

A Transition from basic Micro Grid to Optimization Techniques based on Energy Management System: An Analytical Review

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ABSTRACT

The renewable resources are also utilized to reduce greenhouse gas (GHG) emissions and as well as encourage the improvement of sustainable development. These energy systems are consolidated into microgrids by using various technological solutions to verify distributed generation facilities and customer communication in an optimal way. Microgrids are localized energy systems that integrate with renewable energy resources to increase energy reliability, economic efficiency, and sustainability. Energy management in microgrids introduces the control system and information that provides the assurance of energy production and distribution at the lowest price. This study emphasizes various optimization techniques, problem-solving methods, and simulation tools used for freestanding and connected microgrids. This paper provides a comprehensive overview of current energy management strategies in microgrids, examines the role of emerging technologies, and discusses the challenges and future directions in these respective fields.

Keywords: Micro grid, Energy management system, Control strategies, Homer Software

1.INTRODUCTION

Growing in global population and thus results in increase in energy demand create major problems for depletion of fossil fuels and greenhouse gas emissions. There is need to use more renewable energy resources as the conventional energy resources are near to deplete. Distributed energy resources (DERs) such as solar, wind, geothermal, and hydro are abundant in nature and less polluting. To achieve there is need for collaboration of government and companies and individuals are required to move towards more sustainable and renewable energy methods. [1]The integration of non-conventional and distributed energy resources into energy system results in more sustainable. Many technical difficulties raised when the combination of distributed and non-convention

energy resources is done such as, grid stability and power quality preservation. So, revolutions in grid infrastructure, energy storage system and smart grid are important to address these issues. Pumped hydro storage, flywheels, supercapacitor, hydrogen, battery, storage are the examples of energy storage devices that are solution of intermittency nature of the dispatchable resources of energy such as wind and solar. Additional, improved grid infrastructure and monitoring and energy management system can improve the grid.[2]

Moreover, due to the irregular availability of the renewable energy resources such as solar and wind the combination of these resources with the existing energy system is more challenging, even when it is more important to sustain the

coordination between the demand of energy and supply of energy.[3]

Great innovations in management techniques of demand side, energy storage methods infrastructure of grid are required to solve these difficulties. Surplus energy produce is stored for the time of peak output demand and during the period when energy produced is in low amount. Moreover, improved distribution and management of distribution energy resources are possible by smart grid technology and modernization of grid. Increase in renewable energy resources has proved well positioned and resilient for growing future despite of the difficulties faced during the period of COVID-19. The challenges and interruptions caused by the COVID-19 has result in delay of renewable energy projects, whose has adverse effect on globally growth of distributed power capacity. IEA stands for International Energy Agency declared that the installation of inexhaustible energy resources in 2024 will rise as compared to 2020. Many of the renewable energy projects are expected to come online as economic improve and improve the capacity of generation of energy by renewable energy resources.[4]

Energy storage devices can be integrated with renewable energy sources to maximize output and meet load demands.[5]

Energy flow management demands effective methodologies and control mechanisms when integrating many Distributed Energy Resources (DER). The dispersed energy resources can be managed by the energy management system for the best possible planning, sizing, scheduling as well as control. Monitoring, analysis, generation forecasts, load usage, utility supply pricing, and other cost-based services must all be controlled in an energy management system.[6]Hybrid energy system from a technical and economic perspective, emphasizing the integration of renewable energy sources with the electrical grid to address increasing demand of electricity and energy requirements of future.[7]

An ideal HRES design based on techno-economic analysis is suggested [8]to satisfy the home and agricultural requirements of a small community in India's Yamuna Nagar. With a COE of \$0.288/kWh and a Net Present Cost (NPC) of \$228,353, the

results demonstrate that the PV-WT-Battery hybrid system is the most cost-effective and sustainable option at the research site. The solar system is more cost-effective than grid extension, according to feasibility studies conducted at five different locations in Pakistan. The advantages will grow as local communities receive training[9]. In Nigeria, PV/DG/BESS produces a dependable and affordable microgrid (Esan et al. 2019). The hybrid system reduces emissions of pollutants by 97% when compared to the diesel-only system[10].Similarly, LF, Cycle Charging (CC), and Combined Dispatch (CD) techniques were studied by the authors in [11] the authors examined the effects of LF, CC and Generating order on a PV-WT-DG-BESS system in Iranian regions that have experienced natural disasters. The CC approach demonstrates economic viability in a shorter lifespan because of its higher salvage value[12].

