Sigma J Eng Nat Sci, Vol. 44, No. 3, pp. 2286–2312, June, 2026

Sigma Journal of Engineering and Natural Sciences
Web page info: https://sigma.yildiz.edu.tr
DOI: 10.14744/sigma.2026.2095

Research Article

An assessment of executive strategies for energy management and electric vehicle operations

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ARTICLE INFO

Article history
Received: 26 December 2024
Revised: 27 February 2025
Accepted: 13 April 2025

Keywords:
Demand Response; Demand Side Management (DSM); Distribution Network; Electric Vehicles (EVs); Energy Management; Energy Storage; Energy Storage Systems (ESS); Grid to Vehicle (G2V); Micro-grid; Optimization; Photovoltaic (PV); Renewable Energy, Vehicle to Grid (V2G)

ABSTRACT

This study addresses the critical challenge of efficiently and cost-effectively managing energy in microgrids with high renewable energy penetration. It employs a robust energy management system framework that utilizes advanced forecasting models and incorporates robust optimization techniques to account for the uncertainty in renewable generation and load demand. Key strategies include demand-side management, energy storage optimization, and real-time power flow control. The integration of electric vehicles with vehicle-to-grid capabilities further enhances system flexibility and cost savings. The findings suggest that robust optimization and coordinated control can effectively mitigate the challenges posed by renewable intermittency, ensuring reliable grid operation while minimizing costs and maximizing renewable utilization. The comprehensive approach, integrating advanced forecasting, real-time control, and the flexibility of EVs and energy storage, provides a practical solution for increasing renewable energy adoption in microgrids.

Cite this article as: Kumar M, Sharma D. An assessment of executive strategies for energy management and electric vehicle operations. Sigma J Eng Nat Sci 2026;44(3):2286–2312.

INTRODUCTION

The current power grid paradigm is that energy only flows unidirectionally from central generator to end users. But distributed energy sources like wind, solar, batteries, and turbines have brought about bidirectional energy streams, disassociating from using sources based on oil [1-3]. However, these developments have helped local power dependability and transmission of the energy long distance. Within distinct electrical boundaries, micro-grids can be powered by adequate distributed energy assets. Renewables will supply 40% of the global energy consumption growth by 2040 that is expected to rise by more than 25%. This challenge is made all the harder as renewable energy sources are not equally rated over time due to a discrepancy between energy supply and demand [4] As such, there has been extensive research on renewable power, distributed generation, energy storage and micro grids. Smart Grid technologies are meant to enable more effective and real time monitoring, performance, resilience, flexibility, security, economics and performance [5]. The motivation

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This paper was recommended for publication in revised form by Editor-in-Chief Ahmet Selim Dalkilic

Published by Yıldız Technical University Press, İstanbul, Turkey

behind the development of smart grid technologies that facilitate greater integration of renewable energy sources has been due to sustainable energy goals [6,7]. In this intelligent and self-governing and distributed microgrid framework backed with renewable sources, energy storage systems act as a key component to compensate for renewable generation intermittency [8]. Hybrid energy systems are widely employed to power telecommunication devices, autonomous systems, homes, and farms without grid link [9]. Typically, hybrid energy systems exhibit better reliability and lower in cost when compared to single energy systems [10].

Efforts are underway to improve industrial energy efficiency, to achieve energy savings, reduce greenhouse gas emissions, and increase the productivity [11-13]. Despite the high potential of industrial energy efficiency observed in research [14,15], its uptake is difficult. Specific limitations have hampered the widespread application of energy efficiency solutions; thus, several studies have been carried out at different levels, whether local, regional, national, international, or combinations thereof, to better understand the reasons for industry's lack of adoption of energy efficiency measures. [16,17] Quite a number of studies have identified factors influencing the adoption of energy-efficient innovations. It has been highlighted that technological progress and equipment are important, but there has been a gap in the energy efficiency.[18] Additionally, societal factors have been considered.

1 Micro grains have made its entry in the market with the growing deployment of renewable energy and decentralized power systems.
2 In effect, micro grids face problems in balancing energy supply, demand as well as grid reliability and stability.
3 To overcome these challenges, advanced energy management strategies and control systems based on optimization methods, forecasting models, and bidirectional energy flow among grid, distributed resources and electric vehicles need to be described.

As the literature is rich with theoretical or conceptual investigations of energy management and energy services, less concern has been paid to the empirical studies of energy management techniques.[19,20] However, there is a lot of academic research in the characterization of energy management systems in different scales such as local, regional and international level.[18]. Energy management practices and energy services are considered as having great power in terms of explaining their lack, while there is a dearth of efforts in explaining them, which include the development of evaluation models for the guidance of its think tanks in industrial practices on particular measures to improve the energy management. The first principal contribution of the study was the idea of the "extended energy efficiency gap" caused by technical and administrative difficulties. In spite of energy services' potential to offer a market driven solution to improve energy efficiency,[21], much of the market potential (estimated to be 42–79 TWh) is not being

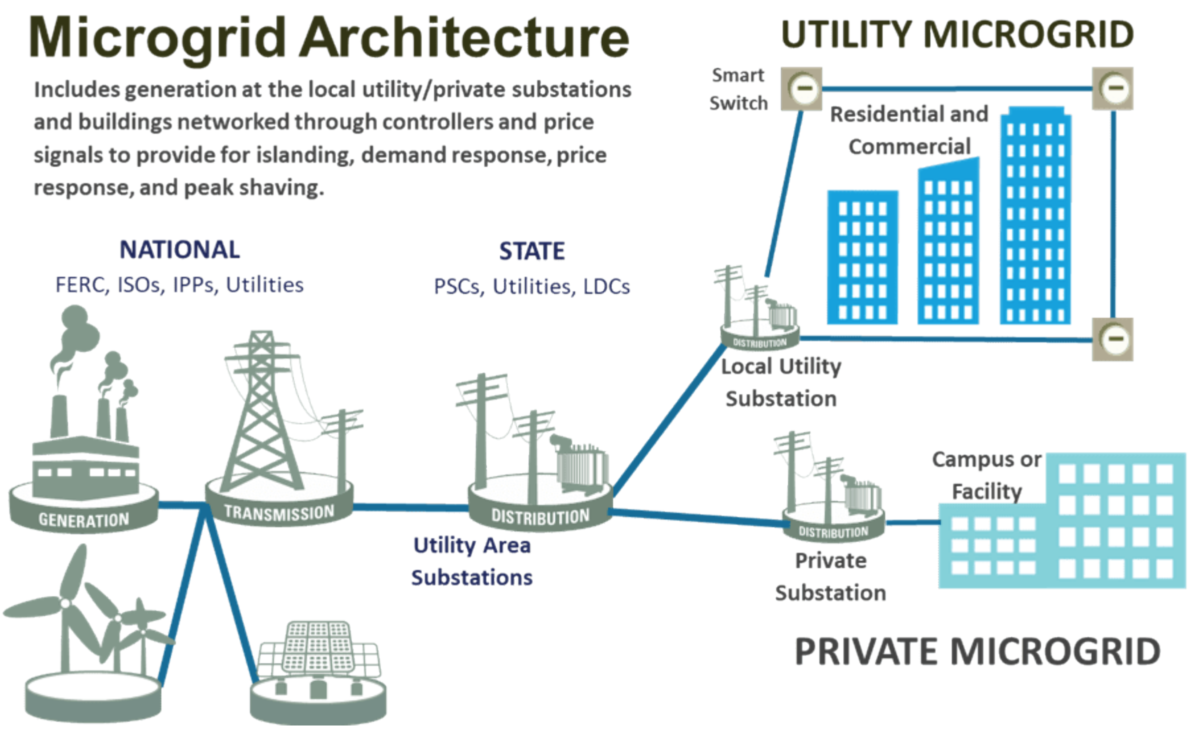

Figure 1. Energy management micro-grid architecture.

achieved due to the high operational costs associated with industrial implementation.

A microgrid is a localized power and energy grid located within an island or connecting to the next grid (grid connected mode), integrating distributed energy resources (DERs, loads and energy storage), and it can be considered an AC or a DC or a hybrid voltage grid as shown in Fig. 1. Increasing uptake of electric vehicles has become a topic of interest in distribution grids that customers are served from a medium voltage transformer. The impact and proposal of implementation improvement approaches has been proposed by researchers as a viable way to measure how much load shifting is involved. Seasons, climate and geographic location are a few of the factors used to categorize load profiles [22-24]. Aggregators or the Vehicle to Grid application differs that enables EVs to participate in the wholesale power market while their charging and discharging synchronizes with the grid. V2G can participate as a grid balancing service and demand side management. Increased profits for EV owners are possible. But regulations and rules are still needed to facilitate EV adoption. For each scenario, the EV charging load would be different and the unique optimal designs are required [22,25]. Another factor rising with this is the emergence of renewable energy sources, which disrupts the process or rather increases the scope of the optimal strategy. They are inherently variable sources, and the contribution diminishes with the sharp increase of the load curve in the power demand [26]. Power fluctuations are mitigated by injecting and absorbing power through battery energy storage systems that affect the form of the load duration curves.

