Micro Grids: Design, Operation and Applications

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Abstract

Micro grids constitute the ultimate form of decentralized electricity, heat and cold supply whose operations separated from the main distribution system i.e. autonomous or connected to the distribution system i.e. grid-connected. Grid-connected micro grid can be of help during a system fault, by supplying power to the main distribution system, feeding part of its loads for fault detection and service restoration. Micro grids have emerged as a competitive alternative to the final delivery of energy to consumers in combination with on-site production of heat. Distributed generation grouped in micro grids can introduce a richer set of tools for supply of o heat and power, at higher reliability, security, flexibility and power quality in the conventional grid. A micro grid is typically managed through a central controller that monitors the system parameters, coordinates energy resources, balances loads and controls electrical loads, and disconnects and reconnects of the micro grid to the primary grid. Micro grids with no central controller are not common but are technically feasible, with distributed energy resource having an individual controller and the individual controllers operate in a coordinated manner.

Micro grids can be an effective option to increase the energy resilience, by providing a functional electric power system capable of operating independently of the main grid. The main grid usually supplies primary power, while the micro grid provides secondary dispatchable power in the event of a grid failure. Emergency diesel generators can provide power directly to loads in the event failure of the primary grid and the micro grid. Proper design and planning of microgrids is important for them to yield all the advantages of the distributed energy concept for the power systems, both local and the clinked central power system. This calls for a reliability -oriented design for microgrids that utilise a large share of the variable and intermittent renewable energy-based, and power electronics-interfaced distributed energy resources. Experience has shown that the power electronics used are prone to wear-out failure and can potentially have adverse effects on the on the performance of the entire power electrics dominated power system. The many benefits associated with application of microgrids have contributed to their significant growth and penetration in decentralized power generation globally. However, challenges are still encountered with respect to design, operation and control for both island and on grid mode of operation.

Keywords:
Decentralized generation; electricity grids; sustainable energy; smart grids; micro grids;

Introduction
Microgrids constitute a technology option that can help deliver a sustainable and efficient power system by employing distributed or decentralised energy resources for efficient generation and supply local electricity load and increase the reliability of a local distribution network(Sandelic et al. 2022). The microgrid concept has gained popularity recently as a result of the need for modernization of the grid modernization, reduction in the use of fossil fuel-based power generation, and maximum integration of new technologies and variable renewables. Physically, microgrids are electrical structures interconnecting small decentralized generation sources located close to the load centers or point of electricity consumption. Microgrids are often connected to larger distribution power systems, but have ability to operate independently(M. Kabeyi & O. Olanrewaju 2022; Kabeyi 2012; Sandelic et al. 2022). as demonstrated in figure 1.

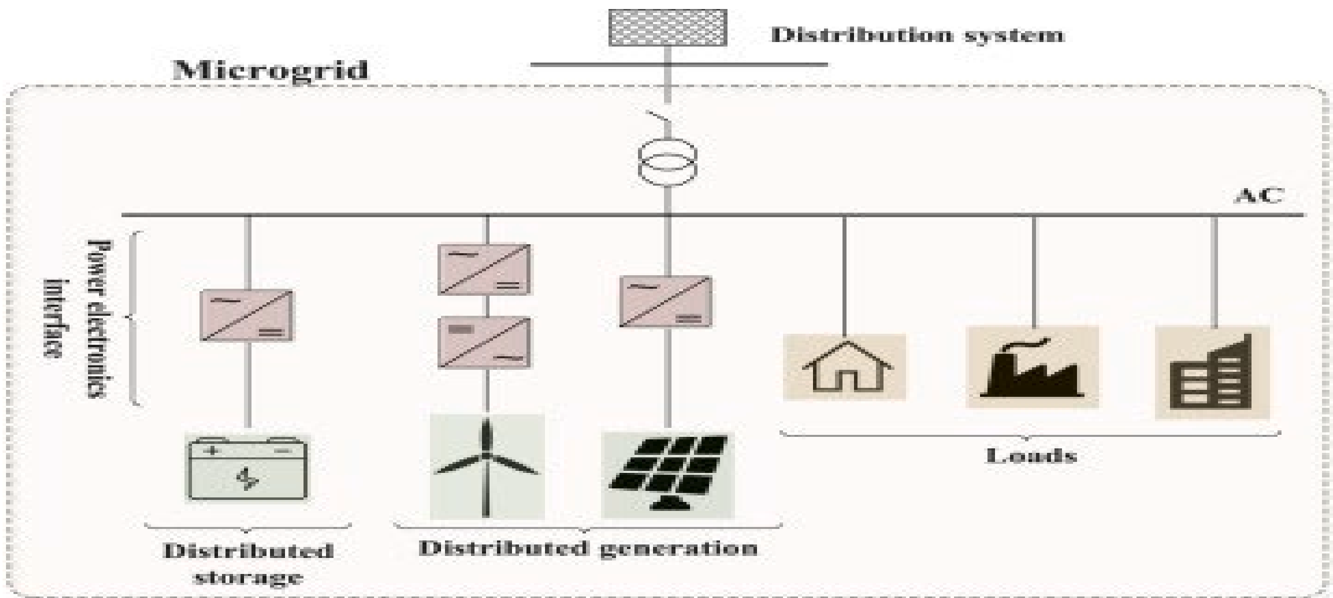

Figure1. A simple microgrid connected to the distribution network(Sandelic et al. 2022)

From figure 1, it is demonstrated that a microgrid can be connected to a distribution grid but can operate separately. They are therefore equipped with the main elements of the conventional grid i.e. the power electronics interface, power generation sources, energy storage, loads and own control systems.

A microgrid is defined as a group of interconnected loads and distributed energy resources operating as a controllable entity with respect to the electric power distribution grid. A microgrid has capacity to be connected or disconnected from the grid operation wise. Therefore, microgrids can be grid-connected systems or off-grid/island power systems(TechTarget 2023).. The US department of Energy defines the Microgrid as a group of interconnected loads and distributed energy resources (DERs) possessing clearly defined electrical boundaries with ability to act as a single controllable entity with respect to the grid with capacity to connect and disconnect from the same grid(Parhizi et al. 2015; Sandelic et al. 2022). The use of microgrids can enhance the reliability and resilience to power grid to system disturbances. Based on geographical coverage, a microgrid is said to be a self-sufficient power system that can serve a discrete geographic footprint, for example a college campus, a military barracks, and medical hospital complex. Therefore, microgrid constitutes a is a small-scale power grid that can either be operated independently or collaboratively with other small power grids(TechTarget 2023).

Microgrids form a typical example of distributed, dispersed, decentralized, district or embedded power generation. A localized power station or small-scale station having its own generation and storage resources operating within definable boundaries is considered a microgrid. A hybrid microgrid is integrated with the an existing main power grid and is typically supported by generators and use renewable resources like wind and solar and are often used as a backup power supplementing the main grid supply during periods of high demand or curtailed supply by the main grid (M. J. B. Kabeyi & A. O. Olanrewaju 2020; TechTarget 2023). A microgrid strategy which integrates local renewable energy resources can provide redundancy for essential services which makes the main power grid less susceptible to localized disaster. Facilities that are equipped with power generation infrastructure like solar panels and emergency generators can supply power and generate revenue, while connection to smart grid deployments, will enable the sale of power back to the local microgrids which provides system resilience and capacity to local electrical grids and generate revenues from power export (M. J. B. Kabeyi & O. A. Olanrewaju 2020; Moses J. B. Kabeyi & Oludolapo A. Olanrewaj 2022; TechTarget 2023).