[13]In this study, a novel approach utilizing the HOMER MATLAB Link (ML) connection for an HRES model comprising PV/WT/BGG/BSS to fulfil the electrical energy requirements of Doganevler hamlet situated in the province of Bingöl's rural area.

El-Maaroufi et al. created an HRES including PV, WT, BGG, and BSS components to satisfy residential buildings' yearly energy needs in Morocco's Zoumi region. Following the study conducted with the HOMER Pro. This system generates 11.14 GWh of energy annually, has an LCOE value of 0.125 USD/kWh, and lowers CO₂ emissions by about 5900 tons annually when compared to diesel generators[14].

In order to construct an off-grid HRES in Pakistan, Nadeem et al. created a model with PV/BSS/BGG. Following optimization with the HOMER Pro software, the system they created includes a 15 kW BGG, 11.5kW PV module, a BSS has a 1 kWh capacity and a 10.8 kW converter. According to calculations, the NPC and LCOE values were USD 95,858 and USD 0.104/kWh, respectively [15].

In the Jordanian Karak region, Khalil et al. designed an HRES with PV/BSS/DG components using the HOMER Pro software. The analysis revealed that the proposed system's LCOE value was 0.488 USD/kWh and that it generates 610.73 kilotons of CO₂[16] emissions annually. Additionally, it was discovered that the LCOE value rose to 0.489

USD/kWh with the addition of WT, while the LCOE value of a system with only DG was determined to be 0.727 USD/kWh[17]. Electric cars, producing, and storage components are all integrated [18]. Different storage and demand-based integration solutions for renewable energy systems have been examined in other recent papers[19]. The latter focusses on two main areas: (1) optimising storage utilisation and (2) increasing user engagement through cooperative strategies and responsiveness to demand mechanisms. Using ML and AMPL (A Modelling language for Mathematical Programming) tools in HOMER Pro, [20]Santos et al. introduced a novel approach for dimensioning and simulating Microgrids. They used data from an MG set up on the university's campus to evaluate the methodology of Campinas. They stated that the ML + EMS approach lessens reliance on the main grid and offers financial advantages over LF and CC alternatives[21].

A method for creating a grid-connected photovoltaic system in Bangladesh using the Homer Pro ML tool was provided by Miah et al.[22]. A 3000 kW PV system with an LCOE of 5.31 taka/kWh and a cost of 493,469,200 taka was projected. For a grid-connected PV/WT/DG/BSS system for a residential area with a daily energy demand of 112.7 kWh in Tehran, Iran,[23] created a new dispatch strategy using ML in HOMER software. They stated that their PS results in financial improvements of 4% and 9%, respectively, over the LF and CC techniques in HOMER. Furthermore, the planned system's NPC and LCOE values were found to be USD 75,861 and USD 0.128/kWh, respectively [19].

For a South Indian community, Yazhini et al. created and evaluated five distinct grid-connected and off-grid model configurations in terms of their economic viability. According to reports, the system, which combines PV, DG, WT, and BSS, has the off-grid versions with the lowest LCOE. Out of all the models, the grid-connected system has the lowest LCOE[24].

A new dispatch strategy for an off-grid HRES made up of WTs, DGs, and BSSs is created using an ML tool in the paper by Aziz et al.[25]. The techno-economic and environmental outcomes of their suggested approach are contrasted with those of the LF and CC techniques in HOMER. The suggested dispatch strategy's NPC value is USD.

56,473, which is less than the NPC values of the CC dispatch strategy (US\$ 62,545) and the LF dispatch strategy (US\$463,681).[26] Additionally, the control objectives of microgrid supervisory controllers and energy management systems (EMS) have been demonstrated in a number of review publications. The authors of[27] suggest control strategies for a synchronous generator and grid-connected inverter.