The following are the contributions made by this paper:

1 To illustrate micro grid, the review offers a concise review of its design as classified on various categorization basis as well as the key components.
2 In this paper, a survey on the energy management systems research has been given for a comprehensive review on recent research using classical, intelligent algorithm and heuristic method. In the article, I discuss the specific tactics which were implemented in each of these methodological frameworks.
3 Energy management applications like minimum requirements, maturity models and frameworks are noted in the paper as tools for describing the energy efficiency range.
4 This paper highlights the on-going research on energy management and its related aspects, which is still at the early stages of development.

This paper is structured as follows: Section 2 gives how to design micro grids and the components. In Section 3, we give a systematic review regarding the energy management systems and strategies. Section 4 discusses applications for energy management applications where energy efficiency gap and energy service gap are considered. In the end, Section 5 concludes the paper and offers some direction in future research. Table 1 also studies methods for energy management systems in standalone hybrid micro grids considering battery degradation.

Monitoring, controlling and optimizing the operating cost of different appliances and equipment's of any workspace is an important palliative that can be handled through the use of energy management systems. They present some versatile ways to address the needs of the various stakeholders. More and more, a solar photovoltaic system is becoming viable as the constantly dropping prices make it possible to recoup the investment from the first year. Such

Table 1. Methods of energy management system

[27]	The authors performed a comparative analysis of micro-grid energy management system decision-making methodologies. These approaches were chosen for optimal micro-grid operation based on their appropriateness, practicability, and tractability.
[28]	The integration of energy management, demand response, and storage systems is being researched. The scientists used more realistic storage models that took into account critical aspects, including temperature charge and discharge rate de-rating and aging.
[29]	The authors conducted research into energy management methods and methodologies in renewable hybrid energy systems that are both stand-alone as well as grid-connected.
[30]	The authors led a careful assessment of the energy of the executives' methodologies in miniature frameworks. Energy the executive's frameworks (EMS) for ongoing power trade and short-as well as long-haul energy the board are being investigated.
[31]	The authors told the best way to settle energy the executives' hardships in miniature matrices before, as well as improvement approaches and apparatuses. Different methodologies incorporate heuristics, specialist-based, Model Predictive Control (MPC), transformative calculations, and others.
[32]	The author presents an outline of the most recent study breakthroughs in micro-grid planning and planning approaches employing optimization algorithms.
[33]	The authors gave an overview of today's hybrid micro-grids, as well as optimization approaches and applications.
[34]	The authors exhibited how to streamline dispersed energy into miniature lattices in both network-associated and solitary modes exhaustively.

an investment can reliably supply an income stream during the lifetime of the installation [1-3] as well as reducing carbon footprint and reliance on fossil fuels.

Energy Storage Systems (ESS)

Utilizing energy storage systems as the principal role in a micro grid, they are utilized as storage of energy produced during off peak periods to balance and manage energy at periods when generation is unable to provide the level of demand, such as periods of high consumption. However, there still are various obstacles to be surmounted, the first critical ones being the coordination of the charging and discharging, the ensuring against safety, reliability, proper size, life-cycle, cost, and the control and administration of charging and discharging [35]. The key energy storage system technologies will be illustrated in the following section:

1 As a component part, a rechargeable energy storage device consists of a cathode, anode, electrolyte and a separator in lithium-ion batteries. Together these elements act to employ the extra energy. Commercial lithium-ion battery technology has advanced because of the increasing demand for energy storage solutions in order to improve energy density, increase safety, decrease costs, and extend lifespan [36].
2 An electrochemical process is used to convert chemical energy to electrical energy in a fuel cell, i.e., an energy storage device. High power density, high efficiency, and low emissions as well as low operating temperature make the polymer electrolyte membrane fuel cell (the most common type) an ever-increasing popular choice [37].
3 In other words, flow batteries involve using an electrochemical process to create electricity. They consist of liquid electrolytes that are cycled across a cell to cause reduction or oxidation reactions at the electrode interface. As such, redox flow batteries are characterized as energy storage systems with large capacity to storing power, which makes them more attractive than conventional battery technologies [38].
4 Accumulation of energy in compressed air form during periods of low demand and then its release for driving a generator to produce electricity: Compressed air energy storage [39].
5 Kinetic energy is stored in a high-speed rotor because they use a vacuum to sustain rotation of the rotor. The accumulated kinetic energy that it can have then can be used to drive a motor generator and produce electricity [40].

Micro-grid network Energy Storage Systems can also be categorized into three configurations based on location and storage technology:

1 In case of aggregation, all Energy Storage Systems are located at a single entity – energy storage system – within the microgrid network, making the model less complicated.
2 Distributed: Energy Storage Systems are formed near multiple locations within the defined micro grid network.
3 Diverse: For instance, no single Energy Storage System technology can satisfy all the required capabilities [41], therefore it is Hybrid.

Energy Storage System (ESS) Role and Objectives of Micro-grid

Generally, Energy Storage Systems provide a variety of vital roles and functions; in particular, within a specific micro grid network. Essential power electronic converters such as these are commonly used in conjunction with them to promote reliable autonomous operation and to facilitate power distribution. Below are the following [42] classifications with which to explain these positive roles.

1 Energy storage system power support to the micro grid network to maintain a given voltage range or set voltage level. Other means are possible to levigate reactive power distribution on the energy storage systems in function of the real power it generates.[4].
2 Energy storage systems will contribute to the grid frequency regulation by delivering power to eliminate energy unbalance between the generator and load; it can occur suddenly due to the reason of Power/energy fluctuations.[5].
3 Energy Storage Systems enable dampening of oscillations as a result of unforeseen occurrences that trigger instabilities in micro grids.[6].
4 Energy Storage System can be used in peak load management as a way to fulfil peak demand or shortfalls in generating when surplus generation is available or off peak is present. Distributed energy storage systems can be used for meeting short term needs without having to add any additional generation capacity. As discussed, this helps facilitate improved integration of and utilization of distributed renewable energies, including solar photovoltaic and wind turbine sources [7].
5 In islanding, Energy Storage System can operate reversely to contribute to supporting the micro-grid network, providing backup power [7].
6 Energy Storage Systems improve the power quality and reduce the problems like handling of voltage regulation, frequency stability, noise reduction, voltage balancing etc. [5].
7 The microgrid system increases its reliability by utilizing the energy storage systems during the high customer demand. Energy Storage Systems and the corresponding stakeholders collaborate to minimize the implementation and effectiveness of these systems in meeting the fluctuating patron electrical needs [8].
8 Energy Storage Systems offer critical energy to help system reliability during a disturbance or voltage drop. It lets electric equipment keep in use though it is disrupted [3].

9 The Energy Storage Systems partnership allows for the compensation of unbalanced loads by means of individual power injection and absorption [9].

MICRO-GRID OPTIMIZATION TECHNIQUES

The term micro grid refers to a localized energy system which are also referred as distributed energy resource in itself and can produce and distribute the electricity across multiple assets called distributed energy resources. Commonly, the system in charge of these distributed energy resources, whether renewable or not, is called a mini power grid. In particular, micro-grids can exist independently from the main grid, being able to sustain themselves, something that is useful in remote areas where energy needs are high. They can instead be connected to the grid as in the case of healthcare facilities requiring constant electricity. An advanced automated system is used for micro grid energy management having the main objective of optimal resource scheduling. [31-33]. It is constructed using state-of-the-art IT and makes it easier to handle dispersed energy resources and storage systems [34].

Micro-grid Components

A micro grid is a small or medium sized power distribution system based on the intelligent premise to meet the fluctuation on energy demand and supply, and guarantee security, autonomy, reliability and flexibility. Decentralized energy systems that can operate independently of the main grid include, for example, energy storage units, power conversion devices, photovoltaic systems, wind turbines, microturbines, etc., or other renewable energy sources. In some of the large-scale applications, the growing integration of the distributed generation could pose some challenges to power system reliability. Micro grids are one of the proposed mitigation approaches to this risk [43,44]. A microgrid is a small system gathering dispersed vitality sources, intermittent creation limit, correspondence foundations, protection elements and controls components to give dependable power supply to unwavering clients [45].

Generations of Distribution (DGs)

Centralized power generation from techniques of traditional electricity generation, such as coal fired power stations, hydropower plants, wind farms, and large scale nuclear and solar power facilities is conducted to transmit power across large distances. In contrast to this, small scale energy resources can be exploited as a source of decentralized energy generation for end users [46,47]. Besides conventional power sources, the implementation of decentralized power generation reduces losses in the transmission and associated expenses. For the most part, these generation units are used to meet peak demand in capacities of 1 kW to several hundred megawatts. Diesel generators, photovoltaic panels, small scale hydropower plants, wind turbines and other distributed generation assets make up the renewable and non-renewable generation sources [48]. Heat and power technology combines heat and power production from reciprocating engines, gas powered engines, and microturbines which can operate on biogas, hydrogen and natural gas. The CHP systems store surplus energy so as to use in optimal performance with over 80% efficiency, much higher than the about 35% efficiency from centralized power generation facilities. Table 2 presents the characteristics of source for dispersed generation.