Distributed energy systems like micro-grids in residential applications may not generate potential benefits due to lack of appropriate system configurations and suitable operation strategies. The design, scheduling and control of decentralised power systems is of great importance for successful practical realization(Liu et al. 2013). The integration of decentralised generation load, energy storage and control devices to form a micro grid system and presenting it to the power grid as a single and controlled unit can respond to centralized-control signals and coordinate the contradiction existing between the power grid and DG well. The main challenge at home is lack of uniform standards for micro grid communication which increases the difficulty in accessing the micro grid to the power distribution network (M. J. B. Kabeyi & O. A. Olanrewaju 2020; Lu et al.2014).

A micro grid is a power system designed to supply power to small communities or institutions with a local power generation unit. The micro grid connects both power generation and the utility grid and prevent outages (sivaranjith 2018). A micro grid system is either grid-connected or standalone (Islanded) consisting of dispatchable distributed generators, non-dispatchable renewable energy resources, energy storage units, and controllable loads capable of load shedding. Grids connected micro grid can sell or buy power from the grid hence the need to optimise micro grid operation to manage the energy resources in a cost-efficient and sustainable way. A complete formulation for an optimum economic operation and scheduling problem of micro grids involves modelling BESS system, demand side management, and power exchange with the utility grid(Sigalo 2022).

A micro grid is also said to be a local energy grid with ability to control its components and can disconnect itself from the traditional grid and operate independently under circumstances like faults which is a boon in scenarios power outages caused by storms or other environmental conditions, and old which might otherwise lead to severe uncertainty in power generation and distribution(Booth et al. 2020; Ramanath 2021). Micro grids are usually designed to integrate multiple sources of energy like solar photovoltaic, wind turbines, energy storage systems, and standby conventional sources like diesel generators locally, but with ability to exchange power with the macro-grid or other micro grids(Olulope et al. 2022)

Micro grids are typically located close to load centres power which reduces transmission losses and the cost of installing power networks. The micro rids have increased resilience due to redundant distributed energy resources (DERs) incorporated in the micro grids. Micro grids are developed in several topologies and sizes to service a single facility or a vast area providing power to critical services and communities located far from utility systems (Ramanath 2021; Sigalo 2022).

Design and Construction of Micro grids

Micro grids constitute an ultimate form of decentralized electricity, heat and cold supply, with operations separated from the main distribution system i.e. autonomous or connected to the distribution system i.e. grid-connected. Grid-connected micro grid can be of help during a system fault, by supplying power to the main distribution system, feeding part of its loads for fault detection and service restoration. Micro grids have emerged as a competitive alternative to the final delivery of energy to consumers in combination with on-site production of heat. Microgrids are said to be a technology option that can help deliver a sustainable and efficient power system by employing distributed or decentralised energy resources for efficient generation and supply local electricity load and increase the reliability of a local distribution network. Proper design and planning of microgrids is important for them to yield all the advantages of the distributed energy concept for the power systems, both local and the clinked central power system. This calls for a reliability -oriented design for microgrids that utilise a large share of the variable and intermittent renewable energy-based, and power electronics-interfaced distributed energy resources. Experience has shown that the power electronics used are prone to wear-out failure and can potentially have adverse effects on the on the performance of the entire power electrics dominated power system(Sandelic et al. 2022).

Microgrids constitute a technology option that can help deliver a sustainable and efficient power system by employing distributed or decentralised energy resources for efficient generation and supply local electricity load and increase the reliability of a local distribution network. Proper design and planning of microgrids is important for them to yield all the advantages of the distributed energy concept for the power systems, both local and the clinked central power system. This calls for a reliability -oriented design for microgrids that utilise a large share of the variable and intermittent renewable energy-based, and power electronics-interfaced distributed energy resources. Experience has shown that the power electronics used are prone to wear-out failure and can potentially have adverse effects on the on the performance of the entire power electrics dominated power system(Sandelic et al. 2022)

Economic Evaluation of Microgrids

Microgrids have significant economic benefits like exploitation of locally available energy resources which are less expensive. Use of microgrids reduces transmission and distribution charges, resulting in to lower electricity tariffs. By selling excess power back to the utility grid is a source of revenue for local consumers who are converted to prosumers. Deployment of microgrids enables enforcement of load management strategies by local consumers, which leads to economic benefits(Sandelic et al. 2022).

Microgrids serve rural communities and large urban centres efficiently, and act as a river for efficient municipal town planning systems, management of resources, and a catalyst of urban and rural growth. Microgrids have high initial, but with proper operation can generate significant income for the society. Use a well-weighted mixture of comparably more expensive dynamic DER and cheap static reactive power sources in a microgrid provide a cost-effective reactive power and voltage support to the grid (Sandelic et al.2022).

Main Components of the Microgrids

The components of microgrids include distributed energy resources, loads, the master controller, smart switches, protective devices, and system communication, control and automation systems. Microgrid loads are classified into fixed loads which must be satisfied under all normal operating conditions and the flexible loads which can respond to control signals and therefore can be curtailed or deferred i.e., shift able loads as a response to economic incentives or islanding requirements. DERs are classified into distributed generation units (DG) and distributed energy storage systems (ESS) located at either the electric utility facilities and/or electricity consumers' premises or non-dispatchable units which cannot be controlled by the master controller because their input cannot be controlled. The dispatchable units of a microgrid are capable of being controlled by the microgrid master controller and therefore are subject to technical constraints like capacity limits, minimum on/off time limits, ramping limits, and fuel and emission limits. Non dispatchable units are mainly consist of renewable generators in particular wind and solar which produce intermittent and volatile electricity(Kabeyi 2012; Parhizi et al.2015).

The intermittency in supply or generation implies that power generation is not always taking while volatility implies that, although generation may be there, it is fluctuating in different time scales. The volatility and intermittency negatively affect the generation and magnify the forecasting errors in planning creating need for energy storage systems (ESS) whose primary role is to coordinate with DGs for guaranteed adequacy in generation in microgrids. The connection between leads and DERs is maintained by protective devices and smart switches in the microgrid by connecting/disconnecting line flows. In the event of a fault at any part in the microgrid, the smart switches and protective devices isolate the affected area and reroute electricity which prevents fault from propagation in the microgrid. It is the switch at the point of common coupling (PCC) that is responsible for microgrid islanding by disconnecting the microgrid from the utility grid. The master controller's main role is the undertake microgrid scheduling in both island and interconnected modes guided by economic and security considerations. Hence, it is the master controller that determines the microgrid interaction with the utility grid, and decided to switch between interconnected and islanded modes, and maintain optimal operation of local microgrid resources. Other important systems in microgrids are control, communications, and automation which are used to implement the control actions and guarantee timely, constant, effective, and reliable interaction between the various components in a microgrid (Kabeyi 2022; Parhizi et al. 2015; Shahgholian 2021). Figure 2 shows the main components in a microgrid and their interaction.

