Microgrid's Architecture and Control Strategies: A Review

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***Abstract*-The concept of electrical power system is changing from centralized large power generators to distributed system that includes non-conventional sources. Small generators were primarily for back up and were not synchronized to the grid. A trend is being observed to change the role of these distributed generations from back up to primary source of electricity in the form of microgrid. The paper discusses the effectiveness of the Microgrid in a distribution system and presents a depth review of the Microgrid. Various architecture and control schemes of the Microgrid are reviewed. The paper aims at providing a broad perspective on the state of art of the Microgrid to the researchers and application engineers dealing with power quality aspects and Microgrid.**

***Index Terms*—Microgrid, Microsource, Droop Control.**

I. INTRODUCTION

Small power generators based distributed energy resources (DER) have appeared as a promising option to meet the ever increasing demand for electric and thermal energy with an emphasis on reliability and power quality [1-3]. Microgrid (MG) is a concept which involves the utilization of distributed energy resources by using the energy generated by small power generators which are located near the customers' site [4-5]. The small generators dissipated throughout the power system were primarily for back up and were not synchronized to the grid power supply. There has been a trend to change the role of these distributed generations (DG) from back up to primary energy supply and to have flexible connection strategies. This created the concept of Microgrid.

II. BASIC CONCEPT

Microgrid (MG) is a single controlled unit in a power system that can be operated as a single accmulated load. The unit is made up of generators, energy storage, load controller and power electronic interfaces like inverters. The MG has two critical components a static switch and micro source, which consists of generator, storage and an inverter. After the tripping event is removed the MG reconnects itself to the power system [5]. Fig. 1 shows the layout of a typical MG.

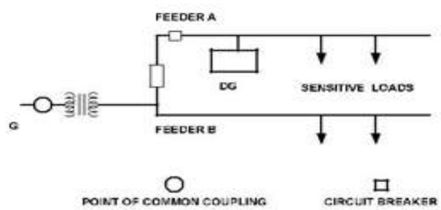

Fig. 1. Layout of a Microgrid.

A. Grid Connected Mode

It is the normal operating mode of a MG with no power quality disturbance on the main grid to which it is connected. In this mode the MG may cater to its entire local load or may either import or export power to the main grid, depending on the total power generation of the local DG.

B. Islanded Model

The MG can separate from the main grid whenever a power quality disturbance occurs on the main grid [6-8].

III. CLASSIFICATION OF MICROGRIDS

The MGs may be classified broadly into two types based on the nature of the output voltage which is fed to the sensitive load. They are (1) ac MG (2) dc MG.

A. AC Microgrid

A MG consists of cluster of loads, distributed generators (DGs), some energy storage systems and is also connected with the utility grid [4, 7]. Some of the energy sources, which qualify for DER like fuel cells, PV units, Microturbines etc. (popularly called microsources, MS) produce either DC output or produce electrical output at frequencies not compatible with the grid frequency. The MS such as photovoltaic (PV) or fuel cell generate dc voltage as the output. Microturbines generate voltage at higher than grid frequency. As recommended for CERTS MicroGrid, the system shown in Fig. 2 is adopted. The DG output is rectified and / or is made to charge a battery, which in turn feeds power to the MG through an inverter [7]. Moreover it is assumed that, if the power demand is within the capability of the device, the DC voltage is kept constant by the primary generator control.

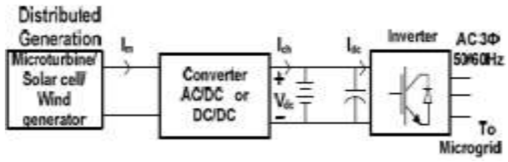

Fig. 2. Block diagram of a Microsource

When several DRs are available on a MS the output of each converter is connected in parallel and controlled to generate the same level of voltage, generating a dc bus. The common dc bus is then utilized to convert dc power into single-phase or three phase ac for consumer use.

