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Microgrids: A Review

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Abstract: ***Distributed generation encompasses a wide range of prime mover technologies, such as internal combustion (IC) engines, gas turbines, microturbines, photovoltaic, fuel cells and wind-power. Most emerging technologies such as micro-turbines, photovoltaic, fuel cells and gas internal combustion engines with permanent magnet generator require an inverter to interface with the electrical distribution system, These emerging technologies have lower emissions and the potential to have lower cost negating traditional economies of scale. Indiscriminant application of individual distributed generators can cause as many problems as it may solve. A better way to realize the emerging potential of distributed generation is to take a system approach which views generation and associated loads as a subsystem or a "microgrid". Microgrid is a very wide concept having its own way of working and different control strategies.***

Keywords: Distributed energy sources, microgrids, grid-connected, islanded, centralized control, decentralized control, etc

1. Introduction

Energy plays a very crucial role in the livelihood of human beings, in improving the social, economic and industrial conditions of any nation. The energy is extracted from various sources like fossil fuels etc. Fossil fuels contribute the maximum amount of energy to the total energy produced and used like coal, petroleum, gases etc. In the earlier days population was limited and hence the resulting demand for the energy was also limited but as the population continues to grow at such a large rate the demand for energy also increases and hence the dependency on fossils becomes more. So it's the right time to go for the renewable sources of energy and some kind of new technologies like distributed generation and microgrids.

2. Microgrids

Microgrid is the face of the latest advancements in the field of power system and is the small-scale versions of the centralized electric system and is capable of achieving certain goals like increased power supply reliability, reduced carbon emission in the environment, saving of money, generating of employment and so many such goals. Microgrid is an ideal and perfect way to integrate renewable sources of energy to the main grid and allow the customer's participation in the newly growing energy market. The various agencies have explained microgrids in their own ways. Most important of them are as defined by Consortium for Electric Reliability Technology Solutions (CERTS) and National Renewable Energy Laboratory (NREL):

2.1 According to CERTS:

The evolutionary changes that are happening in the regulation and operational climate of traditional/classical power utilities and with the emergence of small distributed energy sources such as fuel cells, solar technology, wind technology, microturbines etc have brought up favourable circumstances for the electricity customers to generate the on-site power. The distributed energy sources have emerged as the promising solution to meet the load demand as the distributed energy sources are connected to the local loads to meet their demand with focus of providing quality and reliable power supply. The DER includes power generators, energy storing devices, load control and highly advanced power electronic devices between the generators and the bulk power provider or the main utility.

The U.S. Department of Energy (DOE) Microgrid Exchange Group (MEG) defines a microgrid as "**a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode**." A microgrid is an electrical system comprising of multiple cluster of loads and distributed energy sources that can be operated in parallel with the broader utility grid i.e grid connected mode or in islanded mode/autonomous mode/isolated system.

The Consortium for Electric Reliability Technology Solutions (CERTS) defines the microgrid concept as the cluster of loads and microsources operating as a single controlled entity and providing both power and heat energy. The microgrids are power electronically interfaced as they enhance the power reliability and quality of the power supply. This control flexibility that is because of the power electronic devices enables the CERTS microgrid to present itself to the main utility as a single controlled entity that is capable of meeting the local needs for reliability, quality and security.

A very important feature of the CERTS microgrid is that it is being presented as a self controlled single entity to the surrounding utility grid that is, it appears to the grid as distinct from other currently approved customer sites. The flexibility of the power electronic device, that are used to interface the microsources and the main utility, is the reason for the microgrids to maintain their profile [1].

2.2 According to NREL

NREL's microgrid research and development investigates technologies and methods that enable distributed energy resources to make full-value contributions to the electric grid. A microgrid is a small-scale distributed power system that includes local power generation, individual homes and buildings, wind and solar power systems. Distributed energy

resources can be used to supply the power independently in case of power outage and acts as the backup supply. The interconnection technologies and the government rules/policies allows the customers using the distributed energy sources to sell the surplus amount of energy to the main grid. If the technology is fully exploited in integrating the distributed energy sources into the main grid, they prove very beneficial as they are enable to provide high energy value, power quality improvement, voltage regulation and emergency power backup. [2].

