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Control Challenges and Techniques in Islanded Micro Grid Operation

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Abstract

Climate change and green energy technologies has lead to growing interest in the area of microgrid, which consists of distributed generation, storage and loads. Micrograms have allowed the penetration of large number of intermittent distributed renewable energy sources (DRES) such as wind, solar etc. If the microgrid is islanded, the grid almost entirely depends on these intermittent distributed energy sources in the absence of dominant source of energy. Thus islanding has created the need for power sharing between the distributed renewable energy sources and it cannot be met by a single source to supply the entire islanded microgrid. Therefore Control of islanded microgrid presents great deal of technical challenge to maintain the grid stability in terms of power sharing, voltage, frequency, power quality, protection, reliability and performance. This paper discusses in detail about various modes of operation, classification, challenges and control issues of islanded microgrid. The paper also focus on various control techniques control issues such as angle droop control and frequency droop control, along with supplementary and adaptive control.

Keywords— Microgrids, Islanded mode, Load sharing, Droop control, Interlinking converters.

I.INTRODUCTION

Increased demand for power has lead to power outages and it is creating huge economic loss as well as physical damages to power system. Because the existing power system is unable to handle the increased demand and thereby creating increased transmission and distribution loss as well as power outages. Day to day variation in demand for power also created power flow despatch problems and lead to power quality and reliability issues.

One solution that can solve such problems is microgrids. Microgrids is a singular energy system which consist of interconnected loads and distributed energy resources and capable of operating with, or independently, from the existing Main grid. Since the loads are close to generation it improves the voltage profile, power quality, reduced transmission and distribution losses, increased efficiency as well as ensures reliable power supply to consumers [1]. Microgrids are flexible and can incorporate renewable sources of energy such as solar, wind, Fuel cells, battery storage, and can provide supply to load based on demand response.

II.STRUCTURE OF MICROGRID

A typical Micro grid structure consists of group of distributed renewable energy sources, along with the distributed loads and storage. The Micro grid is connected to the main grid (Utility) through a bidirectional Static Transfer Switch (STS) and this connecting node is called point of common coupling (PCC)

Simple block diagram of microgrid is shown below.

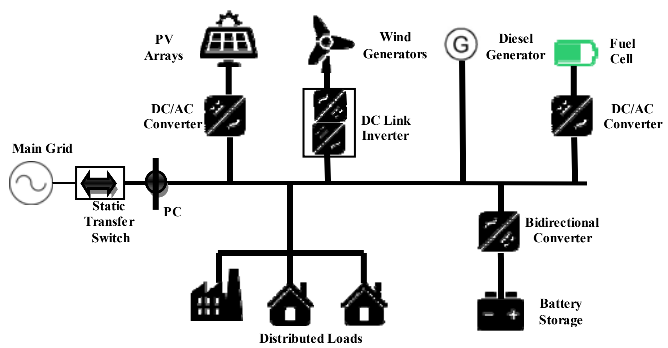


Fig.1

Dynamic needs of the load are met by Microgrids either by connecting or isolating itself from the main grid with the help of bidirectional static transfer switch. The control action is provided in three different levels.

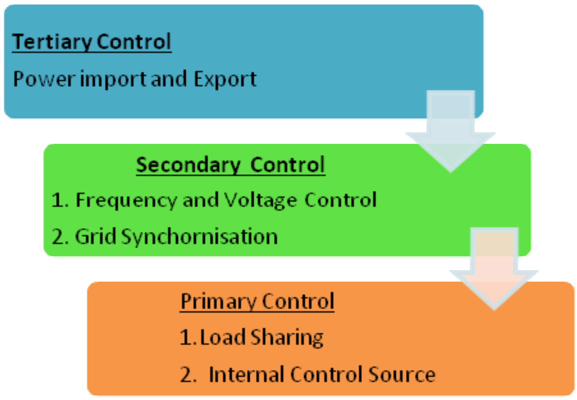


Fig.2

As mentioned above in the flow chart, In the primary control ensures power sharing between the distributed generation as well as internal control. Secondary control provides grid stability and synchronisation and tertiary control takes care of power sharing between the microgrid and the main grid [2]. The Microgrids are adaptive power unit and has three different operating modes.