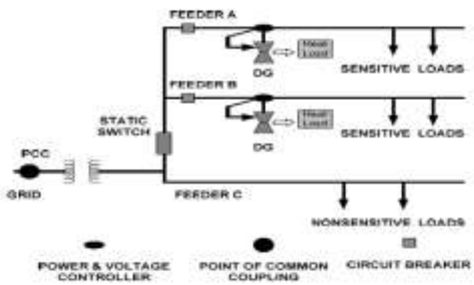

Fig. 3. Configuration diagram of an ac microgrid.

Fig. 3 shows a typical configuration diagram of an ac microgrid. The distribution system is made up of radial feeders – A, B & C and a collection of loads. The MSs are connected on feeder – A & B where the sensitive loads are connected. The feeder C has non-sensitive loads and which are not affected by power quality events on the grid.

The MG can operate in two modes: grid-connected mode and islanded mode. In the grid-connected mode, the MG supports the utility grid while exchanging power with it. In this mode the frequency of the MG is maintained by the utility grid [9-10].

In the islanded mode of operation, the interconnection with main grid is disconnected. The MG can separate from the main grid whenever a power quality event in the main grid occurs. In the island mode of operation the MG is faced with the following issues:

Regulation of Voltage and Frequency

In grid connected mode the MG operates at the grid frequency. The grid being a stiffer voltage source than the MSs the voltage of the MG is regulated by it. In islanded mode, one or more MSs are required to maintain the MG voltage and frequency. Both voltage and frequency are maintained in an acceptable range.

Load Matching

When Microgrid connected to main grid to meet the load requirements, power can be drawn from the main grid. But in islanded condition load matching is done at Microgrid level. It requires appropriate action for generation and load management. To balance the any abrupt change in generation and demand, Microgrid should have enough storage generation.

Power Quality

To avail standard power for easy detective load, Microgrids are set up. For same, it is compulsory to provide sufficient power suffering to go through voltage sags and abnormal conditions. Further sufficient reduction harmonics capability is provided so that the harmonics generated by the nonlinear loads on the MG do not reach the sensitive loads.

B. DC Microgrid

The advancement of semiconductor devices revolutionised the electrical and electronics stream. Home appliances use DC power. All of them have inbuilt converter to convert AC from the supply to the DC. Therefore, it has created a possibility of DC MG. In Fig. 4 a block diagram of LV bipolar DC MG is shown [11].

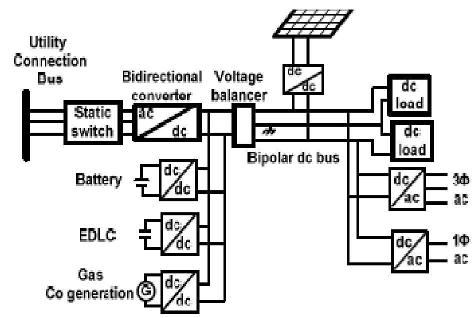

Fig. 4. Concept of low voltage bipolar dc microgrid

Grid Connected mode

Here the rectifier controls dc distribution voltage, and the computer modifies the number of CGS to maintain power within the demand limits [11].

Islanded Mode

Electric double layer capacitors (EDLC) are used to compensate any excess or shortage of power in Microgrid. ELDC also controls distribution voltage. The number of running CGSs is decided by the overall load on Microgrid and stored energy in ELDC. Maximum limit of stored energy in ELDC is balanced by switching on or off the CGSs. Thus to balance load generation demand, the continuous charging and discharging of ELDC takes place and hence it maintains the MG voltage [11-12].

IV. Architecture of Microgrid

Different Microgrid architectures are obtained in the islanded mode of operation, when MSs balance the total local load while maintaining the voltage and frequency within the limits.

A. Centrally Controlled Configuration

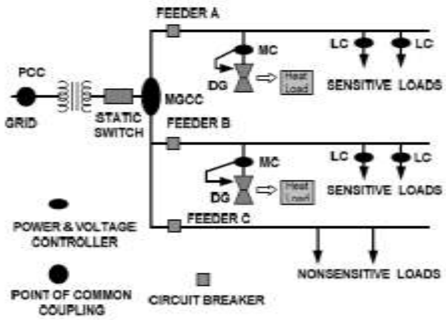

Fig. 5. Architecture of centrally controlled Microgrid.

