Overview of Distributed Energy Storage and Microgrids

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Abstract: *Renewable energy resources (RES) are the most promising sources of energy for the world's future energy requirements. These site-specific resources range in size from a few kilowatts to a megawatts based on their accessibility and location. Contrary to thermal and nuclear power plants, the energy they produce is typically not in large quantities. This essay explored energy storage systems, microgrid architectures, and related topics.*

Keywords: ***RES, ESS, Microgrids, DERs.***

I. Introduction

The majority of the world's countries look to renewable energy resources (RES) as one of their future energy supply options. These site-specific resource range in size from several kilowatts to a megawatts based on their accessibility and area. Contrary to thermal and nuclear power plants, the energy they produce is typically not in large quantities. As a result, they do not need extensive power transmission lines to transfer the power from generators to loading centres. Less money is invested in lengthy transmission circuits as a results, and local distribution connections for the provision of electricity are needed that are relatively inexpensive[1]. In a nation like India, in which at least 30 million people still live without electricity in distant rural areas, they are showing promise as prospective sources of power energy production. The scenario largely applies to underdeveloped nations worldwide and other developing nations.

Researchers have seen a trend toward the usage of renewable energy sources in recent years due to the depletion of fossil fuel resources and, in particularly, environmental and economic concerns. Engineers create power from renewable energy sources locally at distributed energy networks. Distributed Energy Resources are these kinds of resources (DERs). Direct connection of DERs to grids is unacceptable due to their features. Consequently, it is crucial to use electronic power interfaces (dc/ac or ac/dc/ac).. Utilizing DERs and microgrids has advantages in terms of the environment, operations and investment, power quality, cost savings, and market difficulties. Improvements in the dependability and quality of a power system's providers may improve network congestion and lessen the demand for bulk transmission. However, active electricity production and storage at the low voltage level were not intended for the power distribution network.

Due to DERs' unpredictable behavior, Energy Storage Systems (ESSs) might be crucial to electrical power systems and should work with micro sources and make up for active power generation's shortcomings. The flexibility of employing microgrids will be improved by renewable energy and energy storage technologies. Distributed Energy Storage (DES) systems can function in one of three modes: power charging, power discharge, or managing voltage mode, depends on the situation[2]. When operating in power charge mode, DES draws currently from the network to charged, when operating in discharge mode, DES sends current power to the system, and when operating in controlled voltages mode, DES functions as a regulator and attempts to manage DES terminal voltage.

The "decentralization, decarbonization, and democratization" of the world's electricity grids is currently being noted, often from the bottom up. The need to control power costs, upgrade outdated infrastructure, increase resilience and reliability, lower CO2 emissions to counteract climate change, and deliver dependable electricity to areas that lack power grid are what motivates these developments, commonly known as the "three Ds." Microgrids have emerged as a number of use cases for deploying distributed energy resources (DERs) that can meet the diverse needs of different community members, from metropolises New York to rural India[3]. The balancing act of the factors driving deployment and the specifics of the solution may vary depending on the location.

Due to its many benefits, energy production has become more prevalent on the mains network during the past few years. It relies mostly on renewable resources, which lessens the impact on the environment and makes it possible to use and gather localized sources of energy. In order to reduce losses, line loads, and the need for power flow, the mains grid must be examined for the effects of distributed energy resources, which are on the rise. On the other hand, because of their sporadic nature, randomness, and the uncertainty brought on by meteorological conditions, it is difficult to incorporate renewable energy sources direct into to the mains grid[4]. According to the definitions of micro - grids, they are small-scale distribution networks with capacity for generating, storing, and loading. They can operate independently or in conjunction with the power networkThe reliability and power quality of a people connected to them are improved by their capacity to operate both attached to and away from the mains grid. In addition, practically zero energy buildings (NZEB) can be produced if these microgrids are planned using an eco-design.

II. MICROGRIDS

Microgrids can be built to accommodate either direct current (DC) or alternating current (AC) (DC). Each solution has unique qualities, which suggest various benefits and drawbacks that should be thought about. Microgrids are integrated systems where a network powered by distributed energy resources (DERs) supplies a variety of dispersed loads. Both components make up a microgrid's main structure. Residential, industry, and other types of loads can all be linked to a microgrid. Critical/sensitive and Noncritical loading are the two basic categories taken into account [5].

A micro is a self-sufficient power system that provides power to a specific geographic area, such as a neighborhood, business district, hospital complexes, or college campus. One or more types of distributed generation units (solar panels, wind turbines, combined heat and power plants, and generators) are used in micro - grids to generate power. In addition, a lot of more recent micro - grids have grid storage, usually in the form of batteries. Additionally, several now have stations for charging electric cars.