Energy Storage Systems (ESS)

Microgrid energy management uses energy storage systems that convert electrical energy to storable forms such as chemicals or heat and later reconstruct the energy to power as required. The mechanical, electrochemical, chemical and electrical energy storage categories are the main ones. The storage units provided here are crucial components for balancing the problems of supply and demand caused by the volatile sourced from the distributed generation in the microgrid system. Yet, as disclosed in [49], a microgrid system with a few small, distributed energy sources can be built wherein a combination of advanced control mechanisms are applied to ensure Island mode operation with balance of the intermittent generation assets. Energy storage components such as batteries, flywheels and supercapacitors are used in smaller micro grid systems to be used as a means of providing a reliable power supply. At present time, some energy storage options are less cost effective and more environment harmful than others. Another alternative method involves storing the fuel in power modules, that convert the fuel into electricity by chemical process. These power modules function best by consuming oxygen and hydrogen. These power modules can be powered by propane, natural gas, methanol, biogas and hydrogen, and

Table 2. Characteristics of sources for dispersed generation

Characteristics	CHP	Diesel	Micro-Hydro	Solar	Wind
Availability Location	Source-based	Anywhere	Location- Based	Location- Based	Location- Based
Flow Control	AVR and Governor	Controlled	Controlled	MPPT/DC Voltage	MPPT/Torque and Pitch
Carbon emission	Source-based	High	Nil	Nil	Nil
Interface	Generator	Generator	IG/SG	Converter	Converter IG/SG
Output	AC	AC	AC	DC	AC

hydrogen is becoming so popular as it is safe and clean running [50].

Loads and Their Classification

By applying statistical data of feeder usage in distribution system, researchers found various types of loads like agricultural, government, residential, commercial, and industrial load. There are two main approaches used to develop the load model, the measurement based and the component based. The second is a measurement-based technique where load model structure is constructed based on smart meter (or other such measurement device) data. The data should be collected for load characteristics with the effects of environmental factors in mind. First, static, ZIP, and other load models are built using data from smart devices, and the models are approximated and validated using field data and smart error detection methods. The other approach is to aggregate the load usage of the individual components with the information provided with their specification or rating. A required item for this methodology is three datasets.

1. Individual part-load models.
2. The load utilization of each component as a rate.
3. To obtain the singular part model boundaries, Tests were utilized in order to determine the class — private, business, modern — that would bear the entire burden. In Figure 2, it is demonstrated that different burden bunches have various requirement for conspicuous confirmation and control.

Smart load refers to receiving sensor control of such energy integrated loads and getting the real time energy usage data. Using the capabilities of appliances, these smart loads make it possible for smart homes to have real time energy management. This enables customers to use and control energy in innovative ways and adjust patterns of energy consumption to their daily routines [51]

Merger of Electric Vehicles

This resulted in the switch from traditional fossil fuel powered transportation to an emerging profile of electric vehicles in order to address the escalating environmental pollution issues worldwide. Electric vehicles have energy and environmental applications like vehicle-to-grid and vehicle-to-vehicle power integration in excellent potential [52,53]. As depicted in Figure 2 to charge electric vehicles they are connected to power grid. Because electric vehicles can reduce the overall transportation cost and therefore reduce the load of the transportation infrastructure during electricity price peaks, they contribute to the lowering of electric utility cost in energy markets. This is accomplished by means of the VEHICLE TO GRID, in which electric vehicle supplies power to close entities in an attempt to meet the load during peak times. Additionally, electric vehicles are able to accommodate some intermittent power that cannot be directly controlled while communicating with the energy system to use power or adjust the charging rate [54]. VEHICLE TO GRID integration can be facilitated by electric vehicles (both battery electric vehicle and plug-in hybrid electric vehicles). In the absence of versions, the framework facilitates charging of the EV batteries or operating other devices with the batteries. The capabilities of the MICROGRID system are expected to increase as the adoption of electric vehicles escalates. As a result this

Figure 2. Electric vehicle interface.

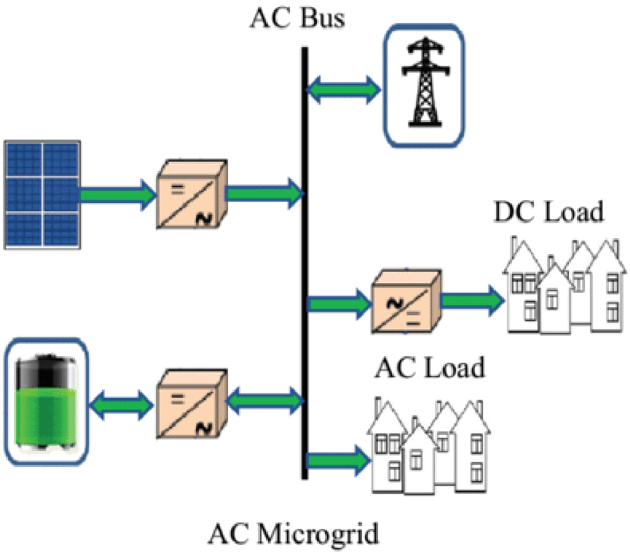

Figure 3. Structure of an AC micro-grid.

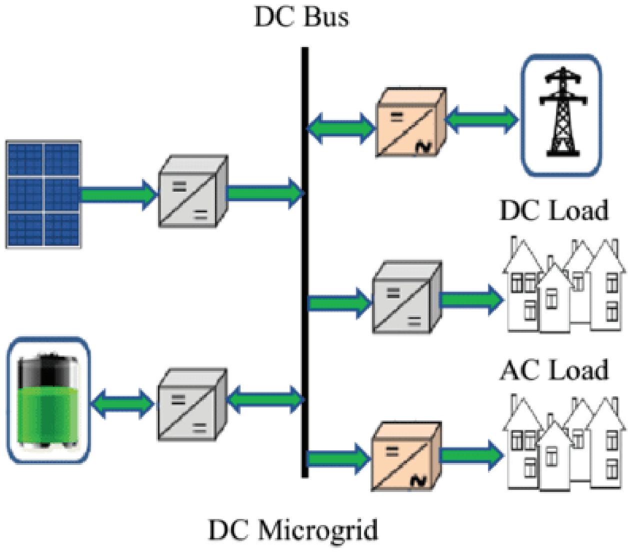

Figure 4. Structure of DC micro-grid.

had improved the overall performance of the system with respect to its reliability and stability.

Classifications of Micro-Grids

The STS connects a microgrid to the main grid at the Point of Common Coupling, where the power system manages frequency and voltage stability. When the main power grid is disrupted or fails, the MICROGRID transitions to an islanded state, disconnecting itself to maintain system security. Power electronic converters are used to interface renewable power sources, such as solar, wind, and hydro, to provide high-quality power output. These converters offer a reliable, resilient, flexible, and effective power source [55]. MICROGRIDs are typically classified into three types based on the type of power they generate - AC microgrids, DC microgrids, and hybrid AC-DC microgrids. The AC microgrid is a common example of variable voltage level transmission using transformers. Distributed energy resources connected to the AC bus are used to connect all distributed energy assets, whether they have DC or AC sources, to AC loads [56,57]. Most power system loads run on AC, and AC microgrids are the most widespread type [58]. The construction of an AC miniature framework is portrayed in Figure 3.

In a DC microgrid, a DC bus interconnects both AC and DC sources, with the power output consumed by the loads. The rationale behind the DC supply concept is to limit the number of required power electronic converters, as DC sources are more readily available than AC sources. This approach also eliminates the potential for harmonics introduced by power electronic converters, as they are absent from the DC supply. The DC microgrid was developed in response to the increasing popularity of DC-powered devices, such as cell phones, computers, and household appliances, particularly in remote locations. A typical DC micro-grid structure is shown in Figure 4.

To properly integrate both DC and AC sources for consumers into a grid system, a DC/AC hybrid microgrid has been developed. The AC and DC sources are connected to their own transmission lines, and the outputs are distributed to the appropriate consumers. The goal of a DC/AC hybrid microgrid is to leverage power from both DC and AC sources simultaneously, reducing overall power usage. The power electronic converters at both buses enable bi-directional power exchange between the generating end and the load, facilitating this integration. A hybrid micro-grid is depicted in Figure 5.

As we can see in Fig5. Microgrid can operate on both AC and DC, so with the help of that in Table 3 we analyze some research and compare their strength and weakness

Micro-grid Control Structure

A microgrid must manage numerous variables and constraints because it is a small-scale electricity distribution network. An energy management system plans, monitors, and manages the supply-demand balance, ensuring reliable, cost-effective, and efficient operation as shown in Figure 6. A control structure is necessary to manage the variables, as a microgrid must address a range of technical, economic, temporal, and infrastructural factors. One widely used and standardized microgrid control structure is the hierarchical control system.