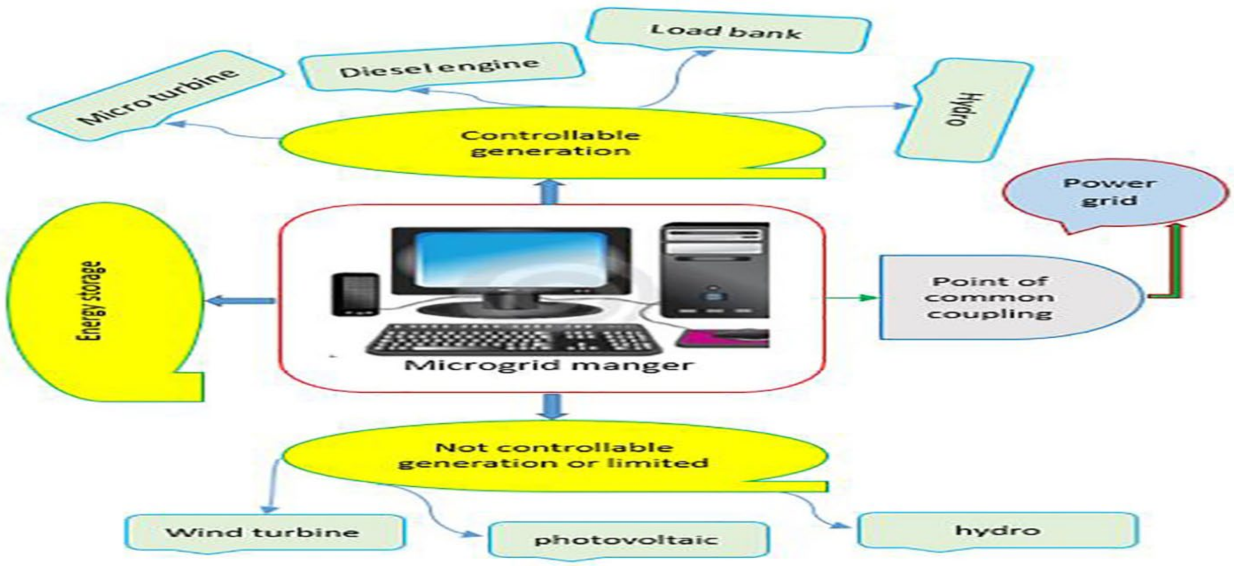

Figure 2. Schematic of a microgrid with different connected energy sources

Figure 2 shows the main elements of microgrids and relational interactions. These components include the microgrid manager or controller, energy storage, various energy sources, the point of contact, and the distribution grid point

Micro grid Control structure

The two main ways of micro grid control are peer-to-peer control and master-slave control the peer to peer technology has high requirement for coordination control of decentralised generation and is still confined to the laboratory. The master-slave control demands reliability and real time performance and hence high requirement for communication and significantly relies on computer system and communication. The Master-slave control is further divided into two-layer control or three-layer control that are used by most pilot projects and lay emphasis on coordinating the operation of DG and load within micro grid(M. Kabeyi & O. Olanrewaju 2022; Moses J. B. Kabeyi & Oludolapo A. Olanrewaju, 2022). A decentralized control method using local information of DG within micro grid can solve the problems of distributed generator and load within micro grid of being dispersive, but doesn't take full advantage of the complementarities of decentralised generation within a micro grid. The challenge with master slave relies is that it relies too heavily on communication and doesn't consider control methods under particular conditions (Lu et al. 2014).

Distributed generation grouped in micro grids can introduce a richer set of tools for supply of o heat and power, at higher reliability, security, flexibility and power quality in the conventional grid(Lu et al., 2014; Mendes et al. 2011).

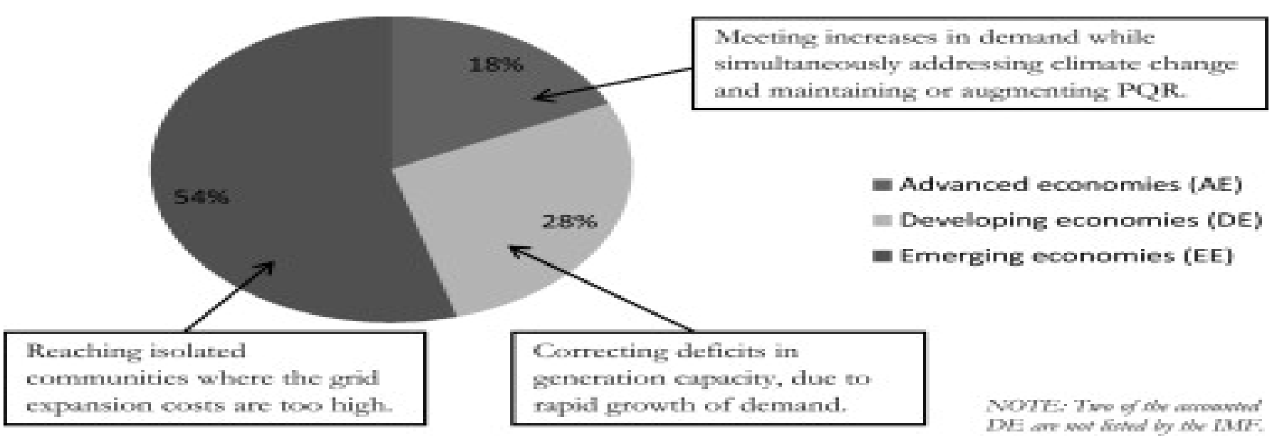

Figure 3. The adoption of the micro grid concept makes sense at various levels.

The micro grid concept focuses on use of multiple decentralized generation into the grid network, with many aspects concerning the grid reliability. (Mendes et al., 2011). The ultimate concept of the micro grid is basically an integrated system of distributed energy generation consisting of both dispatchable and intermittent sources from renewable sources, cogeneration or tri-generation equipment energy storage and power loads working in parallel to or islanded from the grid. This is summarized in figure 4.

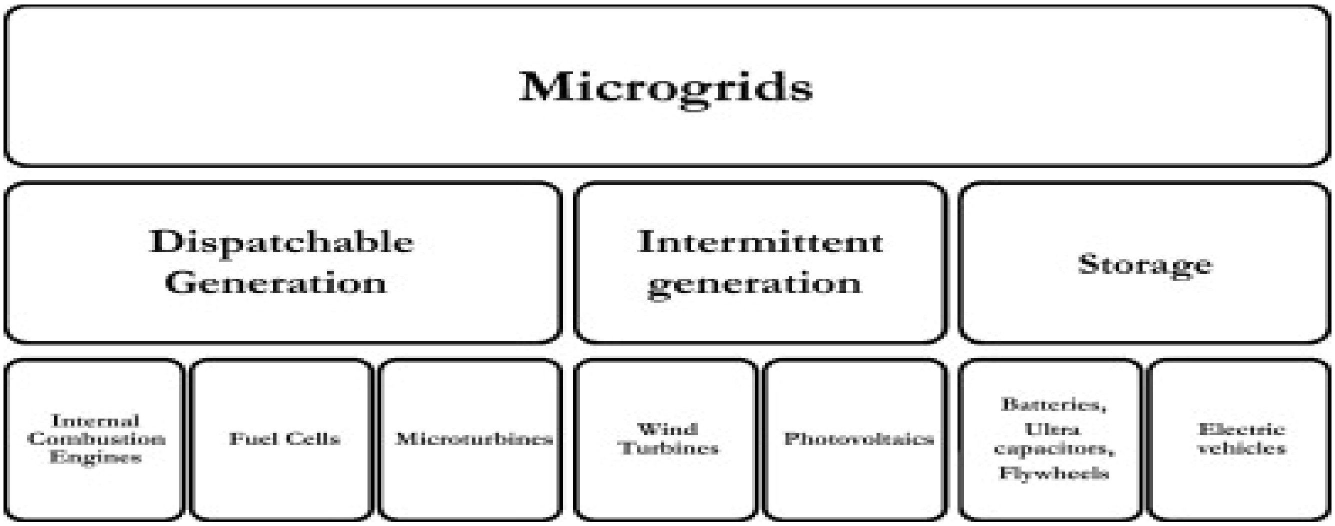

Figure 4. Micro grids and Sources of Energy.