A microgrid is a tiny power network that can run by itself or in cooperation with other tiny power systems. Distributed, dispersion, decentralised, districts, or embedding energy generation are terms used to describe the use of micro - grids. A microgrid could be any small, localized power plant with its own production, storing, and boundary-definable resources. It is frequently referred to it as a hybrid microgrid if it can be linked with the local power grid.

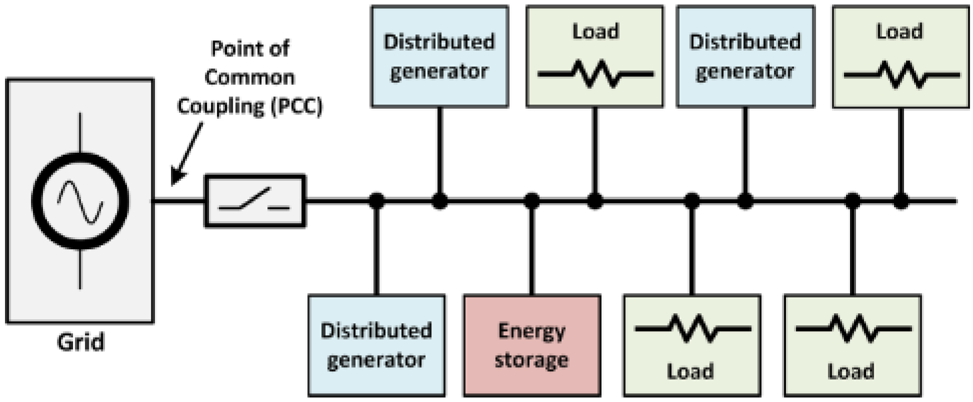

Figure 1 Simplified Microgrid

Microgrids are frequently used to provide backup power or supplement the main electricity network during moments of high demand. They are typically backed by generating units or renewable wind and solar energy supplies. The main grid can be made less vulnerable to localised disasters by using a microgrid plan that incorporates nearby wind or solar resources to offer redundancy for critical services. Buildings having the ability to generate electricity through solar panels and backup generators can also make money when the power isn't on. In conjunction with smart grid developments, surplus energy can be sold back to nearby micro - grids to generate income in addition to giving local power systems resilience and capability.

A microgrid is a network of interrelated loads and dispersed energy sources that operates as a single, controllable entity in relation to the grid and is contained within well defined electrical boundary. In order to operate in both energy and islands modes, a microgrid can link to and disengage from of the network. A microgrid needs a generation source to be able to supply its users' needs for electrical. Since distributed generation are a more recent idea, their electricity has traditionally come from "behind the meter" fossil fuel generators, such as gas-powered generating units. However, many of the micro - grids being constructed today produce electricity with a combination of solar + battery storage due to the declining cost of solar, as well as the environmental advantages of moving away from fossil fuel generating.

III. Literature review

The phrase "distributed generation" refers to the process of generating power at the micro scale, close to the final consumer, employing both renewable and non - renewable distributed energy generation (DEG) resources, such as solar, windy, hydropower, geothermal, and diesel generators, among many others. The optimization methods for hybrids DEG devices are reviewed in this work, taking into account both stand-alone and energy devices. On DEG systems, a variety of optimization strategies are employed, including analytical, artificial intelligence (AI), and hybrid methods. The selected journal papers published, in particular, over the previous five years, are included in this work. A brief history of optimization strategies has been emphasized, with a focus on identifying the most popular methods to serve as the foundation for an investigation of the techniques now used on hybrid DEG systems[6]. Particle swarm optimization (PSO) is the most popular AI methodology, according to the research, and it continues to dominate technologies used for DEG optimisation. The current definition of the objective functions in the optimisation of hybrids DEG systems includes maximizing dependability, minimizing projected interruption costs, and optimizing the DEG resource operation schedule. A review of hybrid renewable/alternative energy (RE/AE) power production systems with a regards to energy sustainability is presented in this document, which was created by a special task force of the IEEE PES Renewable Technology Subcommittee. It draws attention to certain significant problems and difficulties with the planning and control of energy in hybrid RE/AE systems. Energy management and control, storage requirements, generating unit sizes, and system configurations are all covered. As well as providing statistics on the present state and projected growth of renewable energy production, [7] also outlines the major obstacles to the broad adoption of RE/AE power generation systems as well as its future research agenda. Researchers working in this field should find the extensive list of references provided at the end of the publication to be helpful.