The three layers of the hierarchical control system have distinct working times, data inputs, and control equipment. Hierarchical control techniques involve multiple levels:

1 The primary level is responsible for controlling the DER units.

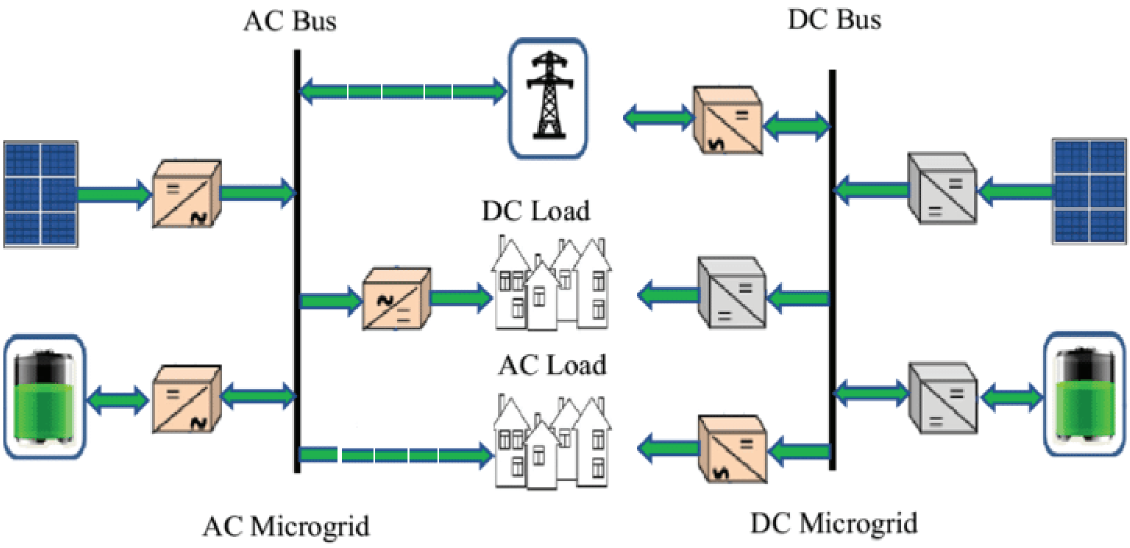

Figure 5. Structure of an AC-DC hybrid micro-grid.

Table 3. AC/DC Project and their characteristic

Project	Strength	Weakness
[59] DC	· Decentralization. · An impedance mismatch has been maintained.	· The SOC balance is not taken into account. · Due to initial current surges that can't be avoided, a rapid procedure is not possible.
[60] AC	· AC · The transient response has improved. · It works well to split a non-linear load. · No frequency or voltage amplitude variations with optimized active/reactive power sharing.	· Due to initial current surges that can't be avoided, a rapid procedure is not possible.
[61] DC	· SOC is balanced. · Decentralization. · An AC micro-grid extension is possible.	· Transmission line impedance mismatch should be considered while installing an AC system. · The SOC type's aversion to various elements (power rating, greatest DC voltage deviation, and exactness of force sharing)
[62] AC	· State of Charge (SOC) balancing has been achieved. · Control and communication infrastructure costs are reduced. · Control with fault tolerance. · Communication and control with less data	· In terms of reducing energy loss, there is no improvement over alternative solutions.
[63] DC	· In the case of load changes, improved current sharing. · It compensates for DC voltage variations.	· A slight current fluctuation already exists.
[64] AC	· Different functioning states are generic. · Decentralization. · SOC balance (considered for determining droop coefficients).	· There is a current dip in bus voltage, but it is within acceptable limits.
[65] DC	· System stability and speed were accomplished. · SOC is balanced. · Disconnection of Battery energy storage system, systems (BESS) due to less State of Charge (less than 10%).	· CPLs are Continuous Power Load (load change has not been thought of).
[66] DC	· is a fuzzy control approach that may achieve several control goals. · Voltage deviation is reduced. · For different Rd values, the same controller can be used (virtual resistance loop). · SOC is well balanced (faster than a set virtual resistance method). · Decentralization.	· A slight voltage variance exists, but it is within acceptable limits.

Table 3. AC/DC Project and their characteristic (continued)

Project	Strength	Weakness
[67] DC	· With good SOC balance and self-control (depending on local parameters). · Expandable and modular. · Decentralization. · Multi-objective management. · Charge faster.	· Prioritization of State Of Charge (SOC) balancing over voltage deviation regulation. · A slight voltage variance exists, but it is within acceptable limits.
[68] AC	· Decentralization. · SOC balance is good. · The addition of a new active generator does not call for any modifications. · The SOC is asymptotically approximated as the operation is being stored. · Faster charging than the standard approach. · Furthermore, the discharge depth is lowered. · FIS can be used in a DC micro-grid.	· A slight voltage difference exists between the batteries. · SOC balance is good but not perfect (there is still some unbalance).
[69] AC	· Excellent frequency balance. · The battery's SOC balance has improved. · Battery life is increased.	· The SOC of the battery fluctuates slightly. · There is no regard for bus voltage.
[70] DC	· Decentralization. · The voltage deviation is eliminated. · Restoration of bus voltage. · SOC recovery, super capacitor · The ability to share transitory power without regard to voltage or SOC	· When the load fluctuates, there is still a high snap of super capacitor current.
[71] DC	· Power balance is quick. · System performance was maintained in a variety of dynamic circumstances.	· The influence of temperature is ignored.
[72] AC	· An accurate load distribution that is imbalanced · A balanced output voltage is present. Power is being used.	· When the load fluctuates, there is already a voltage variation and an unbalance (compensate in 2 s).
[73] AC	· THD compensation was accessible. · There has been no extra equipment installed. · Control structure with less complexity. · Tuning is done quickly.	· There is no difference in results from earlier tactics. The same goals were achieved, but with a simpler control framework.
[74] AC	· Control DG in accordance with State of Charge (SOC) and Energy Storage System (ESS) limits (avoid over-current). · State Of Charge (SOC) balancing capability. · Excellent robustness and rapid transient.	· This is only for AC Micro-grid. · There was a cost associated with communicating.
[75] AC	· Power fluctuations have no effect on the SOC. · The frequency was maintained at a nominal level and was not impacted by power fluctuations.	· When changing control mode, BESS communication fails. · Due to the periodic fluctuation in the output power of DGs, it is difficult to recognize their contribution.
[76] DC	· The ability to control numerous charged batteries. · The batteries' state of charge (SOC) is balanced.	· The State of Charge (SOC) balance was not without volatility and instability.
[77] DC	· All batteries have a balanced SOC. · The complete charge and release force of the batteries was adequate for the ideal activity.	· It's unclear whether a circulating current existed during SOC convergence (The result indicates that some batteries discharge while others charge during discharge convergence.).
[78] AC	· State Of Charge (SOC) is balanced. · Droop control has been established in a new way.	· The lifespan and protection of the battery are unknown.
[79] AC	· Instead of using their rated capacity, multiple resources' power sharing is balanced according to their real power and energy output. · Using fuel as little as possible. · Power-sharing of installed sources was performed no matter what the heap.	· Under load fluctuations, fuel efficiency degrades.

Table 3. AC/DC Project and their characteristic (continued)

Project	Strength	Weakness
[80] DC	· The SOC is balanced within the required values. · The current from the battery has been routed to the specified limitations. · This hook works wonders for powering set points. · Performance surpasses that of the wind case method.	· Battery capacity (30–100%) is only partially exploited.
[81] AC	· It also has the ability to handle solar forecasting inaccuracies of up to 60% without having an impact on dispatch policies. · Performance improvement versus simple control (delta-balance). · Simple to implement, active, and less complicated computing. · Other electrical markets have been adapted.	· Re-evaluation of thresholds and HESS is required.
[82] AC	· Hierarchical control based on optimized power management. · Loads and sources can be plugged in and played with.	· Frequency variations are present up until the frequency reaches 50 Hz. · Until 311 V is attained, voltage variations continue.
[83] DC	· There are greater annual cost reductions when compared to standalone PHOTO-VOLTAIC (PV) and energy storage systems (ESS) with a rule-based controller. · For one day, the consolidated feed of 30 clients can be smoothed. Evening requests diminished by 20% compared with the standard-based strategy. · When compared to rule-based control, more battery life is preserved. · In all operating scenarios, the bigger the annual savings,	· There can be only one Energy Storage system (ESS) and one PHOTO-VOLTAIC (PV).
[84] AC	· The convergence has been guaranteed. · In comparison to other methodologies, effective computation · Linear and nonlinear solvers are used to provide solutions. · The AC SOC-OPF design is recoverable.	· Convergence concerns are expected. · The approximation is inaccurate.
[85] AC/DC	· The voltage stays stable in both islanded and network-associated modes. · Reactive power is used efficiently to protect main grids from voltage fluctuations. · The power distribution is balanced. · The charge or discharge balance is correct.	· When switching from autonomous to grid-connected, there was a current overshoot
[86] AC	· In comparison to other existing tactics, the operation is more cost-effective. · An acceptable restriction was used to provide a favorable balance between peak demand and consumers.	· Heat recovery is not taken into account. ere was no demonstration of using reactive power.
[87] AC	· Enhanced operational planning (because of price variation with time). · ESS's contribution to dispatch able generation · The cost function has been minimized by MPC.	· MPC simplifies the formulation process.
[88] AC	· Without the addition of a new objective function, economic dispatch was achieved. · An efficient operation with high probability and day-ahead scheduling.	· Due to the limited discharge depth of batteries, they only discharge for a few hours at night. · The cost of electricity has not been addressed.