In an overview of the research on microgrid energy management, a number of authors used a variety of strategies to address the problem of energy management in the ideal microgrid configuration. However, when distributed, these systems must improve their problem-solving capabilities[28]. This paper's following portion is organized as follows. Section 2 outlines the microgrid's characteristics, advantages and types. Sections 3 describes the energy management and section 4 describe the mathematical modelling of all system components, as well as problem formulation. Section 5 describes the control strategies of microgrid. Section 6 presents the software considerations, while Section 7 represents the conclusion and future scope.

Microgrids are the small-scale energy system that integrate the distributed energy resources such as photovoltaic solar energy, wind energy storage system. It can work in both conditions either in island connected mode and grid connected mode. Local energy production system, distribution and its consumption are possible by this system, which reduce the dependency on loss of transmission.[29] The brief architecture of Microgrid is as shown in fig 1.

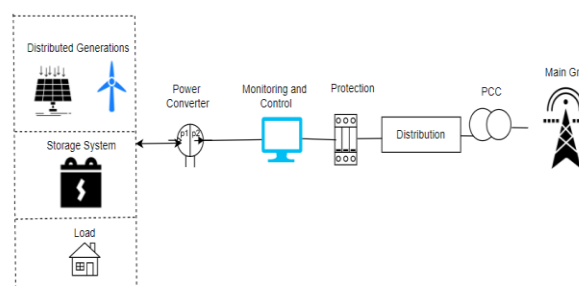


Fig.1 Architecture diagram of Microgrid[30]

Microgrid has some essential elements as stated below:

1. Distributed Generators or micro sources: This includes the inexhaustible energy resources such as solar, hydro, wind, tidal, etc, that power the main grid.

2. Energy storage system: It includes the battery, supercapacitor, flywheel and pumped hydro system are used to store the power for the of low generation or grid disruption. It acts as a backup source and also stores the extra energy to fulfil the energy demand.[4]

3. Control system: This system looks after the system performance and controls the function of different components of the microgrid for the optimization of flow of energy, guarantee the stability of the system, and also satisfying its performance goals.

4. Flexible loads: Microgrid has the load such that they can be defined or managed in case of supply and demand variation for energy, and also permit the techniques of demand side management.

5. Point of common coupling (PCC): Through this point, the microgrid can easily link with the main utility grid and can easily work either in standalone mode or grid-connected mode.[31]

2. Microgrid: Characteristics, Advantages and Types

2.1 Microgrid has various characteristics but some of them are discuss as

1. Economic Efficiency: It lowers the transmission loss and permit the local energy consumption and generation and offer the management of demand side and trade of energy. It offers the optimization of cost and efficiency.

2. Reliability: Its reliability is improved by provides the backup power in case of irregular nature of inexhaustible energy resources and in case of blackout. It can also include cyber defence also.[32]

3. Sustainability: It reduces the carbon emission so make the environment pollution free and reduce the greenhouse gas emission. it also reduces the dependency on the fossil fuels i.e. traditional; sources of energy.

Microgrid system requires the power converter that link the renewable energy resources to loads and also monitor some useful communication, protection system, its configuration increase the

system performance, optimization and effective flow of energy control.

So, due to all its useful characteristics there is drastic departure from traditional sources of energy to the renewable energy resources which has more centralized energy infrastructure. More emphasized on management of optimization methods and advanced metering highlights how it is important to increase the efficiency and resilience of energy system. These systems increase the efficiency, handle the peak loads, increase the supply security and stable the energy prices. [33]

2.2 Advantages of a micro grid system

Popularity of microgrid has been increased due to its many advantages and has the capacity to handle the issues related to range of energy

1. Cost saving: Microgrid is capable of decreasing the requirement for the development of new power plant building and modification in infrastructure because of use of inexhaustible energy resources and energy storage devices.[3]

2. Environmental Impact: Microgrid helps in reducing the greenhouse gas emission as compared with the traditional power plant based on fossil fuels and also decrease the pollution of environment by combine the energy efficiency and techniques of distributed energy resources.