[8] reviews the microgrid architecture and several converters control strategies. A microgrid is described as a linked network of loads, energy storage devices, and distributed generation. Distributed generators' potential is realized by this new idea. Using an inverter, an AC microgrid connects various AC distribution generating, such as wind turbines, and DC distributed distributed generation, such as PV and fuel cells. While in a DC microgrid, a dispersed generator's outputs must be transformed from AC to DC using rectifier diodes before the generators may be linked. The repeated AC-DC-AC and DC-AC-DC reverse conversion that take place in individual AC-DC microgrids can be avoided with a micro grid. All distributed AC generators will be linked to a Micro - grid, and all distribution DC generators will be linked to a Micro grid, in a hybrid microgrid. When one microgrid is overloaded, power is transferred to the other microgrid using an interconnection converters, which is employed in both microgrids for power balancing. A discussion of connecting conversion control mechanisms is provided in the conclusion.

The main barriers to the introduction of microgrid-based power systems are their remote locations, technical and financial limitations, and the negative effects of renewable energy sources (RES). A microgrid (MG) based on hybrid renewable sources, including photovoltaic (PV) and winds, can supply power to a remote area and can either run totally independently of the grid or lessen the impact of RES onto the grid. Additionally, the construction of a hybrid renewable source may significantly reduce the intermittent nature of the individual RES. [9] discusses the critical concerns around an MG's hybrid RES. In this study, stability problems in an MG, advantages of hybridized renewable sources, and capacities optimisation of sources of energy are examined. This study investigates how a D-STATCOM can support transient response.

Modernized power systems are dependent on integrating dispersed energy resources. They can enhance the safety and dependability of electric networks as well as reduce emissions and resistivity losses. They can be of various types and may include solar panels, wind turbines, fuel cells, storage systems, and fossil-fueled producing units. The operation and control strategies of integrating distributed energy resources will be explored in [10] after a brief introduction to the various distributed energy resources. Reviewing the literature in this area and identifying knowledge gaps can provide future researchers with important pointers for their future work.

Investigate the power efficiency of a hybrid AC/DC microgrid in [11] with a penetration level of DERs, such as electric vehicles, heating systems, and solar panels. According to earlier studies, the grid operators typically manages the energies of the hybrid microgrid in a centralized manner, compromising the confidentiality of personal information and increasing the likelihood of a single point failure. To create day-ahead schedules independent with exchange of information and get the best energy management solution, use the AC subgrid and the DC subgrid. The mixed-integer quadratic programming (MIQP) model is used to define the energy management issue for the hybrid microgrid, taking into account the operational limitations of the DER and power storage systems, the system operational constraints, and the converters operating parameters.

Comprehensive evaluations of the literature on a variety of topics related to hybrid microgrids (HMGs), including mathematics, numerous optimization approaches, and commonly used optimization methods with equality and inequality constraints, etc.[12]. The inherent characteristics of both traditional and contemporary optimization approaches can be identified. Special attention should be paid to renewable energy sources, including wind and solar, as well as energy storage devices. In addition, the unpredictability of solar and wind energy resources is addressed, and appropriate forecasting applications are discussed. To determine the benefits and drawbacks of different HMG planning and design approaches, comparisons among them are compiled and critiqued.

Microgrid implementation has proven to be the most efficient way to achieve feasible large-scale integrating of distributed energy resources (DER) into the existing grid infrastructure. [13] examines the key components of DER-based microgrids and provides simulations to look into how DER sources, EVs, and energy storage systems (ESS) affect the resilient functioning of practical topologies. The concept and definition of a micro - grid, a compared of control strategies (primary, secondary, and tertiary strategies), energy management techniques, problems with power quality (PQ) in DER-based microgrids, and applications of cutting-edge technologies like ESS and EVs to microgrid reliability are the main areas of emphasis. Following a review of the various DER source-based microgrid characteristics, simulations are run to confirm the findings of earlier studies on the effects of solar, wind, ESS, and EVs on the microgrid carrier frequency. To evaluate the effects of DERs, ESS, EVs, and their operating techniques on the microgrid dependability elements, additional simulations are performed.

A transition toward co-producing prosumers is necessary for the generating, integrating, storing, intelligence, and demand response of renewable energy sources. Electricity as a commercially, private good distributed via a public grid needs to be recast as a jointly generated common good. Peer-to-peer delivery (P2P) applications is necessary for popular prosumer-based DES[14]. In addition to eliminating legal barriers and transaction costs for P2P and coproduction, policy should refrain from interfering in these matters. Space is the main problem that makes DES scarce, hence prosumers' community should have more authority over the land use decisions that will be made in order to build their DES infrastructures.