(i) **Grid connected mode:**
In Grid Connected mode, the micro grid is connected to the main grid (utility grid) through a bidirectional static transfer switch (STS). Main grid takes control of micro grid by providing voltage and frequency reference points. The Microgrids supplies the most of the power to the local grid and the difference between load demand and microgrid distributed generation is supplied by the main grid-. When there is a excess power in microgrid it can be exported to the main grid through the bidirectional static switch.

(ii) **Transition mode:**
When there is a fault or blackout on the main grid, the Microgrids senses the grid outage and autonomously disconnects itself from by opening the STS, there by operating the grid in islanded mode. The transition control is very crucial to ensure stability of the grid from Grid connected mode to islanded mode, as both can be assumed to be a steady state operation [3]. If the Microgrids was importing the power from the main grid before the islanding, the controller has to increase the distributed generation to balance the power. Similarly if the Microgrids gets connected to main grid after fault clearance the controller has to reduce the power from the distributed generation for power balance. Controller plays a vital role in synchronized transition from Grid to Islanded mode and vice versa.

(iii) **Islanded mode:**
When the microgrid is disconnected from the main grid due to fault, black out or any other reasons (intentional), the micro grid is said to be in Islanded mode [4]. In this

mode grid acts independently supplying its own load demand through proper control strategy. The Operation and control of islanded micro grid pose a number of technical issues such as maintaining stability, reliability and power quality of supply especially with the non linear loads as well as non linear nature of distributed generation. It calls for sophisticated control techniques to ensure stability of operation under islanded mode of operation.

III Islanded Mode operation

Recent years has shown that there is an increased demand for reliable and high quality power which can be achieved by adding the Microgrids into conventional grids. Through advanced controller and strategies the Microgrids can accommodate large number of renewable energy sources to meet significant amount of local demand, and thereby reducing the stress on the main grid. When there is a fault or blackout, the Microgrids can maintain uninterruptible power supply with the help of distributed energy sources, there by ensures optimal power supply to the critical loads even in case of grid failure and there by increases the reliability of the supply system.

Reasons for Islanded Mode of operation

Integration of distributed energy sources such as photovoltaic and wind turbine into the main grid has lead to significant changes and challenges, and susceptible to islanding.

Main utility grid cannot supply uninterruptible power to the critical load or sensitive load as in case of nuclear power plant or in hospital emergency room. Under such condition, whenever there is a power outage, it leads to islanding operation and hence there should be a proper controller that will ensure smooth transition of micro grid, from grid connected mode to islanded mode to maintain the supply to the critical loads.

Islanding is inevitable in hostile geographical locations, and it is not possible to install transmission and distribution networks to supply loads in remote locations, as in villages surrounding mountains or in an islands.

In case of any grid disturbance, the Microgrids sense and isolate from the main grid and yet maintain the load demand.

The static transfer switch (STS) near point of common coupling (PCC) controls resiliency of Microgrids, either to connect or disconnect in case of eventuality. There are instances where in the islanding operation lead to Microgrids to operates as an autonomous compact power system or it may move to islanded mode operation through the control switches to supply critical loads regardless of location of load and distributed energy sources.

The main reasons for islanded operation of a microgrid can be summarized as follows:

I). During grid fault or black out, islanding of microgrid ensures power supply to critical loads.

II) To protect load from disturbances in the grid such as transient voltages or harmonics.

III) To isolate the grid in case of fault in the main grid, there by protect the active power sources in the Micrograds.

IV. CLASSIFICATION OF ISLANDED MICROGRIDS

A. Based on Nature of Power

This is the fundamental classification based on type of power supply to the island during the fault or blackout to the Micrograds

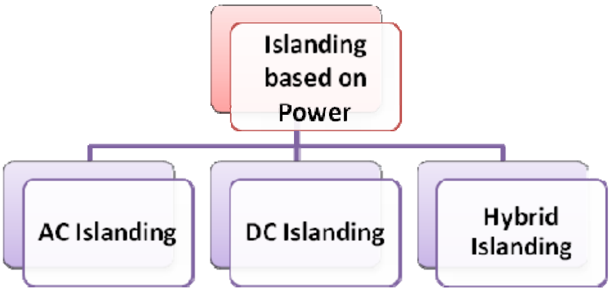


Fig.3

1. **AC Islanding**:

It represents the traditional Microgrids which predominately supplies AC loads during the islanding. Due to the presence renewable sources power converters are used to control the microgrid. In AC Islanded Microgrids, the distributed generators operates either as voltage controlled voltage source Inverter or as an voltage controlled Current Source Inverter (VCVSI or VCCSI) [5] . There are number of challenging issues with respect to synchronisation, stability, power conversion and reactive power compensation.