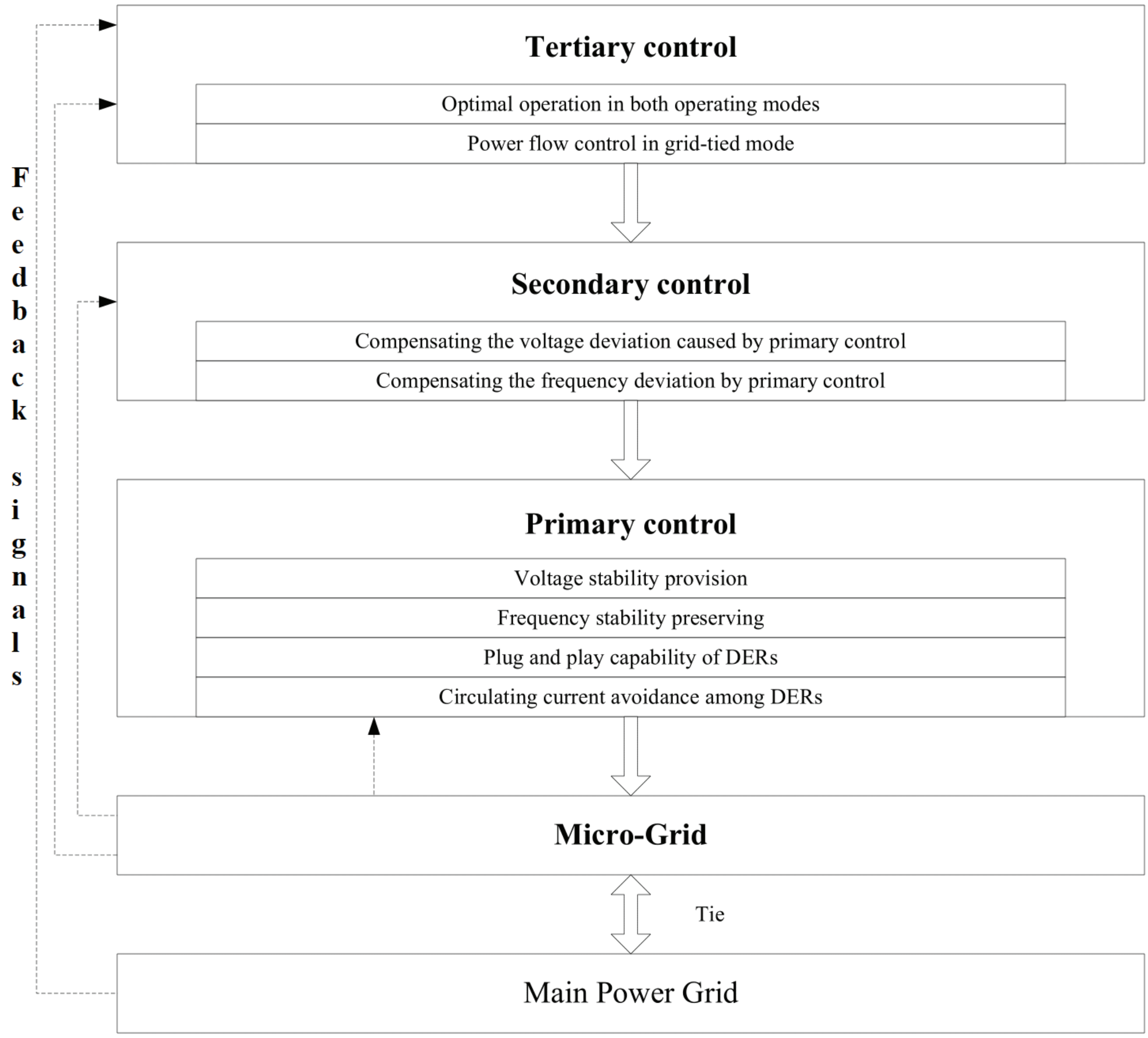

Figure 6. Flowchart for controlling MICROGRID (MG).

2 The secondary level, working in conjunction with the primary level, modifies the system's voltage and frequency.
3 The tertiary level covers various controls, such as requesting supply from the grid, managing energy storage, coordinating renewable power sources, controlling power flow, optimizing parameters, and establishing control strategies.

The energy management system is another term for the tertiary level.

An illustration of the various levels of control of a MICROGRID (MG) is displayed in Figure 6.

RESULTS AND DISCUSSION

Definition of Energy Management

Energy management is the process of monitoring and adjusting energy usage to reduce energy consumption in a facility. The energy management process involves several key steps:

1 Ongoing data collection and analysis.
2 Exploring ways to streamline equipment schedules, set points, and flow rates to decrease energy use.
3 Calculating the return on investment. Just as energy usage can be measured and calculated, so too can the energy savings.
4 Implementing energy-saving measures.
5 Repeating step 2 to continually reduce energy use.

MICs have specialized energy management systems that perform the following functions:

1 Monitoring and controlling the operation of distributed energy resources and distributed generation units, such as photovoltaic panels, wind turbines, and energy storage systems.
2 Coordinating the dispatch of DERs to meet load demand efficiently and economically.

3 Optimizing the operational parameters of the microgrid to achieve a balance between technical, economic, and environmental objectives.
4 Enabling the microgrid to operate in both grid-connected and islanded modes.

Energy management has been the focus of extensive research studies that explore various aspects to define the concept of energy management. This is particularly pertinent when it comes to the critical juncture where energy management modeling or the application of energy system practices becomes crucial. [18] The main facets of energy management that have been extensively studied are energy consumption, strategic considerations, managerial perspective engagement, and people relevance. According to the German Federal Environment Agency, energy management involves the combination of planned and executed measures to ensure preset performance with minimal energy input. B.L. Capehart defines energy management as the skillful and efficient use of energy to maximize profits and strengthen reasonable positions. O'Callaghan et al. describe energy management as the utilization of resources regarding supply, conversion, and use, which includes monitoring, measurement, documentation, critical assessment and analysis, control, and rerouting of material flows through the systems to ensure minimal energy use and achieve significant objectives. Schulze et al. have put together a thorough definition of energy management that takes into account all essential energy management components and industry energy management techniques [89]. Bunse et al. focused on the integration of control, monitoring, and improvement activities for energy efficiency in their analysis of energy management. Then again, Ates et al. stressed the mix of techniques, assignments, and authoritative methodology that lowers energy costs and anthropogenic discharges [90]. Abdelaziz et al. boosted energy management in one of their investigations by using a technique that maximizes energy consumption while also raising energy demand [91]. In academic writing, energy management is described as a comprehensive process that combines applying resources, energy conversion, and energy application [13,16,18,89]. The framework involves evaluating, recording, assessing, and, most fundamentally, dealing with the energy streams to ensure the least conceivable energy utilization while accomplishing the greatest conceivable energy efficiency [13,92]. Scholastics stand out enough to be noticed for a portion of the essentials for the reception and activity of energy the board in ventures [19,90-94]. Table 4 gives an outline of the requests for energy from the executives with whether the necessities are considered in full, to some degree, or not by any stretch of the imagination.

An assessment of the minimum requirements for energy management in Table 4 reveals that the lists of critical prerequisites detailed in the studies varied in both the number of elements and the state of the individual components. Additionally, it suggests a lack of clarity regarding the comprehensiveness of the essential requirements list in fully depicting established energy management. Past research on the topic makes it evident that a comprehensive conceptual framework for energy management is lacking. Due to this research gap, we reviewed academic journal articles on industrial energy management in this work and used the findings to suggest additional research areas. At its core, microgrid energy management must maintain a balance between generation and demand. This can be expressed simply as:

Table 4. Demands for energy management according to the requirement

Minimum Prerequisite	Thollander and Ottosson [19]	Ates and Durakbasa [90]	Abdelaziz et al. [91]	McKane et al. [93]	Christo_ersen et al. [94]
Energy activities through focused duties and deeds.	×	×	✓	×	✓
long-term strategic plan, mention of energy strategy, aims for energy conservation.	✓✓	✓	✓✓	✓	✓
familiarity with the energy manager's management team	×	✓	✓✓	✓✓	×
energy audit to investigate energy-saving options.	✓✓	×	✓	×	×
Policies and proceedings	×	✓	×	✓✓	✓
Developing and implementing a clear energy-saving strategy	✓✓	✓✓	✓	✓✓	✓✓
Meter and monitoring of energy consumption	✓✓	✓	✓	×	×
Identification of key performance indicators	×	×	×	✓	×
Energy reporting	×	×	✓✓	✓	×
Participation of employees in energy management activities	✓	✓	✓	×	✓
Top management commitment	✓✓	×	×	×	×

Table 5. ISO 50001 Energy Management System standard

Phase	Remark
Do	Through the execution of activity plans, activity and upkeep controls, and correspondence, guaranteeing mastery in the energy area, explicitly energy execution in plan and acquisition.
Plan	Fostering an energy supervisory crew, consolidating an energy strategy, taking into account moves in light of dangers and potentially open doors, leading an energy survey, recognizing huge energy utilizes and laying out energy execution markers, making an energy pattern, laying out energy goals and targets, and fostering the vital move plans are steps that can be taken to further develop energy execution in accordance with the association's energy needs.
Act	Non-conformities will be addressed, and efforts to improve energy efficiency will continue.
Check	Energy performance and energy management system management reviews must be carried out, as well as monitoring, quantification, analysis, evaluation, and auditing.

$$P_{Generation} + P_{Storage\ discharge} = P_{Load} + P_{Storage\ charge} + P_{Grid\ exchange}$$

Where:

$P_{Generation}$ - is the total power generated by DERs (e.g., solar PV, wind turbines).

$P_{Storage\ discharge}$ - is the power discharged from energy storage.

P_{Load} - is the total power consumed by loads.

$P_{Storage\ charge}$ - is the power used to charge energy storage.

$P_{Grid\ exchange}$ - is the power exchanged with the main grid (positive for import, negative for export).

Energy Management Model Approaches

When evaluating energy management modeling, there are several research streams that were being studied in both academia and industry.