Control issues develop as dispersed sources of energy are incorporated into traditional power networks at a faster rate. Microgrids can effectively address this. This study looks at the design of micro - grids, classifies them, and explores the literature on the control goals for islanded mode. It finds that the deployment of micro - grids improves the network intelligence of the traditional electricity system. It also lists the goals of microgrid controls along with the most frequent issues and their fixes[15].

Rural electrification is a crucial step toward the rapid and sustainable development of underdeveloped countries. Distribution utilities face a difficult problem when supplying electricity to extremely remote areas. One of the practical options would be microgrids with distributed generation based on renewable energy and employing locally accessible energy resources. An analysis of current microgrid innovations using the Hybrid Renewable Energy System (HRES) in [16] The modeling, control, dependability, and power management of microgrids with HRES are presented together with a brief discussion and analysis of these aspects. This report also includes a brief survey and analysis of the possibilities for HRES energy production in South Asian countries.

Climate variations have an impact on the power generated by solar and wind turbines. If there are inadequate capacities storage devices, like as battery storage, or backup devices, such as diesel generators, then both the wind and solar devices are unreliable. When both devices (wind turbine and photovoltaic) are integrated with the storage systems, the microgrids' reliability rises. It takes a large enough storing battery bank to supply the power needed to meet load demands on cloudy and non-windy days. Therefore, the required elements of the hybrid microgrid are assigned based on the best placement of the component. The present trend of hybrids renewable energy source optimisation shows that artificial intelligence may deliver worthwhile microgrid operations optimisation without the need for comprehensive long-term meteorological data [17]. This study also examines contemporary hybrid energy practices. It gives a physical model of renewable energy sources together with a variety of approaches and ideas for hybrids topology control.

IV. ENERGY STORAGE SYSTEMS

One of the most crucial elements for a microgrid's smooth functioning is its ability to deploy distributed resources (such as solar and wind energy) and maintain a balance between generation and consumption for strength and power. This is done with the help of energy storage devices. Adding it to a DC system is simpler. Then, during times of high demand, electricity can be generated using the energy stored. In three necessary situations [18], energy storage systems assume this duty:

Maintain the balance of power in a microgrid despite load variations and transients as DGs lack the ability to quickly react to these disturbance due to its lower inertia;

- enables the DGs to function as dispatchable units and offers ride-through capabilities if there are dramatic variations in intermittent energy sources;
- Offers the initial energy necessary for a smooth transition.
- However, one drawback is that additional space and upkeep are required for the battery banks where the electrical energy must be kept.

When spread all through the electricity network (for example, at the distribution level, collocated with loads), ES systems can offer a variety of services [19]. Four major categories can be used to classify ES network service:

1) Energy Shifting: Energy produced during times of surplus supply can be stored and transferred to times of high demand. This can significantly increase the value of sporadic renewable sources.
2) Peak Shaving: Local ES systems can provide short-term load surges, which lowers the peak demand higher at different layers in the power network hierarchy. As a result, less generation/transmission infrastructural capabilities are critical, and peak power charges are avoided.
3) Power Quality Regulation: ES devices can be used to solve voltage/frequency offsets, harmonics, voltage instability, and low power factor that are problems with network energy quality.
4) Spinning Reserve: In the event of an islanding, ES systems can supply backup power, enhancing availability.

Once charge/discharge losses and depreciation due to lifetime degradation are accounted, ES devices' relatively high cost of energy provisioned compared to traditional generating units makes proper use of them imperative. ES technology are suited for specific services because to their varied properties. Charge/discharge efficiencies, specific energy (kWh/kg), specific power (kW/kg), cost per kWh of energy and cost per kW of power, cycle life, and self-discharge rate are all significant attributes.

V. ARCHITECTURES OF MICROGRIDS

Depending on how the AC and DC buses are linked, micro inverters can be divided into six major groups. The following categorisation is being suggested: There are several types of microgrids: AC, DC, hybrid AC-DC, AC with DC storage, DC zonal, and solid state transformer (SST) based.

1. AC microgrid - This type is often referred to as the CERTS architectural, or Consortium for Electric Reliability Technology Solutions. The majority of distributed energy resources need DC/AC electronic power interfacing since the AC microgrid has one or more AC buses and all devices must connect to it using an AC interfaces. At the Point of Common Coupling, the microgrid is coupled to the main grid (PCC). As a result, from the perspective of the distribution grid, the entire microgrid can serve as a feeder. The electricity comes straight from the grid in an AC microgrid architecture that is operating in energy modes, avoiding any series-connected converters; this feature offers a high level of reliability. Because the feeds operate at the same frequency and voltage as the grid, all loads, generating, and energy storage systems must comply with grid requirements. The components that operate at network frequency and voltage make use of a fairly mature technologies and are therefore very dependable. It is important to note that the current electricity grids are easily adaptable to an AC microgrid design[19]. The main disadvantage of this architecture is the substantial amount of complicated electronic power interfaces needed (inverters and back-to-back converters), which might lower the overall micro grid's efficacy and dependability. Comparatively to those with fewer components, complex electronic power converters are less reliable.