Fig. 5 shows the classic representation of centrally controlled Microgrid. Microgrid central controller (MGCC) controls different entities of the microgrid in centrally controlled way. In simpler language, MGCC can be understood as central controller. This central controller is connected at the point of common coupling with the utility grid (PCC). Several functions like estability limit control, economic functions & other related functions are also governed by this central controller. This main controller controls next level controllers located at MSs (Microsource controller MC) and at individual or at near the group of loads (Load Controller LC) by providing them real time basis set points [13]. Load shedding is done by LC to control the load. Active and reactive power generated by MS are controlled by MC.

B. Decentralized Microgrid

Fig. 6 shows a typical representation a decentralized microgrid configuration. At PCC Microgrid is connected to utility grid through static transfer switch, STS [14-15]. STS also measures PCC voltage and current, local voltage and current along with determining synchronous status. The DG (of the MG) closes to the PCC gets information about PCC voltage and current. But all other DGs receives information regarding the local bus only.

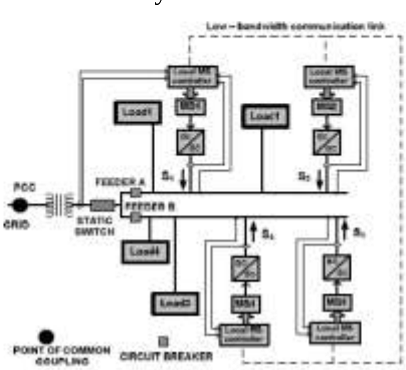

Fig. 6. Schematic diagram with decentralised control

PCC information is shared between DG nearest to PCC and other DGs by using an unidirectional low bandwidth communication link. The PLL (Phase Locked Loop) and power calculation block are additional features of DG, which is closest to PCC. While synchronising MG with grid the closest DG slowly reduces out of phase angel and voltage to match MG voltage to that of the grid. During synchronisation other DGs output command set to zero.

C. Autonomous Control

Autonomous control strategies used in autonomous architecture for each MSs that cumulatively makeup the MG. [7, 16, 17].

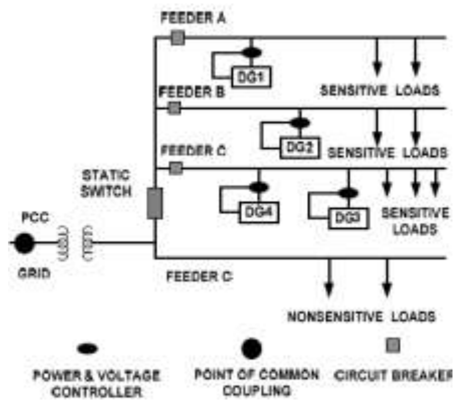

Fig. 7. Schematic diagram of autonomous control.

In this architecture central control unit and central storage are not required. MSs do not have any dedicated communication link. So, MS can be connected at any point on MG and this feature provides associated benefit. Thus a peer to peer and plug and play strategy is utilised on the MG. However for each location on the MG there can be an optimal size of the MG [18].

D. Unit power control configuration

A typical Microgrid layout with Unit Power Control is shown in Fig. 8. In this mode of operation, voltage regulation mode is used for each MS and this helps in regulating voltage at its output, at the connecting point to the MG. Further DGs provide constant supply of power to MS and output a constant power to MG. During the grid connected mode an increase in local demand is fulfilled by drawing extra power from the utility grid. In off grid mode, the MS frequency droop characteristic ensures that the entire local load requirement is fulfilled.

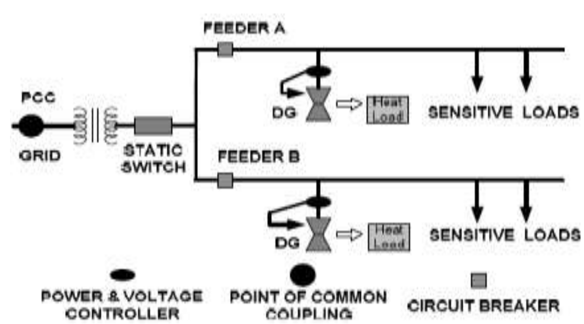

Fig.8. Layout of a microgrid with Unit Power Control.