From figure 3, it is noted that energy sources in micro grids can broadly be classified into dispatchable, intermittent and storage.

Micro grids have many potential applications in office parks, hospitals, residential neighborhoods, military bases and school having their own distributed power, heat and cold generation sources. Today, the concept of micro grids is still emerging, but many experts foresee a multi-gigawatt and multi-billion dollar micro grid market globally(Mendes et al. 2011).

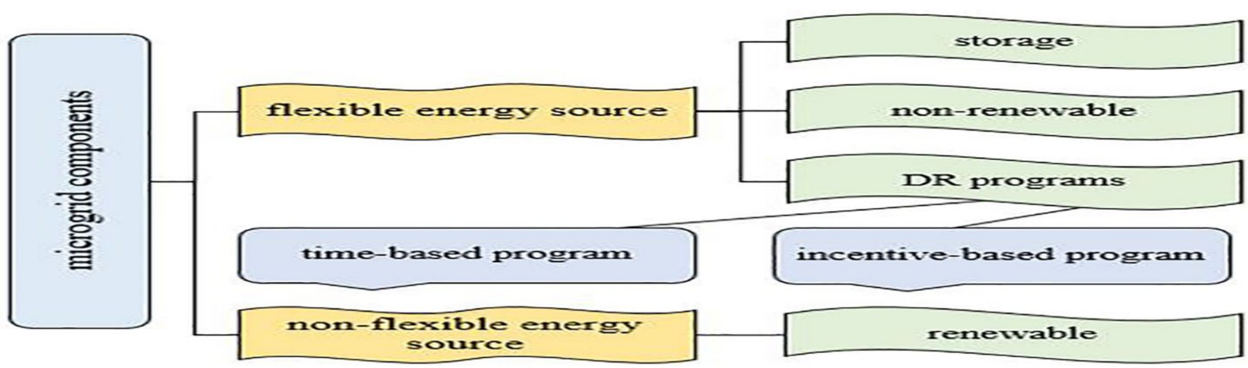

Figure 5. Schematic of a microgrid with different connected energy sources

Micro grid general Structure

The micro grid operates in grid-connected operation and islanded operation with two transients corresponding to the transitions between these steady-states. The micro grid is expected to remain stable and maintain grid code during all these states(sivaranjith, 2018). The components and general structure of a micro grids is shown in figure 6

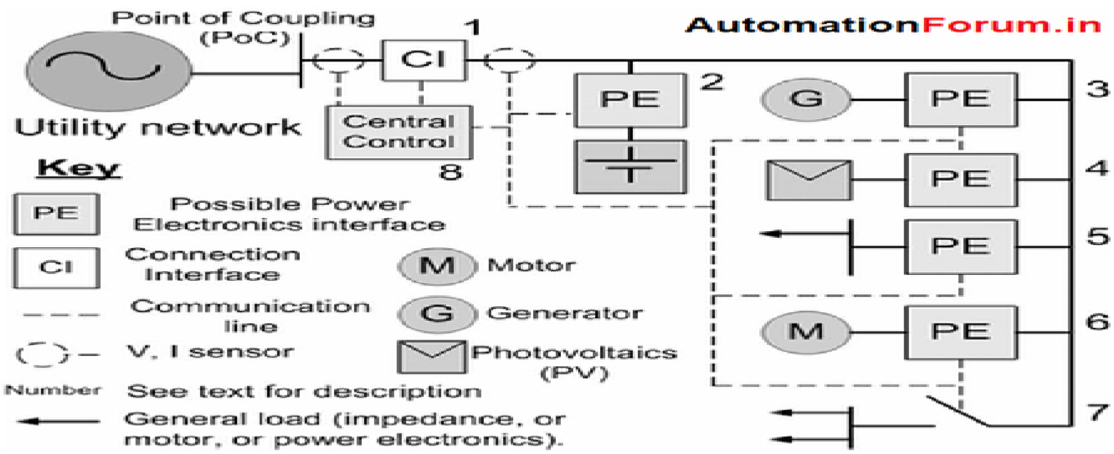

Figure 6. The general structure and components of micro grid

Figure 6 shows the main elements of a microgrids structure which is as follows;

- i.) CI is the connection interface to the utility network assuming the shape of a circuit breaker, but with solid-state switches and also back-to-back power electronic inverter.
- ii.) Number 2 represents energy absorption and injection capability and is used to balance power flows during the micro grid islanding mode
- iii.) Energy storage is applied to control the net power flows to and from the utility in the grid-connected mode, which allows the system to provide improved power quality and voltage control in the presence of high variable renewables.
- iv.) Numbers 3 to7 represent the loads on the system and local energy storage whose requirement is influenced by characteristic.
- v.) 8-1 represents the central control of the system which regulates the instantaneous phase voltages and currents at the point of coupling. Communication is through a telecommunication line, a signal modulated to the micro grid or a signal superimposed on the network voltage(sivaranjith, 2018).
- vi.)

Micro grid Operation

Micro grids are considered to be efficient in allowing higher penetration level of renewable resources and are also considered resilient due to ability to maintain power supply when faults occur in the upstream grid. Micro grids have challenges in control of multiple generators and loads to meet demand and system stability without exceeding operating limits like intermittencies, load mismatches, and voltage instabilities. A micro grid are equipped with Energy Management System (EMS) used to optimize the operation of the micro grid in both isolated and grid-connected mode. Functions of the EMS include forecasting demand and renewable power, generation scheduling of dispatchable units, controls the power exchange with the upstream grid, and execution of demand side management and security assessments. Technically, the energy management system (EMS) stabilizes the micro grid and maintains the voltage and frequency levels during the transition of conditions between different operation modes (Moses J. B. Kabeyi & Oludolapo A. Olanrewaju, 2022; Liu et al. 2013).

Microgrids are designed with capacity to operate in two modes of grid-connected and off grid or islanded modes. During grid operation or grid connected mode, the microgrids trade or exchange power with the distribution utility grid, but they operate autonomously while disconnected to the utility grid during island mode(Moses J. B. Kabeyi & Oludolapo A. Olanrewaju 2022). The two way power transfer characteristics in microgrid, the presence of DGs, DSM, and extensive use of power electronics, challenges of operation control in each mode and need to easily switch between the two operation modes are areas that need further research and development for efficient application of microgrids (M. Kabeyi & O. Olanrewaju, 2022; Parhizi et al. 2015).

The micro grid is connected to the main grid at a point of common coupling (PoCC) which maintains voltage at the same level between the main grid and micro grid and can disconnect when necessary. The switch can be designed to manually or automatically separate the micro grid from the main grid. (Ramanath 2021). The micro grid and main grid coupling are shown below in figure 7