2. DC microgrid - If it is desirable for the DC microgrid to exports the excess energy produced, this electronic power interface must be bi-directional. The DC microgrid is connected to the grid using an AC/DC converters. Most distributed generators require a DC/DC or AC/DC electronic power interface to be linked to the DC microgrid's DC-bus, which has a regulated power supply. To adjust the voltage levels to the necessary conditions for the AC loads, you need a DC/AC converters. Depending on the bus voltage, DC loads may occasionally be usually connected to the DC bus or may require a DC/DC converter. Some capacitors may be introduced to the bus without any electrostatic interactions to give quick and reliable load steps. Since the primary AC/DC converter controls the DC bus voltage, the DC bus voltage exhibits exceptionally good quality even with subpar distribution grids. Without the primary AD/DC converters, the microgrid must control the DC bus voltage when the distributing grid fails. The Micro - grid architecture has some benefits over the AC microgrid, including fewer (and simpler) power converters (DC/DC and rectifiers), the ability to adjust the DC bus voltage to the microgrid's needs, and extremely high-quality DC bus voltage that allows some DC loads to be actually connected to the DC bus.. The series-connected bidirectional AC/DC handling the entire power flow from/to the distribution network is the biggest disadvantage of this architecture because it lowers reliability.

3. Hybrid AC–DC microgrid

The bidirectional AC/DC converter connects the AC microgrid and the DC sub-grid that make up the AC-DC hybrid microgrid. Both the AC and DC feeders can be used to link dispersed generators. In contrast to DC loads, which are connected to the DC feeder and use a voltage regulator to adjust the reference voltage as needed, AC loads are connected to the AC feeder. Based on the power balancing at the DC feeder, the DC sub-grid may operate as a generating or a load of the Micro - grid. In this system, the benefits of AC and DC micro-grids are combined. High reliability is provided by the direct power grid, the opportunity to use existing equipment with the AC feeder, and the ability to employ fewer, simpler converters with the DC feeder. A power converter is not important to link some DC loads directly to the DC feeder. This microgrid architecture is appropriate for installations that combine more durable loads with critical loads (at the DC feeder) (at the AC feeder).

4. AC microgrid with DC storage
It is feasible to deploy the energy storage systems on a separate DC bus from the distributed generators and the AC loads, improving the flexibility of the AC microgrid. A static switch is used to link to the grid; it controls the changeover from meet this requirement to grid-connected operating modes and vice versa. The name of this design is AC microgrid with DC storage. Generators and loads may be dispersed among several feeders or clustered at a solitary one. Each power storage device is connected to the others via an AC/DC bidirectional electronic power interface, which is installed in a separate DC bus for the energy storage system.

5. Solid state transformer based microgrid
A solid state transformers is used in place of the frequency control transformer in this type of construction (SST). In comparison to frequency control power transformer, the size and weight of the SST can be reduced by using a high

frequency transformers, and it also supplies AC and DC feeds to the microgrid. The SST also controls the flow of electricity between the feeders and the grid. In contrast to DC loads, which are connected to the DC feeder, AC loads are connected directly to the AC feeder. Connecting decentralized generating to the DC feeder is favored because it has simpler and more reliable electrical connections and control algorithms.. The AC/DC converter is the first phase; it maintains a constant dc voltage and controls the current flow with the power system; the DC/DC converter is the second stage; it adjusts the reference voltage to the needs of the DC loads; and the DC/AC converter is the third stage; it produces the high-quality voltage for the microgrid AC feeder.

VI. CONCLUSION

Microgrids frequently use power electronic interfaces like DC/AC or DC/AC/DC converters to interact with the power system, such as solar PV (which generates DC power) or micro-turbines (which output high frequency AC power). According to the review of the literature, inverters can be useful for controlling grid frequency in island microgrids as well as for easing the use of black start tactics. The static disconnect switch (SDS), which may be configured to trigger very quickly on over-voltage, under-voltage, overfrequency, or directed over current, is a crucial microgrid component for islanding and synchronization. This essay explored energy storage, micro grid architectures, and related topics.

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