E. Feeder flow configuration

In this architecture only radial feeders are considered. One MS feeds one feeder with some local loads. Each MS regulates the real power flowing through a particular feeder in the MG. It controls the amount of power it is generating to regulate the amount of power flowing through the particular feeder.

V. CONTROL STRATEGIES

It is the MS controller which defines basic operations of Microgrid. Few control strategies are discussed below. [21, 23].

A. Inverter Control Strategies

Normally PQ inverter control and voltage source inverter control strategies are used for controlling inverters of MSs.

(1) PQ inverter control: In Fig 9, representation of PQ inverter control system is shown. Controlling of MS can be done to achieve its constant real and reactive power outputs. The reactive power is derived locally or controlled by central controller (MGCC). The required active power is provided by inverters [13, 19, 21].

The MS – inverter combination works as current controlled voltage VSI. From here, the direct and quadrature component of terminal voltage are measured. From PCC current direct and quadrature current components are computed along with the inverter behaves like a current-controlled VSI.

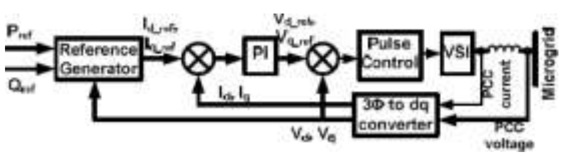

Fig. 9. PQ inverter control system.

(2) Voltage source inverter control: VSI supplies predefined voltage and frequency to the Microgrid load. The active and reactive power will be determined by the load [13, 19 21]. In islanded mode, this active and reactive power will be supplied by microsources. The inverter behaves as synchronous machine. Frequency and voltage control is obtained through droops as per the following equations.

$$f = f_o - k_1 * P$$

$$V = V_o - k_2 * Q$$

Where P and Q are the inverter active and reactive power outputs, k_1 and k_2 are the droop slopes and f_0 & V_0 are the inverter frequency & output voltage at no load. Here, we are considering Microgrid with two microsources and a storage device which is importing (Pgrid) from the grid. The output power of the storage device and two MSs are zero, P1, and P2, and the frequency is f_0. When the MG islands, the MSs and storage device will provide the power originally imported from the grid. In the islanded mode, power is provided by microsources and storage device. The individual droop characteristics of microsources will finally decide the new frequency.

B. Combination of V_g/V dc and P/V control

L. Vandevelde, et al [22] proposed that there is absence of notable inertia on which conventional active power control is based. Therefore, P/V-droops discussed here. In islanded mode, the power control can be achieved by using a combination of the two control strategies, which are: 1) V_g/V_{dc}-droop and 2) P/V_g – droop control. In the constant-power region the power balance in Microgrid is done V_g/V_{dc}-droop controller only. If V_g surpasses this constant-power region only then P_{dc} is changed and then only P/V_g -droop control is done. This width of the constant-power region can be changed according to the power source characteristics so that power frequency changes can be avoided and full utilisation of power source control abilities can be achieved.

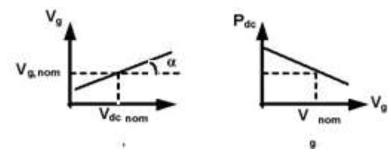

Fig. 10. Vg/ Vdc droop and P/Vgdroop.

B. Energy source control

Shifting the droop characteristic (secondary control action) can also be utilised to maintain frequency and voltage to the reference values [20, 23].