3. Energy Efficiency and Stability: More flexibility and control of microgrid technology make it possible to manage the more efficiently which decrease the energy dependency on fossil fuels and increase the stability and efficiency.[3]

4. Capability of Ride Through: Microgrid offer the ride through capability incorporated with energy storage system, which make the system running even when there is interruptions or situation of unexpected disruption occur to grid and boost up the grid resiliency. [34]

2.3 Types of Micro grid

Microgrid has three types AC, DC, AC-DC Hybrid microgrid and each has its own merits and demerits.[35]

1.AC Microgrids: With the use of power converter AC microgrid Power to both DC and AC load. It can connect the various power generation sources and loads using the AC bus in their network system. It consists of inexhaustible energy sources such as solar energy, wind energy etc., and traditional power-based energy resources such as engine-based systems. Also, this microgrid contains the energy, storage system to store surplus energy such as batteries, supercapacitors, etc., to store the energy from dispatchable sources of energy due to their intermittent nature of availability to make the continuity supply of energy. The AC Microgrid structure as shown in fig 2. [36]

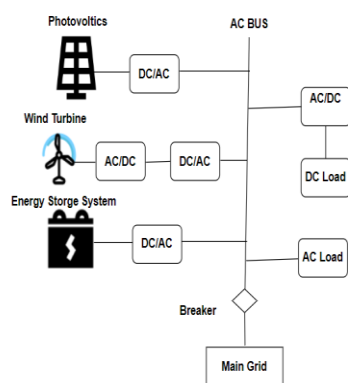


Fig. 2 AC Microgrid[4]

2. DC Microgrids: For small-scale use, such as for business and home, DC microgrids are most preferred. They provide more effectiveness and improved controllability by converting surplus power stages required for the AC system. Through rectifiers AC generators are connected to the DC bus, which is the common bus in the DC microgrid. DC Microgrid structure is as shown in fig 3.[37]

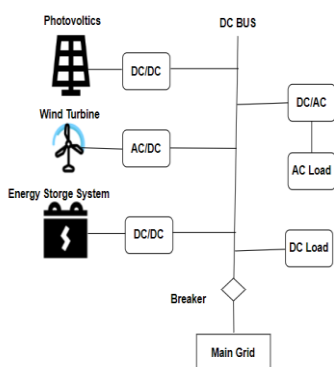


Fig. 3 DC Microgrid[37]

3.AC-DC HYBRID Microgrids: This microgrids combine both DC and AC systems to maximize the benefits of both systems. In this microgrid, converters are used to balance the energy flow between various source and load types. In this system, AC and DC loads operated in parallel. This microgrid maximizes the distribution of energy and efficiency by providing flexibility of a range of loads and sources.[4] The selection of a microgrid means whether an AC, DC, or AC-DC Hybrid microgrid is used depends on various aspects such as the kind of load, the system's scale and sources it used, and also the need of the project. Each type of microgrid has its own merits and demerits.

3.Energy Management System (EMS)

EMS offers more efficient energy production, distribution, and transmission, which is the most important component in the optimization of microgrids. The main objective of the use of this system is to use decision-making techniques to reduce the adverse effect on the environment. It increases the system efficiency, cost-effectiveness. Features of EMS [13]:

1. Optimization of cost: The energy management system's main objective is the reduction in cost of energy production, transmission, and distribution. To meet the demand for energy at the lowest feasible cost, this uses the distributed energy resources for the optimization.
2. Increase Systems' Efficiency: EMS uses the control algorithm to enhance the efficiency of the microgrid system. To enhance the system's efficiency, it is necessary to decrease the energy losses, optimize energy storage devices, load scheduling, and demand-side management.
3. Enhance the Reliability: Preventive actions must be taken to deal with the possible disruptions in the energy supply and preserve the system stability. Techniques involved in this system are for detection of fault isolation, restoration, and detection to decrease the downtime and increase the resilience.
4. Use of inexhaustible energy resources: Resources such as solar energy and wind energy are examples of energy resources that are taken into account by EMS (energy management system). To maximize the usage of inexhaustible energy

resources, control algorithms and forecasting approaches are used.