1 Minimum requirements
2 Maturity models
3 Energy management matrixes

Are the three streams [18]. There is also an assessment instrument known as the

4 Characterization Framework for Energy Efficiency Measures

This can be used to adapt the energy management components suitably. This is a practice-based approach; hence, it is based on specific energy management methods.

Minimum requirements

The first stream includes the ISO 50001 standard, which addresses energy management-related topics and provides guidelines for establishing an energy management system. The primary objective of the ISO 50001 Energy Management System standard is to assist businesses in becoming more energy efficient. The standard was researched and published in 2018 by ISO/TC 301: the Committee for Technical Standardization on Energy Management and Energy Conservation [95]. The protocol is divided into ten chapters with a unified architecture and hierarchical organization. The "Plan-Do-Check-Act" framework outlines the continuous improvement of organizational processes in the ISO 50001 standard. The phases covered by the ISO 50001 Energy Management System standard are summarized in Table 5. However, it does not provide a critical evaluation of how effectively a corporation has implemented a specific energy management strategy. Additionally, the first stream devotes significant effort to analyzing energy management while maintaining the analytical limits. [90,94].

Maturity model

This subsequent stream looks for a deliberate method for evaluating energy use in organizations [12], which includes investigating the means required to set up an energy administration framework [96]. One of the key components of the maturity model is the ability to continuously improve. The

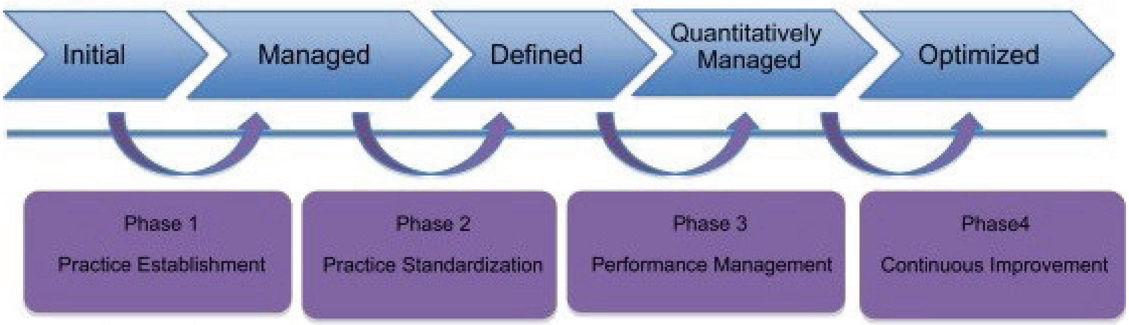

Figure 7. The levels of energy and utility management maturity models.

maturity model has gained widespread recognition and prominence in both academia and business. By assessing organizational maturity based on established standards, maturity models help organizations overcome inertia and improve quality. On the other hand, maturity models are single-layered and focus either on object maturity or process maturity, with process maturity levels dominating in the model-based approach [97,98]. The more modern phases of energy management at various action levels were recognized by Bojana et al. The levels considered in energy and utility administration development models are displayed in Figure 7.

Energy management matrixes

The third stream involves energy management matrices, which share many characteristics with maturity models. These matrices provide insights into a company's current approach to energy challenges and assist management in improving energy efficiency by incorporating feedback. Additionally, they represent the significant potential for development in energy efficiency that must be achieved through specialized efforts. The adoption of energy management matrices in a wider range of industrial organizations has revealed various initiatives focused on enhancing energy management practices. Furthermore, these matrices integrate previously dispersed technology-based efforts to boost energy efficiency into a more effective management framework. Some similarities between energy matrices and maturity models include a strong analytical approach, the interpretation of the development concept into a refinement level, and a self-examination process from the organization's perspective. However, these models do not offer additional advantages in terms of methodology, or the factors considered for reasoning. Even though crucial components have not been addressed for evaluation, the introduction of assessment models has led to the establishment of a full list of actions that are thought to be energy management techniques.

Characterization framework for energy efficiency range

Long-term reductions in electricity use occur through energy-efficient techniques built into machinery rather than relying on user behavior. The San Francisco Public Utilities Commission suggests the following steps to reduce demand:

1 Installing machinery that becomes more efficient with each use. For example, modern high-efficiency fluorescent lighting consumes 40% less energy than traditional types.
2 Dimming or turning off equipment, such as computer monitors, when not in use during peak periods.
3 Implementing systems that use energy when demand is low.

Reduced demand also includes the city's economic development goal of investing more in local investment and job creation, which helps the city, companies, and individuals save on monthly electricity costs.

Construction can mitigate its environmental impact and improve the reliability of transmission and distribution networks by deferring or delaying the development and operation of power systems, especially those using renewable energy as shown in Table 6.

Table 6. Presents a summary of the current management assessment models

Category	Reference	Model Narration	Remark
Minimum requirements	[94]	Energy policy, quantified energy-saving goals, or expectations for energy-saving projects and their execution are examples of significant qualities. Energy-saving purchases, as well as a clear distribution of energy responsibilities and activities. Attempting to influence, inform, and educate stakeholders, especially employees, in order to engage them.	According to this strategy, energy management is a component of a larger management system. The emphasis is on setting and achieving energy-saving goals and projects. But the approach does not take into account the idea of an energy manager. Furthermore, top or middle management support for energy conservation is not explicitly outlined in any policy. However, it is advised that staff members get involved in energy-saving initiatives.
	[95]	The "Plan-Do-Check-Act" cycle is the foundation of directives. Some of the management risk factors to take into account are the energy review, energy execution record, pattern, targets, and energy the executives' plans, capability, preparation, and mindfulness, correspondence, chronicling, and the purchase of energy services, as well as the activity and control, checking, estimation, and investigation, consistence evaluation, and maintenance of legal requirements. Review of the executives' framework for inner energy, board evaluation, strange, restorative, protective action, and record administration.	The framework of ISO 50001 has nineteen features. The model is also favored by management commitment and energy managers. Furthermore, the framework incorporates employee participation as well as documentation and records for later evaluation.
	[90]	The creation of a dedicated energy manager in the industry, the addition of metering of key actions to the very minimum criteria from (27)'s list.	Christoffersen et al[44] model has been expanded in this model. The model incorporates energy metering, energy management, energy policy, energy objectives, and energy-focused saving projects.

Table 6. Presents a summary of the current management assessment models (continued)

Category	Reference	Model Narration	Remark
Maturity Models	[99]	There are five stages - preliminary, arrange, delineate, quantify, and reform. Novel process channels are regulated toward progress with an emphasis on the environment, The four maturity phases include practice implementation, practice standardization, performance management, and a repeating improvement phase.	The model applied the Capability Maturity Model Integration (CMMI) structure to the area of environmental management. It was made up of certain energy and resource management procedures. There is no defined policy for a dedicated energy manager.
	[105]	Tips for improving energy efficiency and following energy management standards, especially ISO 50001. Using the PDCA cycle, energy management actions are divided into five maturity phases.	The PDCA cycle-based framework is adaptable to various energy management strategies. For instance, the framework includes senior management support. Roles in energy management are described. There is no substantial evidence, though, that an energy manager will be involved.
	[106]	The five stages include emerging, defining, integrating, optimization, and uniqueness. In addition, there are four parts based on the PDCA cycle there are 16 pillars and 63 sub-pillars. To assess maturity, the model provides five attributions for each sub-pillar.	An action plan and an energy management evaluation are included in the framework. There is also a feature for increasing competency.
	[12]	The primary ISO 50001 features for regulating energy consumption. The five phases are: initial, intermittent, planned, supervisory, and ideal. Success is cited as requiring the following 5 factors: strategy alignment, institutional design, energy performance management, archiving system, consciousness, information, expertise (most critical), and methodological proposal.	With the addition of the energy manager, the tool is not included.
	[98]	Creation of a knowledge base for self-evaluation, monitoring, and development, integration with ISO 50001. Each ISO 50001 method that Eric et al. [54] adopted has its levels displayed.	The assessment process combines the appointment of an energy manager and support from top management with other energy management strategies.
	[96]	Notable characteristics include the examination of persuasive arguments for adopting energy management as well as the contribution to a better understanding of the proper energy management configuration through maturity level assessment.	The model takes into account the energy supervision team or an energy administrator. Additionally, coordinated with top administration support are the model's features.
	[107]	They include arbitrary guidelines, a PDCA cycle-based evaluation methodology, a global energy supervisory team, a SWOT analysis tool, and external peers.	They combine their clear, directive, and almost application-explicit skills. The energy administrator's and other executives' approaches are included.
	[108]	Three criteria exist - (1) attributes of energy efficiency, (2) levels of energy efficiency maturity, and (3) methods of implementation that are familiar to SMEs and the ZED plan. Accountability, structure, and procedure, financial and legal compliance, archival system, innovation in products and processes, internal communication, and ethos. There are a total of nineteen traits.	For the model, 19 distinct energy proficiency boundaries are retained. Key requirements and energy strategy are the two categories of administrative duty.