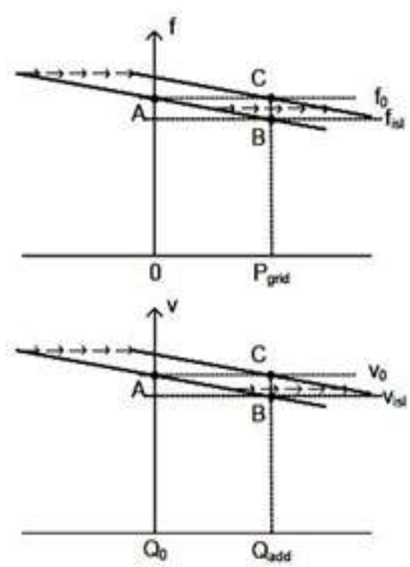

Fig. 11. Energy source control

Frequency & voltage regulation by shifting the droop characteristics are shown in Fig. 11. Let us assume that in the grid connected mode storage devices absorb PA and Q_A represented by point 'A'. In islanded mode the operation shifts to the point B as frequency and voltage value will drop. And when storage device supplies the active power P_A and reactive power Q_B, the droop characteristics shifts to the right and point C becomes the new operating point. And hence voltage and frequency control is obtained.

C. *Voltage power droop/ Frequency reactive power boost control.*

The voltage–power droop/frequency–reactive power boost (VPD/FQB) control scheme has been discussed for VSCs control, operating in both islanded and grid connected modes [19, 23]. Current references are set by (VPD/FQB) controllers. In this control each VSC in Microgrid has its own controller to regulate Microgrid voltage and frequency in such a way that droop references can be tracked. Multiple VSCs regulates the V and f and share load that is active and reactive requirement in proportion to their droop coefficients depending upon voltage and frequency respectively.

Single Master Operation: A cluster of MS on a MG connected to the grid can have all its inverters operated in PQ mode, because voltage and frequency references are available. In case of disconnection from the grid the MG can still continue to function normally without changing the control modes of the inverters if one of the VSC is used to provide the reference for voltage and frequency.

VI. PROTECTION

Protective relay Design for a Microgrid power system is different than a grid distribution system. It is because:

(1) In general protection system is designed for unidirectional flow of electrical energy but in MG because of DERs, the flow of electrical energy is possible in either direction.

(2) The short circuit capabilities of grid connected and islanded mode are different and when there is switching from grid connected mode to island or vice versa, there will be significant difference in short circuit capabilities. Fault current in grid connected mode is much greater than the load current. We know that most of the Distributed Energy Resources are connected to the Microgrid through inverter interfaces. These Inverters are capable of supplying up to twice the load current or less than fault current. Therefore it is clear that conventional over current protection has its limitations in the case of Microgrid.

Protection of Autonomous Microgrids

It is desired to have same protection design for both grid-connected and islanded mode [24]. An autonomous protection of MG with plug & play feature is shown in Fig. 12. In this scheme static switch (SS) opens for all faults, irrespective of the islanded or grid connected mode of operation. After SS opens, for fault clearing in the MG is done with techniques where fault clearing do not depend upon the large fault currents. If fault occurs in Zone 2 the Static Switch will open first and then CB 3, 4 & 5 will operate.

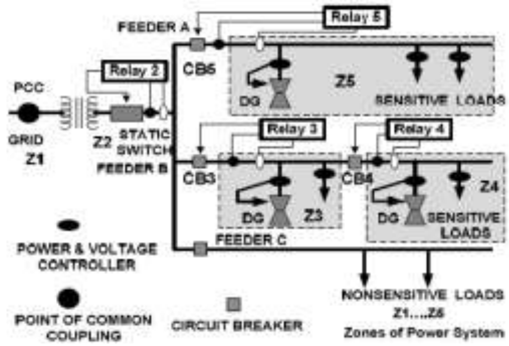

Fig. 12. Protection of MG with plug & play feature

If Zone 4 has fault then the SS would operate first followed by CB 4. But in this scenario CB 3 & 5 will not operate. With such fault conditions the DER of Zone 4 would also shut down.

VII. CONCLUSION

Electrical energy demand is increasing day by day. We are already utilising full capacity of transmission and distribution network. To supply extra power for future demand new transmission and distribution infrastructure will be required. The concept of Microgrid can help us in this regard. Distributed generation sources are utilised to meet the demand on Microgrid. Microgrid is congregation of distributed energy sources.

In this paper detailed discussion on Microgrid is done. The review of different Microgrid architectures and control methodologies, suggested by various authors are done here.

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