5. Reduction of greenhouse emissions (GHG): With the combination of inexhaustible energy resources, the greenhouse gas emitted from conventional sources of energy is reduced by EMS, making it more efficient.

EMS, is an information system that provides the most important function that generation cost, transmission cost, and cost of distribution of energy supply are minimum. A basic block diagram of EMS is shown in Fig. 4. An important objective of the EMS energy management system in a microgrid is as stated below:

1. To decrease the cost of operation of a microgrid.
2. To decrease the environmental cost.
3. To increase the lifetime of the energy storage system.
4. To increase the generator's output power at a particular time.

Various EMS energy management methods have been put forth in the literature to achieve the best and most appropriate microgrid operation. There are two types into which EMS energy management techniques may be divided. i.e., artificial intelligence method and classical method as shown below in fig 4.

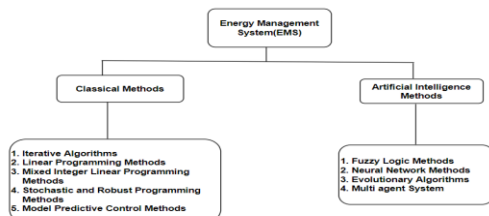


Fig. 4 Energy Management System (EMS) [14]

Different optimization techniques can be utilized in compatibility with EMS to enhance the output. Some of the optimization techniques are given in Table1.

4. Different Methodologies in Use

There are different methodologies that are used in a microgrid system, but the most important are as follows:

4.1 Solar energy

The energy produced from photovoltaic (PV) energy systems reduces the fossil fuel's demand and also provides a reliable, non-polluting source of distributed energy. The use of PV systems has been growing worldwide, reflecting significant statistical improvements in solar energy adoption

4.1.1 Photovoltaic Module Modelling

The output characteristics of a photovoltaic (PV) array are affected by three main factors: temperature of cell, irradiation of solar, and output voltage. These three factors play a very important role in finding the efficiency and performance of PV modules. [42]

4.1.2 Cell Temperature

Efficiency of solar cells is affected by temperature. Higher temperature generally reduces the efficiency of the cells, as they increase the internal resistance and reduce the open-circuit voltage. This thermal effect must be carefully managed to optimize the performance of the PV modules

Table 1. A Comparison of the Optimization Techniques. [38]

Optimization Techniques	Merits	Demerits
Particle swarm optimization (PSO)[3]	Superb brings about optimization and scattering.	Its calculation is highly complicated.
Artificial bee colony (ABC)[13], [15]	It is population-based algorithm whose implementation is easy and its convergence is fast enough	Its formulation is complicated
Genetic Algorithm (GA)[7]	It is population-based algorithm for the best answer by using selection, mutation and crossover	The parameters of mutation and crossover must be resolved
Artificial fish swarm[6]	It is more flexible, required less parameters, more precise and rapid convergence	It can maintain the advantages of GA but without its disadvantages
MILP[16]	It solves the complex issues with simple actions	Minimal potential for application based on non-differentiable and
MINLP[16]	It has non-linear mathematical function	Various iteration

4.1.3 Solar Irradiation

Solar irradiation, or the amount of sunlight received by the PV cells, directly impacts the amount of electrical power generated. The more sunlight the cells receive, the more electricity they can produce. This parameter is highly variable and depends on geographical location, time of day, and weather conditions.

4.1.4 Output Voltage

Electrical characteristics of the cell determine the output voltage of the PV array and the configuration of the modules. This voltage can vary significantly depending on the load and the overall design of the PV system.[34]

Mathematical modeling:

$$P_s = S_c d_s \left(\frac{M_{sr}}{M_{ST,STC}} \right) [1 + \beta_s (T_c - T_{c,STC})] \quad (1)$$

Where P_s -Solar power system's output, S_c -Solar PV modules rating, d_s -Derating factor of PV, M_{sr} - Irradiance of solar incident on PV module, $M_{sr,STC}$ - Irradiance at standard test condition(stc), β_s - Temperature coefficient of solar power (%/°C), T_c - Temperature of PV cell, $T_{c,STC}$ -PV cell temperature at STC.