Table 6. Presents a summary of the current management assessment models (continued)

Category	Reference	Model Narration	Remark
Energy Management Matrix	[109]	The five levels of energy in the board lattices deal with strategy, association, inspiration, data design, promoting, and supporting.	The framework for the policy segment is fully integrated with top management support. Managers of energy play a part in the hierarchy of the organization.
	[100]	Energy the board plans, associations, staff inspiration, following, overseeing, and announcing frameworks, worker mindfulness, preparation and advancement, and finance can all be evaluated using five tiers of energy in the executive's grids.	An organizational structure suggestion is linked with the energy management functionality. Additionally, this framework takes into account energy management.
	[101]	Six institutional issues—strategies or explicit rules, coordination, planning, execution assessment, correspondence, and subsidizing—are surveyed using five degrees of energy from the executive grids. Regulation and strategy, energy methodology, hierarchical design, guidelines, procurement procedure, funding plan, perception and examination of energy use, objective setting, choice recognizable proof, staff commitment and preparation, functional cycle, and interchanges are all taken into account by the evaluation model.	There were five aspects to the Carbon Trust criteria. This approach does not include the inclusion of a specialist energy manager. However, the concept includes a commitment from senior management to improve energy efficiency activities.
	[102]	selecting an energy leader, establishing an energy group, putting emphasis on executive training, data collection, benchmarking, specialist assessment, examination, and energy reviews, investigating and describing the degree, evaluating options for improvement, identifying goals, Indicate the innovation cycles, goals, positions, and asset distribution. Bringing up issues, broadening the scope, persuading, adhering to, and observing Results evaluation, internal and external recognition, and repetition of the activity plan.	The ENERGY STAR guidelines underline the importance of appointing an energy director who leads a specialized energy team. The model also aims to provide baselines for gauging energy efficiency.
EEMs Characterization framework	[103]	Consideration is given to three crucial characteristics. There are numerous subcategories for each attribute. Repayment time, upfront costs, the inward velocity of return, and non-energy benefits all have an impact on the original term, "relative benefit." The next variable, "specialized setting," is influenced by the change type, the influence of an important open door, the time interval between essential cycles, and the lifetime. The final section, "Data setup," is impacted by transaction costs, planning and execution skills, spread improvement, and field-explicit pertinence.	The framework's incorporation of non-energy advantages is one of its most important aspects. The framework lacks an energy manager.
	[104]	Payback time and application costs are included in the economic evaluation. Resource conservation and energy conservation are associated with energy. Waste minimization and emission reduction are responsible for environmental categorization. Productivity, working conditions, and operation and maintenance are all factors that influence production. Energy-saving strategies, types of actions, ease of implementation, success probability, corporate community participation, the distance between important processes, and audit regularity are all implementation-related features. Direct effects are responsible for interaction-related characterization.	Corporate commitment is one of the defining qualities that modern executives value. The importance of looking at energy productivity measures from various angles is emphasized, with the highlights being specifically coordinated to provide a deeper understanding of the key viewpoints regarding the measurements of energy productivity.

Using Predictive Control Techniques to Manage Energy

Among the various approaches available, model-based predictive control techniques have emerged as particularly promising solutions for effectively managing energy as shown in Table 7. This type of method will be the focus of the search. Additionally, energy costs and tariff sensitivity are common characteristics of the problem: A dynamic energy management system connected a residential application to a microgrid. A solar grid-connected system and a storage model were optimally designed using a demand response framework that responds to energy pricing to schedule energy flows. They employed a model predictive control strategy, and the dynamic model's performance was validated using experimental data and an intelligent metering system.

Table 7. Predictive control techniques to manage energy

Zhai et al. [110]	An anticipated robust control the suggested for a standalone MICROGRID (MG). Mixed-integer programming is used in the management paradigm. Batteries, loads, PHOTO-VOLTAIC (PV), and wind generators make up the MICROGRID (MG).
Zhang et al. [111]	Model predictive control (MPC) is a technique that has been presented for regulating a MICROGRID (MG) using distributed and renewable power. The strategy intends to reduce costs and limitations on both energy demand and generation.
Minchala Vila et al. [112]	It was suggested to use predictive control to manage energy in a standalone MICROGRID (MG). The controller balances the MICROGRID (MG) power output by centrally managing the battery energy and employing a load-elimination approach.
Ju et al. [113]'s	When designing an energy management system for a half-breed MICROGRID (MG), the depreciation costs of the energy-storing technology were taken into account. A two-layer foresight control for crossover MICROGRID (MG)s that combines batteries and super capacitors as capacity is included in the concept. In this paper, the depreciation costs of the batteries and super capacitors were presented, enabling a more precise assessment of the MICROGRID (MG)'s operating costs.
Valencia et al. [114]	It is a predictive control-based energy management technique for MICROGRID (MG)s that employs fuzzy logic to forecast intervals. This makes it possible to depict the dynamic and nonlinear behavior of renewable energy sources.
Genesan et al. [115]	For a MICROGRID (MG) to combine and manage various burdens, such as PHOTO-VOLTAIC (PV), diffused age, energy capacity, and UPS, as well as a variety of age sources from the inventory matrix, they promoted a control calculation-based energy board framework. To tackle the problem of communication between storage systems and PHOTO-VOLTAIC (PV) generators, the TCP/IP protocol is used for control and communication.
Garca Torres and Bordons [116]	Ideal writing programmers were created in a half-breed MICROGRID (MG) using a vision control model that was solved using combined whole number quadratic programming. The depreciation costs of all mixture framework components, including hydrogen-based capacity frameworks, were taken into account when combining functional costs and MICRO-GRID (MG) improvement.
Solanki et al. [117]	Clearly identifiable MICROGRID (MG)'s clever burdens and energy were modeled mathematically across the board. The use of brain organizations demonstrates loads. The forward-thinking control process provides energy to the executives by completing a perfect power dispatch while taking into account the variables and managed loads.
Oh et al. [118]	For a MICROGRID (MG) with 15-minute adds, a multi-step foresight control conspire with a 180-minute time skyline was developed. There are traditional and ecologically friendly power sources as well as basic and non-basic burdens included. The cost capacity took into account the price of fuel, the amount of load shedding, the state of the battery charge, and the decline in sustainable power.
Prodan et al. [119]	A strategy for managing a MICROGRID (MG)'s energy consumption was proposed as a deficit-minded foresight control system. One of their main benefits is the reduction in charge and discharge cycles, which lengthens the useful battery life.
Wu et al. [120]	A perfect method for operating a solar-powered hybrid system that also stores batteries was suggested. During off-peak hours, the battery stores energy, and during periods of high demand, it provides the capacity to customers. The half-breed framework's planning reduces a client's monthly bill and network power consumption.
Thirugnanam et al. [11]	It was advised to administer batteries. The main goals are to reduce DG fuel consumption, balance PHOTO-VOLTAIC (PV) power, and manage battery charge and release rates to extend battery life. In order to prevent overcharging or undercharging of the batteries, the battery charge/release rate control model takes into account their SOC restrictions.
Dufo-López et al. [121] Schiffer et al. [122]	A strategy for improving the daily performance of a diesel-wind-PHOTO-VOLTAIC (PV) hybrid was put out by Dufo-López et al. using MPC and forecasted data on irradiance, wind speed, temperature, and daily load. This study's main addition is daily optimization, which uses the advanced model created by Schiffer et al. to account for capacity losses and lead-acid batteries' deterioration due to corrosion. This feature is essential for determining the MICROGRID (MG)'s operating costs because it makes it possible to estimate the battery's replacement and useable life with greater accuracy. Genetically algorithms are used for the optimization.

Energy Administration Based on Artificial Intelligence Techniques

A novel methodology that employs artificial intelligence algorithms is proposed to address the energy demand planning challenge in smart homes as shown in Table 8. The innovative strategy, conceived as a multi-objective scheduling problem [123], aims to strike a balance between energy cost and user comfort. The approach utilizes the concept of demand-side management, considering fluctuations in electricity prices over time, priority in equipment use, operational cycles, and a battery bank.

Energy Management Using Other Diverse Methods

Apart from the discussed techniques, the literature also presents the other various techniques for microgrid energy management. The problem for microgrid control has been widely studied and the utilized Model Predictive Control has been widely researched and adopted in the microgrid domain as shown in Table 9. The operation of the microgrid is optimized based on receding horizon approach using forecasted information of demand, renewable generation and market prices.