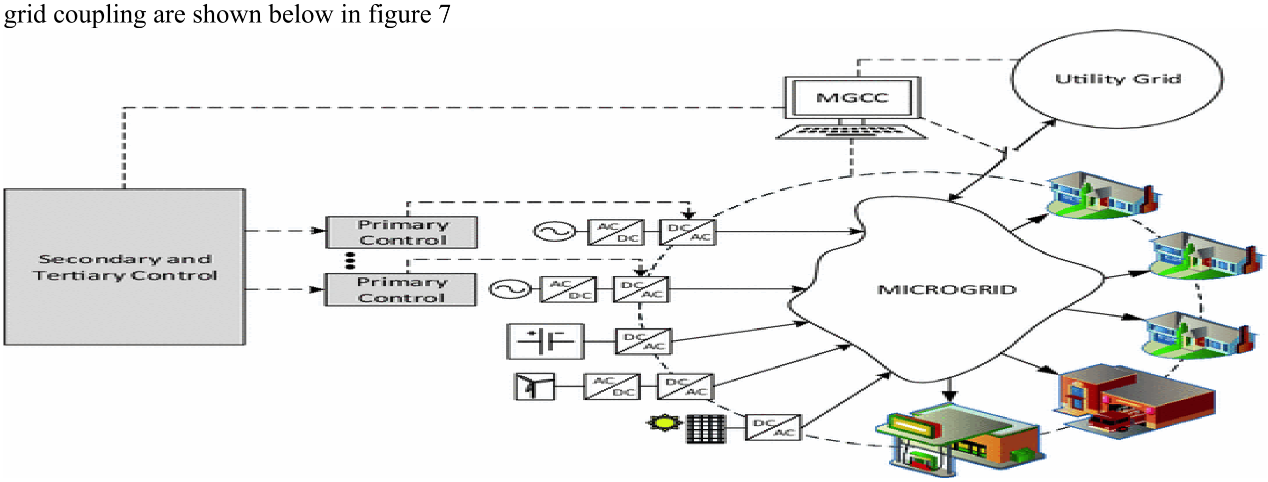

Figure 7. Operation of a micro grid [4]

From figure 11, it is noted that the main components of a micro grid include a power source, power management system, intelligent controls and energy storage system.
2.6 Microgrid Control

Micro grid control enables sharing power among multiple energy sources to maintain stability. The control hierarchy has the primary or inner control embedded in the micro grid, secondary and tertiary controls designed to interface with the main grid and communication purposes. The primary control is local to the micro grid while the secondary and tertiary control form the central control system, that require communication and limiting flexibility while at the same time add complexity and additional costs. This is a plug-and-play type which enables autonomous primary control with minimal or no secondary and tertiary control(Ramanath 2021). Figure 6 shows the microgrid control hierarchies.

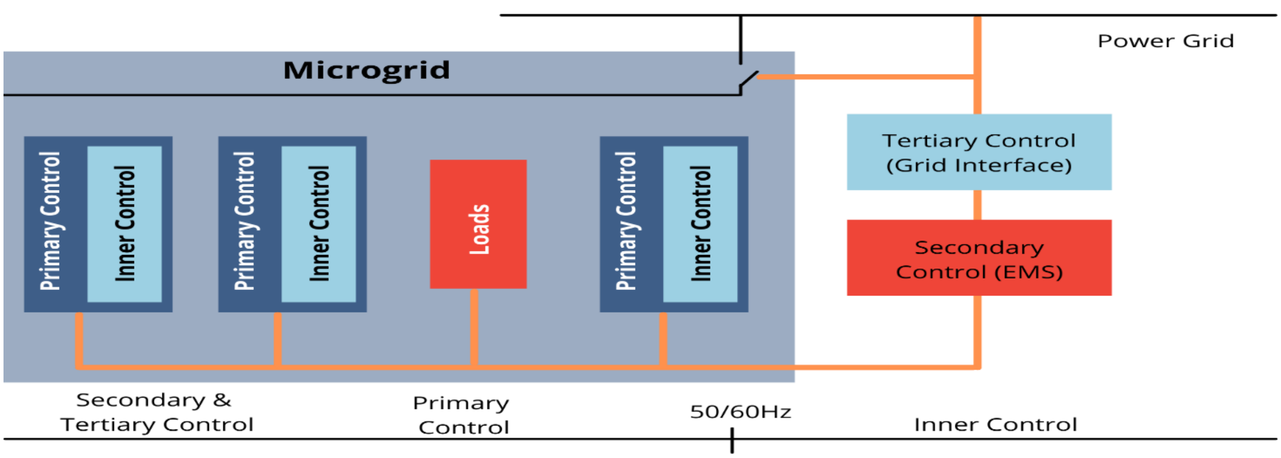

Figure 8. Control hierarchies.

Simulation of micro grids can be done using hardware-in-the-loop technique. Control interface can be simulated using a simulator, and the rest of the system simulated in real-time. Physical systems can be simulated with localized controls and additional system-level secondary and tertiary controls to emulate to represent a complete micro grid behaviour. This facilitate understanding of the behaviour and architecture of the entire system (Ramanath 2021).

A microgrid is a grid system designed to supply reliable power, autonomously, and with high-quality to customers. Coordination of different micropower types to establish a stable frequency and voltage is a complex operation. The control objective in microgrids consist of:

i.) Maintain independent active and reactive power control
ii.) Correction of voltage sag and system imbalances, and
iii.) Fulfil the grid's load dynamic requirements.

Proper control strategies are necessary to ensure proper operation of power systems. The main elements of microgrid control are the micro source and load controllers, microgrid system central controller, and the distribution management system. The microgrid control has three main sections: The upstream network interface, the microgrid control, and protection, local control. (Shahgholian 2021). Figure 7 shows characteristics of the microgrid control level

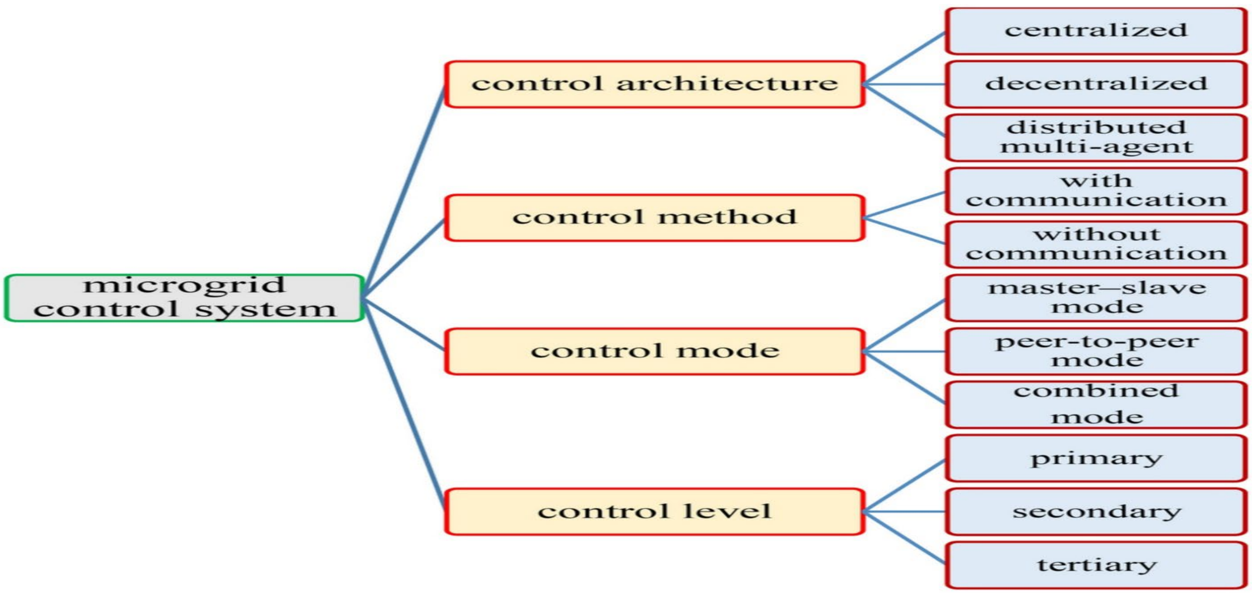

Figure 9. Microgrid Control

From figure 9, it is noted that microgrids control structure can be centralised, decentralised or distributed agent, control methods are use of communication and without communication. The control modes can be master slave, peer-to-peer or combined mode. Based on control level, microgrid controls can be primary, secondary or tertiary.