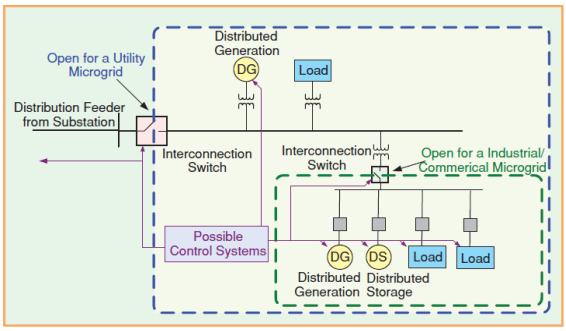

Figure 1: Microgrid and components [10]

3. Working of Microgrid

There are two operating modes of the microgrids and are named as grid-connected mode and stand-alone mode/islanded mode/isolation mode. When the microgrid is in connection to the main utility it is in the grid-connected mode while when isolated from the main utility it is in the islanded mode. The microgrid is isolated from the main grid because of the faults caused by transients, increase of load, it may be intentional or unintentional. In intentional islanding microgrid is disconnected from the main grid by itself may be because of the some kind of repair and maintenance work or to protect the micro sources from the instability on the main grid side. Unintentional islanding is natural and can be caused by faults, etc.

Utility-connected microgrids can be operated in parallel with the local utility or islanded seamlessly with a fast switch when necessary to preserve the reliability of critical loads in the microgrid. Once the disturbance passes, the microgrid is able to reconnect to the utility without disturbing critical loads. A microgrid can be viewed as a single system with specific load and generation characteristics that can be dispatched to provide a controllable load and generation profile to the interconnected utility.

3.1 Grid connected mode

Most of the renewable energy sources such as solar technology and wind power technology totally depend on the environmental and weather conditions therefore producing unpredictable output characteristics. Other renewable sources like microturbines, fuel cells, etc have very slow responses that they hardly meet the dynamic local load demands inspite of the fact that they are independent on the environmental and weather conditions. As the sources are mostly rely on the weather conditions their ouput is weak. Therefore various sources are integrated together with the latest technologies so as to produce desired results and reliable power supply.

The single energy supply system is suffering from the problem of instability and the need of the hybrid energy system is to address this problem of instability and achieve the desired output with additional advantages like improved efficiency of individual energy sources by utilizing different characteristics of various micro-sources and simultaneously enhancing the reliability and quality of the power supply.

In such kind of system i.e. hybrid energy system, the problems faced are the topology, design, modeling of key components and control strategy to be used.

1) Structure and main components selection in Distributed hybrid Energy System (DHES): The power electronic devices like rectifier is not used in the nearby supply system where the load is located near to the generation source as it uses DC bus to supply the local load and for the loads which are located at far off places the hybrid energy system structure uses AC bus to supply them hence it is concluded that this type of system uses AC DC dual bus system. Special attention is paid while selecting the key components of the system like energy storage system and their properties like capacity and structure are selected and modeled correctly. The topological characteristics based on converter helps in achieving the desired functions.

2) Design of the circuitry and modeling of various components: The parameters of the design of key circuit and various components are deeply examined and then applied. Based on the study and the examination of the various characteristics of the energy storing devices, microsources the equivalent circuit diagram, performance equations, mechanical and electrical equations are brought up. Simultaneously the advanced power electronic devices are studied and discussed to get the best possible control system for the distributed hybrid energy system. The validation of the results of the assumed model is checked by the simulation analysis and once the results are validated, the main circuit design is ready and this step is completed.

