As air near the equator cools and moves toward the poles, fluid mechanics creates wind. Solar energy converts only 1%–2% into wind power. Wind turbine installation must account for local wind variability. The average wind speed and consistency are carefully considered before building a wind power plant. Altitude and time affect wind distribution. Wind turbines are damaged and fatigued by irregular winds with peaks and turbulence. Measure wind speed from the top to the bottom of the blades because wind weakens as it passes through obstacles or nears the ground.

E. *Recent Review of Using Optimization Approaches in the study area*

Considering the energy management system as a whole is beneficial when designing it. Since the system is comprised of various parts, it is important to take into account the constraints imposed by each of those parts. As the number of components and constraints in a system increases, complexity follows. Energy management in conventional microgrids is carried out by a centralized controller using a supervisory method of software engineering. Software with rules like "if the battery is empty, then charge it" would have a very long "If... else if...........then" control structure. In our context, the charge of the battery, which is always a prerequisite, and the total amount of power available in the microgrid system will determine this conventional understanding. Taking advantage of cheaper electricity rates during off-peak hours is made easier by the unit cost structure. This classical approach is very popular in the field of energy management; of course, if it is well designed, the microgrid's total energy price and emission rate can be optimized, allowing for good management of the power flow, i.e. ensuring system reliability and balance between consumption and production, and also having the lowest energy billing price for microgrid consumers.

1. *Single Objective Approach*

Single-objective optimization is used when there is only one criterion to meet. When this occurs, determining which solution yields the best result (minimum or maximum) is straightforward. Finding the optimal point, S, from the set of solutions (W), which maximizes the value of the objective function ($f(x)$) within the constraints, is the formal definition of solving an optimization problem. The optimization problem can be stated in its general form as follows: constraint minimization or maximization of $f(x)$, $g_i(x) = 0 \; for \; i \in I \; and \; h_j(x) \leq 0 \; for \; j \in D$. Most optimization problems have requirements that must be met in order for the solution to be considered valid. The relationships between the decision variables and the problem parameters are defined by the constraints. These limitations are typically expressed as $C_j(x1, x2, ..., xn) \leq 0$. style inequalities or equality conditions. There are two distinct classes of optimization problems—linear and non-linear—that are distinguished by the form of the objective function and the constraints involved. Based on this the various research conducted based on the optimization algorithms are shown in Table 1.

Table -1: Review of Methods

Reference	Contributions and Discussions
[15]	Utilizing a control approach that can foresee the system circumstance, we propose a robust strategy for minimizing the cost function in microgrids' Energy Management Systems.
[16]	In order to determine the cost function in a community microgrid, the authors put forward a testable method. One of the best optimization techniques they found was Particle Swarm Optimization, or (PSO). This cost function has the potential to save you up to 12% on your monthly electricity bill.
[17]	Microgrid activities multi-agent cooperation system established to comply with decentralized energy management system. Evidence suggests that the microgrid is more likely to function autonomously if the performance of all agents is aggregated.
[18]	In this work, a genetic algorithm that takes into account demand administration, reactive energy loss, and uncertainties is used to help alleviate some of the issues plaguing

	microgrids. This technique has been shown to reduce recovery costs by up to 16%.
[19]	A max-min fuzzy energy management strategy for a microgrid was proposed by the author. Their goals, which take into account the innovative homes application and Demand feedback, are to reduce operating costs, emissions, and the medium point ratio. The findings demonstrate a 16-17% decrease in operational expenditures and carbon output.
[20]	To reduce expenses in a microgrid-based energy management system, the author developed a stochastic optimization strategy.
[21]	The author presented a particle swarm optimization method for reducing Microgrid systems' operational expenses and carbon footprints.

3. CONCLUSIONS

Based on the review it can be seen that most of the studies are using optimization techniques like PSO [21], [16], Genetic Algorithm [18], Beetle Antennae Algorithm [22]. However, it can be seen that these algorithms have less convergence speed. Several factors can slow optimization convergence speed. Reasons include:

i. Exploration-Exploitation Tradeoff: Optimization algorithms must balance exploring the search space for better solutions and exploiting promising regions to refine the solution. An algorithm that explores more of the search space before refining the solution may take longer to converge. For instance, when the algorithm uses a high exploration rate or random exploration.

ii. Premature Convergence: An optimization algorithm prematurely converges to a suboptimal solution without exploring the search space. If the algorithm gets stuck in a local optimum and doesn't explore other regions for a better solution, this can happen. Early convergence slows convergence and prevents the algorithm from finding the global optimum.

iii. Algorithm Parameters: Learning rate, population size, mutation rate, and selection criteria affect convergence speed. Suboptimal parameter settings may slow convergence as the algorithm struggles to balance exploration and exploitation or adapt to the problem.

iv. Problem Complexity: Optimization problem complexity affects convergence speed. Complex problems with a large search space, many variables, or non-linear relationships may require more iterations and computational resources to converge to an optimal solution.

In an energy management system, the microgrid operator buys electricity at the lowest prices to reduce consumer costs. Consumer load demand on the microgrid must be reduced to optimize power purchase and cost. This requires a more efficient optimization algorithm. Thus, a better optimization algorithm is needed to improve the energy management system and reduce consumers' electricity procurement costs. This algorithm should quickly converge to an optimal solution, allowing the microgrid operator to make cost-effective load management and power purchase decisions.

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