Communication in Microgrids

The communication systems provide a means to exchange data and monitor various elements to enable control and protection in the microgrid is to. The communication network facilitates communicate of control signals to components in a centrally controlled microgrid. For microgrids having distributed control, the communication network enables components to talk with other components, make decision on its operation, and realize the system predefined objectives. Communications in microgrid facilitate rapid fault clearing and increase the during islanding. (Parhizi et al. 2015). It is necessary to use the communications system to update the protection of microgrids due to the variable nature of microgrid operating conditions. Because of variable microgrid operating conditions and meshed topology of microgrids there is need to use communications for updating the communication settings. The traditional communication-less protection schemes do not apply in a meshed microgrid in which a fault at one location is may not be distinguished from another.(Parhizi et al. 2015; Sandelic et al. 2022).

Demand Side Management

Matching demand and supply real time ensure that the power grid is stable. In the traditional setup, generation has to be increased in response to growing load demand. Demand side management (DSM) concept includes application of measures like energy efficiency and demand response (DR), by working from the consumer side. The U.S. Department of Energy defines demand side management as "changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized for some reason"(Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022). The role of demand side management (DSM) programs is to motivate the electricity consumers to modify their consumption pattern by reduce consumption in a way that it is shifted from the peak. DSM is an indispensable component of microgrids for application inn direct load control or real-time electricity pricing. As a result of the restructuring of power system g and establishment of electricity market, the electricity prices fluctuate based on the time and location of consumption/generation(Kabeyi 2012 , 2022).

There are several benefits of demand side management which widely range from economic, environmental, and technical like reliability. Demand side management leads to cost reduction, alleviates electrical system emergencies, reduces outages or blackouts, enhances power system reliability, and delays or defers capital investment in capacity expansion and delays expansion in transmission and distribution network capacity(Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022).

To achieve efficient load management in demand side management (DSM), the following measures are encouraged:
Promote the use of energy-efficient products and equipment e.g. more efficient lighting technologies,
Sensitize customers and encourage them to shift non-critical power consumption from peak hours to off peak
Encourage construction of high efficiency buildings, and
Create energy awareness and education.

Therefore, deployment of demand side management treats consumers like virtual power plants because they actively participate in stabilization of the grid by planning and monitoring their activities, as they are compensated for lowering, shifting, or modifying energy consumption. Successful implementation of DSM depends on the ratio of controllable loads to the total system load in the grid. Development and adoption of new types of electric equipment and technology like use of plug-in hybrid electric vehicles (PHEV) enhances the ratio of controllable loads hence demand side management. Energy storage in PHEVs enable the storage of electricity and use during peak hours, thus making. PHEVs important components of demand side management (DSM) as a tool for balancing power supply and demand in smart grids and microgrids (Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022; Sandelic et al. 2022).

Microgrid Scheduling

The objective of microgrid scheduling problem is to minimize operation costs of decentralized resources and power exchange with the utility grid, to deliver projected or forecasted microgrid loads for a typical time period. Constraints in microgrid scheduling include energy balance, load management, and DER limitations. (Sandelic et al. 2022).

1.1. Energy Management

An appropriate energy management system is required since a microgrid is an aggregation unit that represents s a generation or load, (Shahgholian 2021). The EMSs in a microgrid are shown in Figure 10

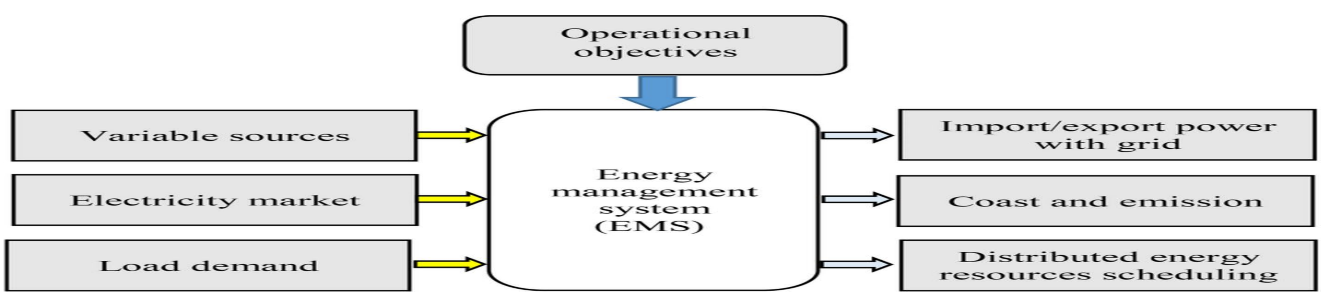

Figure 10. Energy Management System

When we have a massive access into the regular grid by a microgrid, the EMS controlled energy storage is able to smoothen the randomness and intermittency of output power. A decentralized EMS can be applied to coordinate the networked microgrids operation in a distribution system. In the case of islanded mode, the objective of microgrid is to maintain a reliable power supply to its customers. In the case of a grid-connected mode, the microgrid and the distribution network operator are considered as distinct entities own objectives in minimizing their operation costs. (Shahgholian 2021).

Generation Scheduling Aspects in Micro Grid

Generation scheduling in micro grids needs decisions like power exchange with the upstream grid and charging and discharging storage systems. Availability of limited resources to meet demand and the reserve requirement in micro grids makes isolated mode operation of micro grids a challenging task. Additionally, higher penetration renewable generators in micro grids compared to large power systems leads to significant concerns over intermittency of renewable generators and stability of the power system (Liu et al. 2013).

The standards on integration of micro grids are still under development since the concept of the micro grid is still relatively new. The objectives in generation scheduling in micro grids include minimizing the costs, or maximizing by minimizing the total expenses of the micro grid on operating cost of the local generators and the cost of the power supplied by the upstream grid. Others are maximizing the use of renewable generators, minimizing gas emissions, and minimizing power imports the main grid(Liu et al. 2013).

Generation scheduling can be done using a two-stage process that included day-ahead and real time scheduling. A real time digital simulator (RTDS) can be applied to model the operation of a micro grid in real time. RTDS provides the feedback needed to perform the real time scheduling. Decision making modules apply computational intelligence techniques like genetic algorithm (GA). This may not however guarantee an optimal solution(Liu et al. 2013).

3.2. Handling Uncertainties in The Scheduling of Micro-Grids

The main objective behind solving the day-ahead unit commitment problem is generation scheduling in a system to meet the demand and the reserve requirement at a minimum operating cost. Uncertainties in a problem, leads to A solution that may not be optimal or even feasible. It is necessary to consider the uncertainties when solving day-ahead unit commitment problem. The two approaches used to handle uncertainties are additional reserve requirement and multi-scenario stochastic models. Uncertainties are modelled implicitly in the first approach, but the second approach considers multiple scenarios for the load and renewable power generation, thus uncertainties are explicitly represented(Liu et al. 2013)

3.2.1. Sources and effects of uncertainties

Causes of uncertainties include unexpected variations in the system's demand during the day. Integration of intermittent renewable resources introduces similar uncertainties to the unit commitment problem. The variations are however not continuous variations in the renewable power generation, but are due to the partial unpredictability of the wind and solar power because of their forecasting errors. Wind power forecasting tools still suffer from a mean absolute error of 10% on average for day-ahead forecasts. Uncertainties associated with the renewable generators are more significant micro grids because of their high penetration level. And the effects of uncertainties grow as the micro grid size decreases.(Liu et al. 2013) Outage of generating units is another cause of uncertainties in the classical unit commitment problem. Dispatchable generation units can fail to produce power generate power as planned causing a power shortage in the system. The spinning reserve is used to meet such shortage and is equal to unused capacity of the other committed units. A major outage for micro grid include disconnection from the upstream grid which forces the micro grid to operate in isolated mode to supply the entire demand with adequate reserve using only its local generators(Liu et al. 2013).