3) Control coordination problem of the microsources: Better coordinated control strategy is required for the distributed hybrid energy system because various micro-sources are connected to either AC or DC bus of the distributed hybrid energy system and that too with the involvement of the advanced technology of power electronic devices. Each of them are having their own individual voltage-current and frequency-power characteristics, and each having different time constants.

Because of the connection to the main grid, power reliability and load demand are met at each time so the main objective is to increase the revenue from the hybrid system as per the market. To save our environment and to have the clean and green energy solar and wind energy are being utilized.

3.1.1 Why microgrids are integrated to main grid?

1) The main power grids will act as an backup source for microgrids.
2) The direct connection to the main grid helps in having the power reliability and stable operation.
3) It reduces the need of having the energy storing devices, when using renewable energy sources.

4) It helps in reducing the investments and increasing the revenue from this kind of system i.e. grid- connected mode.
5) Microgrids are planned in such a way that if there is surplus amount of energy that is not required to meet our load demands, it can be fed to the main grid helping in generation of the revenue.
6) Grid interconnection allows to reduce fuel operational costs by providing choice to the customer when they want to use the power from the grid specially when the cost is low.

3.2 Islanded Mode

An important characteristic of microgrid is its ability to get separated, or isolate itself from the main utility grid. The microgrid is structured in such a way that it has got the capability of operating independently, still the shift from grid connected mode to islanded mode is very challenging. It is seen in various applications that if the main grid is lost the microgrid is expected to shut down for a while and then starts acting like a backup source for meeting the local load demands.

Uninterrupted power supply is required to those loads who are more prone to the voltage disturbances and the microgrid can prove very beneficial in such cases and is very promising, will act as the backup power supply. The microgrid is isolated from the main grid because of the faults caused by transients, increase of load, it may be intentional or unintentional. In intentional islanding microgrid is disconnected from the main grid by itself may be because of the some kind of repair and maintenance work or to protect the micro sources from the instability on the main grid side. Unintentional islanding is natural and can be caused by faults, etc.

4. Control of Microgrids

To operate the microgrid in grid connected mode or isolated mode one has to design the control strategy properly so that it can allow the operation of microgrid in both the modes safely. The system may have the central controller which will control the whole system or it may have individual controller for all the micro sources. The controller controls the local frequency when isolated from the main grid by sending or receiving the instantaneous difference of real power between generation and demand, protecting the internal microgrid.

The frequency control is the challenging problem in case of isolated operation of microgrid. The rotating masses connected to the larger power systems unit are connected to ensure the stability of the system and the frequency response of the system is totally based on them. In contrast, distributed energy sources (or microgrid) are converter controlled or power electronically controlled for such operations, and hence there is no need for the rotating masses. But some microsources like microturbines and fuel cells are showing very weak response to the control signals and hence are raising the issue of load tracking in the scenario of islanded operation. The control strategy based on converter operation is utilised to ensure the response of the system to be same as obtained from connecting the rotating masses to the system. The voltage regulation must be proper as it is necessary for reliability of the power and stability without which the system can have voltage and reactive power fluctuations and oscillations. Voltage regulation is the problems faced in both the operating modes; i.e., stand-alone or grid-connected.

4.1 Centralized microgrid control:

The centralized control helps in increasing the local production, that depends on market scenario and the security constraints, by optimizing microgrid central controller of the host system to the microgrid exchanged power. This is done by setting and issuing of the control set points to distributed energy source units and controllable loads within the microgrid. Two way communication is set up between the MCC and LC of the system in order to exchange information of the centralized control strategy The communication channel is through the telephonic lines, PLC, or some kind of wireless source. The microgrid central controller takes decisions for pre-specified time intervals; e.g., every 20 minutes for the next hour or hours. The local controllers issues bids to the MCC based on the market scenario and unit capacities. Similarly, the load LCs issue bids for their demands considering their priorities for service.