Solar PV's temperature is calculated as

$$T_c = \frac{NOCT - 20^\circ C}{T_{rf}} M_{st} \quad (2)$$

Where, T_{rf} and NOCT are the solar irradiance and the cell operating temperature for reference is 0.8 kW/m².

4.2 Wind energy

Wind energy is one of the most useful and important distributed energy sources for producing electricity. The industry of wind is increasing very fast due to advancements in technologies of turbines and innovations in power systems, evidencing the growing interest in wind turbines.[30]

Wind generators use either synchronous motors or induction motors. Induction motors are mostly used because they are small in size, lightweight, and easy to maintain.

4.2.1 Mathematical model

The wind power generation's output is given by

$$P_w = 0.5 \mu A v^3 \quad (3)$$

Where A-the swept area of the turbine rotor(m²), μ - air density (1.225 kg/m³), v- the wind (m/s).

It is important to define that the wind speed of a location is influenced by the hub height as determined by the power equation: [43]

$$V_{hub} = V_{an} \left(\frac{h_h}{h_{an}} \right)^\alpha \quad (4)$$

Where h_h -turbine hub height (m), V_{hub} -the speed at the hub height (m/s), h_{an} -the anemometer height(m), α -wind speed at anemometer height (m/h).

4.3 Battery

The voltage and current are the main focus parameters of the battery mathematical model. The battery's terminal voltage change can be used to calculate the current. The movement of electrons from one electrode to another is what produces current [44]. The battery's open circuit voltage is found by the positive and negative electrodes' potential difference.

4.3.1 Equations:

Charge power of the battery expressed in KW at the maximum charge rate (MCR) is expressed as:

$$P_{MCR} = \frac{(1 - e^{-\beta \Delta t})(Q_k - Q)}{\Delta t} \quad (5)$$

Where, β -battery MCR(A/Ah), Q -Total battery energy at the beginning of the time step(kWh), Q_k -battery size(kWh), Δt -the length of the time step(hr).

The maximum charge power of the battery (MCP) at the maximum charge current (MCC) can be determined by the equation [45]

$$P_{MCC} = \frac{(N_{at})(I_b)(V_m)}{10^3} \quad (6)$$

Where, V_m -Voltage of a single battery cell (V), I_b Maximum battery charges current (MCC), N_{at} , Number of battery cells.

The maximum charge rate P_{MCR} is equal to three parameters' minimum value as described in the equation below assume that each one is applied after the loss of battery charging

$$P_M = \frac{\min\{P_{KBM} P_{MCR} P_{MCC}\}}{n_{b(eff)}} \quad (7)$$

Where, $n_{b(eff)}$, P_{KBM} and P_M is the battery round trip efficiency (%), maximum power absorbed by battery each time step as defined by the kinetic battery model principle and battery MCP (kW) respectively. The size of battery, daily electricity demand and the autonomy are determined by equation:

$$A_b D_{de} = N_{at} V_m Q_m n_{b(eff)} \left(1 - \left(\frac{Q_{min}}{100}\right)\right) \quad (8)$$

Where, A_b - Autonomy, D_{de} -Energy demand daily, Q_m capacity of single cell (Ah), Q_{min} battery's minimum state of charge (%) r.

The battery's minimum state of charge corresponds to 100 minus the maximum depth of discharge of battery (%). The size of battery (Ah), is the multiplication of $N_{at} Q_m$, which is expressed as

$$N_{at} Q_m = \frac{A_b D_{de}}{(n_{b(eff)}) (V_m) (DoD)} \quad (9)$$

Where DoD is the battery's depth of discharge (%).