Application of Micro grids

The traditional grid connects many, businesses, building and other critical infrastructure with power enabling them to utilise multiple appliances and electronic systems. However, the users are interdependent and any failure in one of the interconnected components affects others in the system. This challenge can be solved by micro grids which have ability to operate as standalone systems, whereas they remain typically connected to the main grid. This becomes particularly handy during a crisis, like wide spread power outages or storms(Ramanath, 2021).

A micro grid is typically managed through a central controller that monitors the system parameters, coordinates energy resources, balances loads and controls electrical loads, and disconnects and reconnects of the micro grid to the primary grid. Micro grids with no central controller are not common but are technically feasible, with distributed energy resource having an individual controller and the individual controllers operate in a coordinated manner.

Micro grids can be an effective option to increase the energy resilience, by providing a functional electric power system capable of operating independently of the main grid. The main grid usually supplies primary power, while the micro grid provides secondary dispatchable power in the event of a grid failure. Emergency diesel generators can provide power directly to loads in the event failure of the primary grid and the micro grid.

Many organizations are shifting towards hosting micro grids to reduce possible risks and improve operational performance(Ramanath 2021). Micro grids can be used by organizations to reduce energy cost, increase reliability, and achieve energy sustainability. Since micro grids strategically integrate renewable and non-renewable energy sources, variations due to weather conditions and time-of-the-day based availability concerns can be handled effectively(Ramanath 2021).

Results and Discussion

Microgrids have emerged as important solutions in decentralized generation for both off grid and on grid operation. The microgrids islanding capability is one of the most salient features of a microgrid which is enabled by application of switches and power electronics making it possible for microgrid to be disconnected and reconnected from the utility grid which effectively increases reliability and availability power supply to consumers(Nageswara Rao et al., 2019; Parhizi et al., 2015). There are many advantages and disadvantages of using microgrids in power systems as discussed below.

Advantages of Micro Grids:

i.) Microgrids have significant benefits to customers and utilities as a result of higher reliability introduced by self-healing capability at local distribution network
ii.) They have the ability to disconnect from the main utility grid and operate independently in case of a disturbance
iii.) Micro grids reduce demand on utility grid which reduces chances of grid failure
iv.) They can be linked to both heat and electricity which increases the overall system efficiency(sivaranjith, 2018)
v.) Micro grids provide more reliable power because they are networked with more redundancy than a single building level backup generator.
vi.) Micro grid components are used in both grid and off-grid operations making the system more reliable because this allows more frequent use and testing compared to stand alone systems.
vii.) Micro grids are designed to share load across generators which increases overall system efficiency by allowing powering more load with the same amount of fuel than individual generators I applications involving diesel engines. Sharing load also help prevent a potential technical problem called wet stacking where unburned fuel passes into the exhaust system due to low load operation of generators.
viii.) Micro grids are more flexible to varying critical loads and mission requirements in cases of emergency. In a micro grid, power can be sent to different loads compared to cases where a generator is tied to specific loads.
ix.) Micro grids can accommodate more variable renewables like wind and solar as well as variable loads like electric vehicle charging.
x.) Use of micro grids provide cost savings from operation during grid connected modes
xi.) Use of microgrids leads higher power quality by efficient management of local loads
xii.) Microgrids increase the use of mostly renewable local energy resources leading to reduction in carbon emission by the diversification of energy sources.

The use of microgrids is economical due to reduced costs of transmission and distribution (T&D) costs by use of cheaper local resources and offering energy efficiency through real-time response to market prices.

Disadvantages of Micro Grid

As much as micro grids have significant advantages, they also have various disadvantages compared to the traditional grids or purely of grid systems (Booth et al. 2020):

i.) challenge in maintaining voltage, frequency and power within acceptable limits compatible with the main grid
ii.) they require storage banks which are expensive and require space and maintenance
iii.) it is difficult to resynchronize to utility grid is difficult

iv.) difficult and expensive protection is dis needed(sivaranjith, 2018)
v.) micro grids have higher upfront capital costs based on site and available infrastructure.
vi.) micro grids complex and require more specialized skills for operation and maintenance.
vii.) micro grids require more controls and communications infrastructure and generally have a higher cyber-security risk(Booth et al. 2020).

Classification of Microgrids

Microgrids can be classified into different categories. A flexible microgrid should have capacity to import and export energy from/to the grid, and also control the active and reactive-power flows, trough management of energy storage(Shahgholian 2021). Figure 11

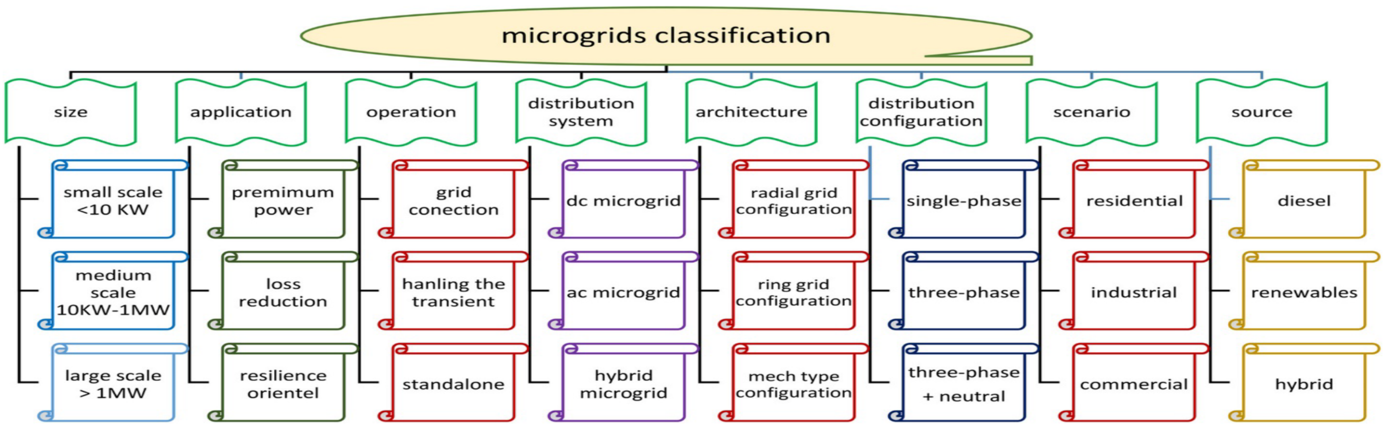

Figure 11. Classification of microgrid

From figure 11, it is noted that microgrids can be classifies based on various dimensions and parameters e.g. based on size, they can be small scale, medium or large scale; based on applications, microgrids can be used for premium power, loss reduction or for resilience purpose; on the basis of mode of operations, microgrids ae grid connected, standalone or mixed; based on the type of distribution systems, microgrids can be dc, type, ac type or hybrid; on the basis of architecture, microgrids can be classified as radial, ring grid or mesh configurations; based on distribution configuration, they can be single phase, three phase or three phase plus neutral; on basis of scenario or application, they can be commercial, industrial or residential; while on the basis of power source, microgrids may be diesel engine based, renewable energy base or hybrid based sources.