Figure 2: Flow of information in centralized controlled microgrid [3]

Based on the bids issued by the microgrid central controller the LCs balances the load and demand and generates bids. To have the centralized control of a microgrid specific functions need to be implemented such as load demand, generation, heat forecasting unit commitment, economic dispatch, and security constraints.

4.2 Decentralized Microgrid Control:

This kind of control strategy believes in providing full autonomy to the local controllers of the distributed energy resources as it trusts that they are intelligent and smart enough and can communicate with each other to form a larger intelligent, smart and efficient unit. In the decentralized control scheme the main focus is not on the economy that is on generating the revenue but on the improvement of the overall performance of the system. Environmental conditions, weather conditions, etc are the main deciding factors for the decentralized scheme and hence the multi agent system is used in this control strategy.

The MAS is evolved from the classical distributed control system having the abilities to control large and complex systems. The main feature of the MAS that makes it unique from the traditional/classical system is that it has got the software which makes it more intelligent. Each unit uses

its inherited intelligence to decide the market forecasting and the environmental conditions. Mult agent system uses the artificial intelligence based methods like fyzzy logic or neural network technology. An intelligent MAS must be having the most efficient and intelligent software with it and effective communication channel in it [3].

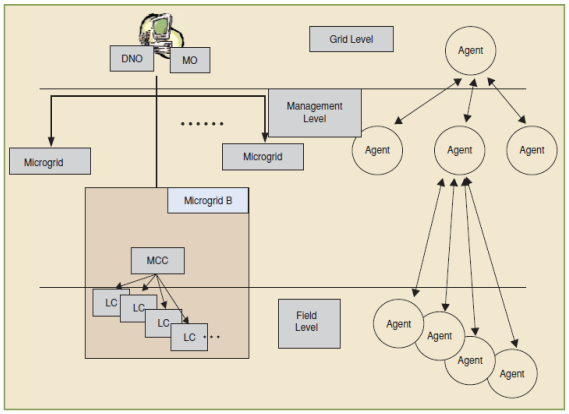

Figure 3: Schematic architecture of MAS in decentralized controlled microgrid [3]

Studies have shown that in the stand alone system the main problem is of the frequency control. As in the larger systems the frequency response is based on the rotating parts like flywheel that are connected in order to store energy [4]. But in the smaller systems the response is not appreciable because of the absence of the rotating parts like flywheel and very slow response to the control signals. Therefore converter control system is applied which was previously done by the connected rotating parts.

In both the islanded mode and the grid parallel mode the common problem faced is of voltage regulation. It is because of the reactive circulating currents injected in the sources. The control system must ensure that there is no circulating current in the system. This problem can be eliminated by using the modern day power electronic devices which adopts the method of voltage vs. reactive current droop control.

The increasing share of distributed generation (DG) units in the electrical power systems has an appreciable impact on the operation of the distribution networks which are increasingly being confronted with congestion and voltage problems. This demands for a coordinated approach for integrating DG in the network, allowing the DG units to actively contribute in the frequency and voltage regulation. Microgrids can provide such coordination by aggregating DG, (controllable) loads and storage in small-scale networks, that can operate both in grid-connected and islanded mode. Here, the islanded operating condition is considered. Analogous as in the conventional networks, a hierarchical control structure can be implemented in islanded microgrids. In recent years, many different concepts for primary, secondary and tertiary control for microgrids are studied and thoroughly investigated [5]

4.3 Primary control strategy

The primary control for microgrid consist of the power electronic based devices and the DGs. The microgrid is connected to the main grid through the static switch at the point of common coupling. Each DG consist of a source, an energy storage system, a power electronic interface (dc – ac inverter), connected to load directly or to the ac bus directly [6].

The dc ac inverter that are used are either voltage source inverter or the current source inverter. The current source inverters are used to inject current in the grid connected mode and the voltage source inverters are used to keep the frequency and voltage stability in the autonomous/isolated/islanded mode.