Table 8. Energy administration based on artificial intelligence techniques

Elseid et al. [124]	A system that optimally dispatches utilities and microgrids (where interconnected) to meet energy demand is referred to as energy management in a MICROGRID (MG). The authors of the study made use of IBM's CPLEX algorithm.
Mondal et al. [125]	A game hypothesis-based energy model for a cunning MICROGRID (MG) was introduced using a scattered energy board technique. The MICROGRID (MG) decides on a method for this framework in order to increase its financial and energy-saving benefits.
De Santis et al. [126].	For a networked MICROGRID (MG), a fuzzy logic-based Mamdani algorithm-based energy management system was recommended. The MICROGRID (MG) model, which also includes energy storage and renewable energy sources as components, has several goals, but the main one is to choose the energy flow management duties for the MICROGRID (MG) model. A technique that integrated fuzzy logic with conventional algorithms was used to carry out the optimization.
Venayagamoorthy et al. [127]	Executives for a MICROGRID (MG) were given a viewpoint on energy that was related to the main power matrix. The MICROGRID (MG) increases the use of green electricity while reducing the byproducts of fossil fuels, increasing its independence. The administration framework is presented using two brain networks and ideas from transformational, powerful programming and learning. A first brain network controls the process, and a second brain network makes sure it runs smoothly. The presentation list includes elements like battery life, eco-friendly power use, and reduction of the controlled burden.
Ma et al. [128]	It was suggested to use a leader-follower system for energy management. The goal of this strategy is to a maximum of the advantages provided to MICROGRID (MG) active consumers while maintaining the Stackelberg balance to give an equitable benefit distribution.
Jia k.[129]	An adaptive intelligence technique for energy management was provided for a networked MICROGRID (MG) that makes use of energy storage devices. The goal is to decrease load swings brought on by intermittent renewable energy output. Utilizing ultra-capacitors and storage components, the load profile is controlled.
Arcos Aviles[130]	A home grid-connected MICROGRID (MG) with renewable distributed generating and batteries was given a low-complexity, fuzzy logic control-based energy management method.
Aldaouab et al. [131]	We presented a genetic algorithm-based optimization technique for household and business MICROGRID (MG)s. The MICROGRID (MG) draws its power from a number of sources, including PHOTO-VOLTAIC (PV) solar energy, micro turbines, diesel generating, and an energy storage system.
Liu et al. [132]	Using a Stackelberg game strategy for managing energy in a MICROGRID (MG) A utility model for PHOTO-VOLTAIC (PV) consumers and the fee for PHOTO-VOLTAIC (PV) energy were integrated with the earnings from the MICROGRID (MG) operator to produce a management system model.
Nnamdi and Xiaohua [133]	For matrix-related MICROGRID (MG) tasks, they created an interesting reaction impetus-based plan. The game hypothesis-based request reaction programming was used to test the matrix-associated functional technique of a MICROGRID (MG) (GTDR). The results demonstrated that lower expenses might be achieved in the MICROGRID (MG) by utilizing the lattice administrator's DG advantage at the expense of limiting fuel/exchange costs.

Table 9. Energy management using other diverse methods

Astaneh et al. [134]	An optimization strategy was created in addition to several energy management control methodologies to determine the most economical configuration for a freestanding MICROGRID (MG) with a lithium-ion battery storage system. The lithium battery lifespan is estimated and battery longevity and lifetime are examined using a novel electrochemistry-based model.
Neves et al. [135]	The different optimization techniques for managing standalone MICROGRID (MG)s were contrasted. The basis of this method is linear programming and genetic algorithms. The findings demonstrated that controllable load management could result in lower operating costs and maximum use of renewable energy sources.
Wei et al. [136]	To further develop the energy board and control in a private MICROGRID (MG), a novel programming-based iterative and adaptable method was suggested. The battery's charge and release levels are monitored separately every hour. Constant decisions are made on the energy source for a family load in relation to the energy cost.
Yan et al. [137]	The development of a MICROGRID (MG) was focused on using techniques such as probabilistic Markov modeling to reflect PHOTO-VOLTAIC (PV) age vulnerability and blended number programming for executive progress. The MICROGRID (MG) lifetime in the plan was examined using a direct model.
Akter et al. [138]	For a linked home MICROGRID (MG) revamping client, a multi-leveled energy board viewpoint that incorporates a local control tool that provides the energy executives' information to a focal regulator has been introduced.
Basaran K. [139]	An EMS for a hybrid system using wind, solar, and diesel power was built in the research described. The system works both on and off the grid. As a result, the inverter has a system in place for managing transfers between utility and micro-grids.

Case Study: Blue Lake Rancheria Microgrid [140]

The solar PV, once coupled to battery storage and a diesel generator, has proved to be successful integration into this microgrid, achieving energy resilience and cost reduction especially during the COVID-19 pandemic. It showed that the system can perform efficient automated EMS for both resilience and economic benefits.

Validation with Review Insights

The points we can use to analyze the Blue Lake Rancheria case are from this review paper.

1. Automatic Response vs. its Control Architecture: Although [140] does not explain the control architecture, the automatic response implies the use of centralized architecture. This is consistent with the review's key point on the superiority of centralized methods in achieving the cost and resilience goals shown.
2. Mitigation of the photovoltaic intermittency: Blue Lake Rancheria microgrid mitigates the undecidable nature of solar PV. It shows that the system can change with grid conditions in order to minimize costs when there are electricity price fluctuations. It implicitly faces uncertainty by adapting to variations in generation and grid price.
3. Robust Communication Network and Coordination: The first indication of a robust communication network and coordination is the automated nature of the system that [140] does not specifically mention. This corresponds to your review's main focus on reliable communication.
4. The case study is effective for tackling multiple objectives in a Multi Objective Optimization context. Performance under pandemic lived up to the reliability improvements while reducing costs by responding to price signals.
5. Battery Storage Integration: Battery storage is essential to the solar integration into the grid and providing grid services. It is likely that the system optimizes storage dispatch for both economic and reliability purposes. Such an integration has been highlighted in your review and in its wake reflects the importance of energy storage.
6. They mention how the microgrid enabled community support during the pandemic and also shared the demand response and load management case. Although not standard demand response, this does represent some degree of load management in order to keep the essential services running.
7. Resiliency and reliability: The uninterrupted power supply at a critical occasion clearly reveals the system resilience and reliability, confirming your remarks here.

The review of the prominent studies on MICROGRID energy management systems reveals several key insights: [141-146].

1 Centralized vs Decentralized Energy Management [142]: There are two main approaches to MICROGRID energy management - centralized and decentralized. Centralized methods use a central controller to optimize overall MICROGRID operations [144-146], while decentralized approaches employ distributed controllers at each distributed energy resource and load to coordinate in a distributed fashion [146,147]. Centralized methods tend to have better overall optimization but may suffer from single point of failure issues [141], whereas decentralized methods are more robust but may not achieve global optimal performance [144].

2 Uncertainty Handling: Accounting for uncertainty from renewable energy generation and load demand is crucial for effective MICROGRID energy management. Various uncertainty quantification techniques have been used, including stochastic programming [146], robust optimization [145], and fuzzy logic [144]. These methods help MICROGRID operators handle the inherent variability in MICROGRID operations [143].
3 Communication and Coordination: Reliable communication networks and coordination algorithms are essential for MICROGRID energy management, especially in decentralized approaches. The choice of communication technology and coordination protocols can significantly impact the performance and cost of MICROGRID energy management [148].
4 Multi-Objective Optimization: MICROGRID energy management often involves balancing multiple, sometimes conflicting, objectives such as cost minimization, emissions reduction [141] and reliability maximization. Advanced multi-objective optimization techniques have been applied to address this complexity [149].
5 Incorporating Storage: Energy storage systems, such as batteries, flywheels, and ultra-capacitors, can greatly enhance the flexibility and reliability of MICROGRID operations. Optimal sizing, placement, and control of energy storage have been widely studied [150].
6 Demand Response and Load Management: Engaging end-users through demand response and load management strategies can provide additional flexibility and cost savings for MICROGRID operators [143,151].
7 Resiliency and Reliability: Ensuring the resilience and reliability of MICROGRIDS in the face of grid disturbances, natural disasters, and cyber-attacks is a critical concern that must be addressed by MICROGRID energy management systems [152].

Overall, the research on MICROGRID energy management systems has evolved significantly, with advanced techniques being developed to address the unique challenges and opportunities presented by these distributed energy systems [144-146,153].

Future Scope

1 Improved forecasting and decision-making through AI and machine learning [154].
2 Created blockchain-based energy trading systems for peer-to-peer transactions in microgrids [155].
3 Implemented advanced IoT sensors for real-time monitoring and control of microgrid components [156].
4 Investigate Vehicle-to-Grid (V2G) integration in microgrid EMS for better energy storage and load balancing [157].
5 Study multi-microgrid systems and their coordinated operation to improve resilience and efficiency [158].
6 Develop advanced battery management systems to extend lifespan and improve performance [159,160].
7 Research the integration of hydrogen-based storage systems in microgrid EMS for long-term energy storage [141].
8 Incentives for customer engagement in EMS [151,160].
9 For load forecasting, use weather forecasting to reduce uncertainty in renewable energy sources [161].
   - Optimal placement and sizing of distributed generation using advanced optimization algorithms (e.g., see [141]). This topic continues to be an active research area with ongoing efforts to improve the efficiency and computational performance of these algorithms.
   - Integration of different types of distributed generation units for enhanced grid stability and resilience (e.g., [146] discusses different DG types). Research focusing on the optimal mix and coordination of diverse DG resources is crucial for the future of microgrids.
   - Advanced forecasting techniques for dynamic line rating and renewable energy generation (e.g., [161,162] discusses forecasting and smart grid technologies). Improving the accuracy and timeliness of forecasts is essential for effective energy management in microgrids.
   - Cyber-security and resilience of microgrid energy management systems (e.g., discusses cybersecurity challenges in microgrids) [163].

CONCLUSION

This review has examined the critical role of energy management systems in optimizing the operation of microgrids, particularly those with high penetration of renewable energy sources. The inherent intermittency and variability of these sources necessitate advanced control and optimization strategies to ensure grid stability, minimize operating costs, and maximize the utilization of renewable resources. While significant progress has been made, several challenges remain, including the development of more accurate and computationally efficient forecasting methods, effective integration of diverse distributed energy resources, and the design of scalable and robust control architectures. Further research is needed to address these challenges, particularly investigating the coordination and control mechanisms for optimizing the interaction between microgrids and the main grid, considering factors such as grid stability, market participation, and ancillary services. Addressing these research gaps will pave the way for wider adoption of microgrids and accelerate the transition towards a cleaner and more resilient energy system.

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