4.4 Economic analysis:[30], [46]

In designing and planning a hybrid microgrid system most important element is economic analysis. NPC and LCOE of the proposed system can be expressed using the equation as given below in HOMER Pro:[47]

$$NPC = \frac{C_{ANN,TOT}}{CRF(D,yR)} \quad (10)$$

$$CRF = \frac{D(1+D)^{yR}}{(1+D)^{yR}-1} \quad (11)$$

$$D = \frac{I-F}{1+F} \quad (12)$$

$$LCOE = \frac{C_{ANN,TOT}}{E_S} \quad (13)$$

Where, $C_{ANN,TOT}$ -the total system cost, CRF -capital recovery factor, I -nominal interest rate, D -discount rate,

F -inflation rate, yR -projected life time, E_S - total electricity load served (kWh/Yr).

5. Control strategies of a microgrid

Control strategies of microgrids are important for managing renewable energy resources to ensure the most efficient operation, reliability, and stability. There are three main supervisory control strategies, such as centralized, decentralized, and distributed control systems. [48]

1. Centralized Control: In this control, a master controller supervises the whole microgrid and makes the decisions based on all the data collected from all the components. This approach allows for global optimization, such as maximizing the efficiency and minimizing operational cost. But a

main problem associated with control is that it requires the robust communication infrastructure, and if there is some problem in communication links, it may face many challenges.[49]

2. Decentralised Control: In this control system has its own local controllers that can manage individual distributed energy resources (DERS) based on local information with no communication between them. This method enhances the system resilience and flexibility, supporting plug and play functionality. However, to achieve the optimal performance is challenging because of the lack of coordination among the controllers.

3. Distributed Control: It combines both centralized and decentralized control strategies. Information can be shared among the local controllers through communication and can collaborate on decision making and aim to balance the benefits of autonomy and coordination. It can improve the system performance and reliability but has a drawback that it may introduce complexity in communication and control algorithm.[50]

Each control strategy has its own advantages and challenges. As centralized control totally depends on a single point controller, providing simplicity but risk of failure of that single point failure and depends mostly on communication reliability. Decentralized control distributes the control among local controllers, provides robustness and flexibility, and enhances fault tolerance but can struggle with system-wide optimization. Distributed control further spreads resources across multiple locations, optimizing performance and reliability.[38]

5.1 Microgrid Hierarchical Control Structure

A microgrid hierarchical control structure has been created to optimize the function of the system by considering all the complexities that come from the integration of renewable energy resources (wind, solar, battery storage, etc.) and loads. For distinct purposes, this control structure is divided into three layers: [51]

A. Primary control

Objective: It ensures the reliability and stability of the microgrid at the local level, responding to

changes that occur in generation, demand, and system disturbances.

Components: Local controller for each DER or load. [52]

Responsibilities:

1. Direct and fast response to local disturbances such as voltage and frequency regulation.

2. Synchronization of DER with local requirements and grid conditions.

B. Secondary control

Objective: Supervise the microgrid performance as a whole and also ensure that it meets set operating parameters such as frequency, voltage and power quality.

Components: Microgrid Central Controller (MGCC) [56]

Responsibilities:

1. It ensures that microgrids can operate in both standalone mode and grid-connected modes.

2. Adjust the local controller for optimal operation.

3. Coordinates the primary control actions of the local controller.

C. Tertiary Control

Objective: It controls the interaction between the microgrid and main grid and optimizes the power flow and economic advantages of both entities.

Components: Distributor Network Operator and Markets [57]

Responsibilities:

1. It can control the coordination between the main grid and the microgrid for energy exchange.

2. Optimize power dispatch from the microgrid to the main grid and vice versa.

3. Energy trading, scheduling, and ensuring that both the microgrid and main grid operate in harmony.

Microgrid hierarchical control structure has three different layers: primary, secondary, and tertiary, as shown in fig. 5