The inverters are programmed in such a way that they work as generators, as they include the virtual inertias through the droop method, which helps in ensuring the proper sharing of the active and the reactive power between the inverters. To restore the microgrid values to the normal values the supervisors send the proper signal using the low band width communication medium. Before integration of the microgrid to the main grid, this type of control is used to synchronize the microgrid with main utility grid, helping in the safe transition from the autonomous mode to grid-parallel mode. The main objective of the primary control is to have proper sharing of powers and this is achieved very satisfactorily [7].

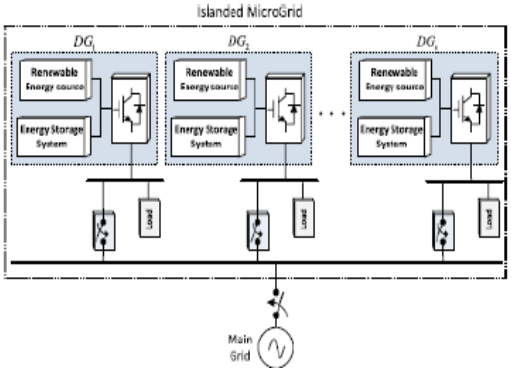

Figure 4: General structure of microgrid [6]

The primary control further consist of voltage and current loops, virtual impedance loop and droop control strategy. The droop controller and the virtual impedance loop generates the reference value for the voltage control loop. According to the real power and reactive power, the droop controller adjusts the frequency and amplitude of the voltage reference. The main purpose of adding the virtual impedance loop and the voltage reference is to maintain the output impedance of the voltage source inverter.

4.4 Secondary control

Since the primary control is local and have no communication with the other DG units, the secondary control is required which have the overall controllability of the microgrid. It utilizes a communication channel which collects the data from each of the DG unit and whatever control is required, is done. Secondary control is placed just in between the primary control source and the communication channel. The operation of the secondary control is a step by step process first it collects all the measuring data i.e voltage, frequency, active power and reactive power then average them and in last provide the primary control level with the proper control signal simulateneoulsy it removes all the steady state errors from it.

This stage of control strategy is used to compensate for the voltage and frequency deviation occurring during the operating conditions. The secondary control is so much efficient that it makes the voltage and frequency regulations to reach to zero on every change in generation or load of the system [8].

Restoration of the frequency and voltage deviations in the system produced by the droop controllers is regulated by the microgrid central controller. The main aim of the distributed networked control system is to replace the microgrid central controller with the secondary control system. This strategy not only helps in restoring the frequency and voltage deviations in the system but also balances the reactive power sharing. As there is no central controller used in the system, the problem of shutting down the whole system at the time of disturbance in the system is solved and the secondary control works independent of central controller [9].

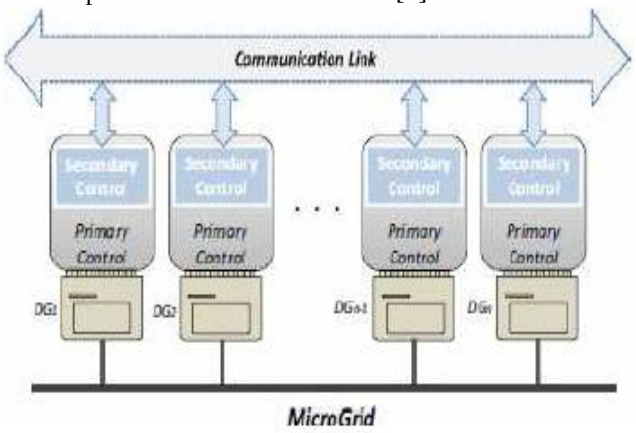

Figure 5: Networked controlled Microgrid system [6]

4.5 Tertiary Control

The main focus in this stage of the control is the economic data that is used to take decisions in the microgrid system because the power flow priority depends on it. The local or global power flow is managed by the set points of the inverter used in the system and the tertiary control scheme allows the necessary changes to be made in the set points of the system [7].

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