Based on Operation Modes

Microgrids can be classified as grid-connected, transited, or island, and reconnection modes, which enables microgrid to have higher reliability of energy supplies by disconnecting from the grid in case of reduced grid power quality or when power supply fails. For islanded or standalone operating state, the microgrid should be able to independently maintain reactive power balance because of nonexistence of an infinite bus. The main challenges in islanded mode are maintenance of appropriate magnitude and frequency of voltage and maintenance of power balance in the system. When operating in islanded mode, the microgrid has no support from grid and making the microgrid control more complex. For in grid-connected mode, microgrid is coupled to the utility grid via a static transfer switch. The voltage for the microgrid is imposed by the host utility grid. The microgrid can also exchange power with the external grid to maintain supply in the microgrid with a bidirectional flow of power. The power supply of islanded microgrid should be able to meet load demand. (Shahgholian 2021).

Classification based on distribution system

The microgrid can be classified into an AC power system, a DC power system, or a hybrid system in terms of power. The DC microgrid can be used in grid-connected mode or in autonomous mode with the distribution network being either: monopolar, bipolar and homopolar type. In AC microgrid, all the renewable energy sources and loads are connected to a common AC bus. The main limitation of AC microgrids is that they are more difficult to operate and. Based on the distribution system, the three types of AC microgrids are single-phase, three-phase without neutral-

point lines, and three-phase with neutral-point line. DC microgrids are more reliable, more efficient and convenient in for connection to different distribution energy resources compared to AC microgrids (Shahgholian 2021).
It is through the power electronic interface that power flow between the utility grids and networks is done. The direction of power flow is a result of the balance between power generation and the load. Hybrid microgrids systems improve overall efficiency of the network, by minimizing conversion stages, enhance reliability, reduce interfacing devices, and minimize energy costs. There is significant research interest in on the application, protection, and stability of hybrid, DC, and AC, microgrids (Shahgholian 2021)

Results and Discussion

The demand for decentralized energy resources has been growing particularly for solar and wind that can be exploited without relying on the traditional grid. On the other hand, advances in digitalization and power electronics have transformed the industry. Microgrids, which small scale power networks have emerged as a result of these developments. Microgrids maximize efficiency and deliver uninterrupted power supply by integrating multiple energy sources including storage (Ponstein 2022)

Microgrids constitute a more cost-effective and efficient electrical power systems having higher reliability, flexibility and scalability compared to the conventional grids. The share of microgrids in modern power systems has increased considerably as reflected in the number of newly deployed microgrid projects globally which are increasing annually with the as much as 546 new microgrid projects deployed in 2019 in the US alone which accounted for 4 times higher the number of the power projects compared to 2013(Kabeyi, 2012; Sandelic et al. 2022). Microgrids have also proved to be a reliable solution for electric power supply in the event of failure of the main grid is as demonstrated in the case of Texas blackout in January 2022(M. Kabeyi & O. Olanrewaju, 2022; Sandelic et al. 2022).
Locating microgrids at the proximity of consumers minimizes transmission and distribution loses (Sandelic et al. 2022).

Microgrids offer numerous s benefits to power consumer and the utility like offering a healthier power quality and they are ecologically friendly. (Nageswara Rao et al. 2019; Parhizi et al. 2015). Microgrids have economic and reliability benefits to electricity customers and the utility grid as a whole. Even though an accurate assessment of microgrid economic benefits is difficult while some results reliability improvements, may be difficult to comprehend for customers which leads to the desire to have efficient planning models to ensure e economic viability of microgrid deployments and justify investment (Sandelic et al. 2022). The reliability of microgrids is enhanced by incorporating multiple sources of energy and technologies e.g. renewable energy sources like solar panels, diesel generators, wind turbines, battery storage, diesel gensets and combined heat and power (CHP) modules–operating separately or in parallel. gas turbines and storage batteries used both on grid and off grid modes(M. Kabeyi & O. Olanrewaju, 2022; Sandelic et al. 2022).

There is no single compulsory design process that must be followed in microgrid design since the procedure is still being standardized, but certain standards and technical brochures like IEEE and Cigre may be applied to different aspects in the design process like benchmarking, modelling, design of communication and control systems and validation instructions (Sandelic et al. 2022). The design objective of microgrids according to IEEE standards, are categorized as economic, environmental, and reliability-related, each with some design criteria. For reliability-oriented design, the standard distribution system reliability indices are used as adequate design criteria (Sandelic et al. 2022).

It is recommended that reliability evaluation should incorporate the power electronics reliability since they are prone to failure (Sandelic et al. 2022). Power electronics impact on microgrid system reliability for microgrids that have large installation rate of power electronics-interfaced DERs. Their wear-out failure rate ought to be included in the standard power system reliability procedure to avoid deteriorated design reliability(Sandelic et al. 2022). For accurate reliability assessment, of power electronics-based microgrid, procedures should cover different layers of the system namely converter level, component level, system level and interaction need in design(Sandelic et al. 2022).

Microgrids have revolutionized and continue to revolutionize the energy sector by combining energy storage renewable energy sources, and backup generator sets. The microgrids can incorporate systems and devices like Solar panels, battery banks, wind turbines, diesel gensets and combined heat and power (CHP) modules operating both on grid and off grid. Benefits of using microgrids include power diversification, energy security and supply efficiency and can be applied by organizations to achieve their green initiatives, cut emissions and energy cost optimization.

optimize costs. Studies have shown that well designed microgrids can deliver a good return on investment(Ponstein, 2022; Shahgholian 2021)

Conclusion

Microgrids constitute a technology option that can help deliver a sustainable and efficient power system by employing distributed or decentralised energy resources for efficient generation and supply local electricity load and increase the reliability of a local distribution network. Proper design and planning of microgrids is important for them to yield all the advantages of the distributed energy concept for the power systems, both local and the clinked central power system. This calls for a reliability-oriented design for microgrids that utilise a large share of the variable and intermittent renewable energy-based, and power electronics-interfaced distributed energy resources. Experience has shown that the power electronics used are prone to wear-out failure and can potentially have adverse effects on the on the performance of the entire power electrics dominated power system. Micro grids constitute an ultimate form of decentralized electricity, heat and cold supply, with operations separated from the main distribution system as autonomous systems or connected to the distribution systems as grid-connected systems. Grid-connected micro grid can be of help during a system fault, by supplying power to the main distribution system, feeding part of its loads for fault detection and service restoration. Micro grids have emerged as a competitive alternative to the final delivery of energy to consumers in combination with on-site production of heat. Distributed generation grouped in micro grids can introduce a richer set of tools for supply of o heat and power, at higher reliability, security, flexibility and power quality in the conventional grid. A micro grid is typically managed through a central controller that monitors the system parameters, coordinates energy resources, balances loads and controls electrical loads, and disconnects and reconnects of the micro grid to the primary grid. Micro grids with no central controller are not common but are technically feasible, with distributed energy resource having an individual controller and the individual controllers operate in a coordinated manner.

Micro grids can be an effective option to increase the energy resilience, by providing a functional electric power system capable of operating independently of the main grid. The main grid usually supplies primary power, while the micro grid provides secondary dispatchable power in the event of a grid failure. Emergency diesel generators can provide power directly to loads in the event failure of the primary grid and the micro grid.

Microgrids have expanded in scale of operation, coverage and penetration due to their e significant benefits. The deployment of microgrids is however still facing challenges to efficiently design, control, and operate them both as off grid and islanded systems hence the need for extensive research activities. As a result of the need to have an across-the-board view of the microgrid integration in power systems, this study presented a review of issues concerning microgrids and identified various aspects of microgrids including their role in distributed generation, microgrid value propositions, the applications of applications of power electronics, and other system elements, microgrid benefits and limitations and areas for further research.

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