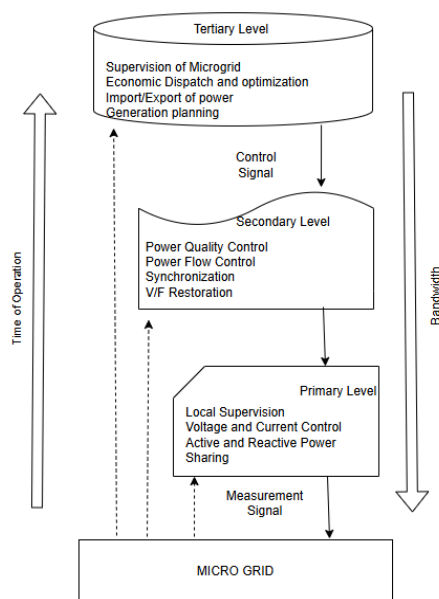


Fig. 5 Microgrid Hierarchical Control Structure[55]

6. Software Considerations

6.1 HOMER

HOMER abbreviated as Hybrid Optimization Model for Multiple Energy Resources, is highly powerful model for simulation of microgrid design and renewable energy resources. It is developed by National Renewable energy Laboratory US abbreviated as NREL. Nearly, more than 200 countries and 210,000 user are using HOMER software for their work. It can operate in both standalone and grid connected mode. Optimization, simulation and sensitivity analysis can be performed by HOMER. [25] configurations can be simulated through HOMER. Optimization process includes that HOMER explores the all-possible configurations and eliminates the infeasible options that are unable to meet the given problem demands and then sort them according to the all-feasible solutions and display them according to choice of variable for optimization. In the sensitivity analysis process, it can perform many optimizations under the range of many inputs to find the effect of variables over which the user has no control of the user, such as the cost of components, solar radiation variation, wind speed variation, etc., and make it understood that how the optimization result can change these variations.

HOMER has different dispatch strategies are used for optimal design of hybrid microgrid system and techno-economic analysis of system, which is the most attractive part of HOMER and increases the attention in recent scenarios. This optimally designed system has many advantages, for example, energy security, system reliability, lower electricity costs, use of different renewable energy resources with the microgrid, rural area's economic growth to provide electricity to remote areas, and carbon emission reduction. Some software tools are listed below in table 2 that are mostly used in the simulation of microgrid.

6.2 MATLAB

MATLAB stated as Matrix Laboratory. It is a high-level language used for programming and MathWorks developed numerical computing environment. It is used by scientists, researchers for data analysed, engineers for algorithm development, to create model in various aspects such as control system, image processing, signal processing, and energy system [20].

7. Conclusion and Future Scope

The Optimization of hybrid distributed energy systems' design and functioning has been made possible by the incorporation of HOMER software into the microgrid energy management. HOMER makes it possible to find affordable solutions that strike a compromise between technological, financial, and environmental goals by simulating different configurations. Its effectiveness in scaling components like solar panels, batteries, and generators has been shown in studies, resulting in reduction NPC net present cost and LCOE levelized cost of energy.

Additionally, HOMER is more useful in dynamic energy environments due to its flexibility in handling various scenarios, such as integrating electric cars (EVs) and demand response tactics. The creation of grid-connected PV-storage microgrids with EV integration, for example, has been made easier by multi-scenario planning with HOMER, which optimizes performance across environmental and economic parameters.

Future Scope

Looking ahead, several avenues for advancing microgrid energy management using HOMER can be explored:

1. **Incorporation of Advanced Control Strategies:** Integrating predictive control algorithms and machine learning techniques can enhance real-time decision-making, improving the responsiveness and efficiency of microgrids.
2. **Enhanced Modelling of Component Behaviour:** Developing more detailed models for components like batteries and inverters, including their degradation over time, can lead to more accurate simulations and better-informed planning decisions.
3. **Integration of Cyber-Physical Security Measures:** As microgrids become more interconnected, ensuring their resilience against cyber threats is crucial. Incorporating cybersecurity frameworks into HOMER's modelling capabilities can bolster the security of microgrid operations.
4. **Expansion of Multi-Objective Optimization:** Enhancing HOMER's ability to simultaneously optimize multiple objectives, such as cost, emissions, and reliability, can provide more comprehensive solutions for microgrid design and operation.

By pursuing these developments, HOMER can continue to serve as a pivotal tool in advancing the efficiency, sustainability, and resilience of microgrid systems worldwide.

Declaration of Interests

All authors declares that they have no conflicts of interest.

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