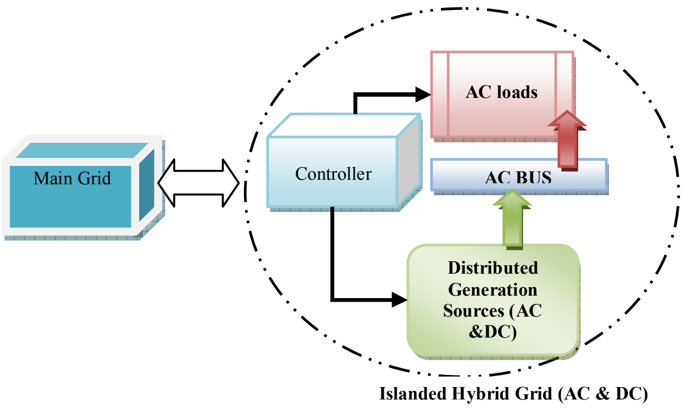


Fig.4

2. **DC Islanding**:

DC Islanding does not have the demerits of AC Islanding (Synchronisation, stability and reactive power compensation) and it can integrate renewable energy sources such as photovoltaic, fuel cells, storage devices (Battery) and variable speed wind turbine [6]. They do not require Power conversion stages, and therefore have higher efficiency, low cost and system size; however there is a limitation with respect to operating voltage and protection. In DC Islanded microgrid, battery plays vital role in providing stability and super capacitor supports for sudden power requirements.

3. Hybrid Islanding:

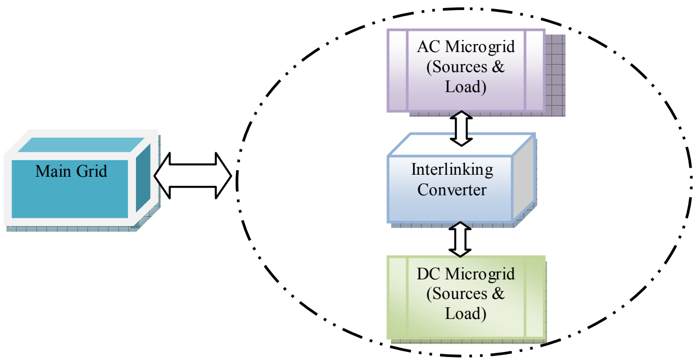
Hybrid islanding, in this microgrid manages power sharing between ac sources and dc sources as well as ac microgrid and dc micro grids [7]. It uses interlinking converter to share the required power between sources and respective loads. Due to the presence of larger of number of converter creates control and stability issues as well as reduced efficiency. It operates in four modes in hybrid islanding

1. Balanced Power

DC microgrid $\Sigma P_{DC\text{-}Gen} \geq \Sigma P_{DC\text{-}Load}$

AC microgrid $\Sigma P_{AC\text{-}Gen} \geq \Sigma P_{ACLoad}$

Interlinking Converter $\mathbf{P_{IC} = 0}$



Islanded Hybrid Grid (AC & DC)

Fig.5

2. DC unbalance

DC microgrid $\Sigma P_{DC\text{-}Gen} < \Sigma P_{DC\text{-}Load}$

AC microgrid $\Sigma P_{AC\text{-}Gen} > \Sigma P_{ACLoad}$

Interlinking Converter

$\mathbf{P_{IC} = \Sigma P_{AC\text{-}Gen} - \Sigma P_{ACLoad} - \Sigma P_{DCLoss}}$

3. AC Unbalance

DC microgrid $\Sigma P_{DC\text{-}Gen} > \Sigma P_{DC\text{-}Load}$

AC microgrid $\Sigma P_{AC\text{-}Gen} < \Sigma P_{ACLoad}$
Interlinking Converter
$\mathbf{P_{IC} = \Sigma P_{DC\text{-}Gen} - \Sigma P_{DCLoad} - \Sigma P_{DCLoss}}$

4. Load shedding
DC microgrid $\Sigma P_{DC\text{-}Gen} > \Sigma P_{DC\text{-}Load}$
AC microgrid $\Sigma P_{AC\text{-}Gen} > \Sigma P_{ACLoad}$
Interlinking Converter $\mathbf{P_{IC} = 0}$

B. Based on Nature of Application.
They are based on the nature of load to connected to the islanded microgrid

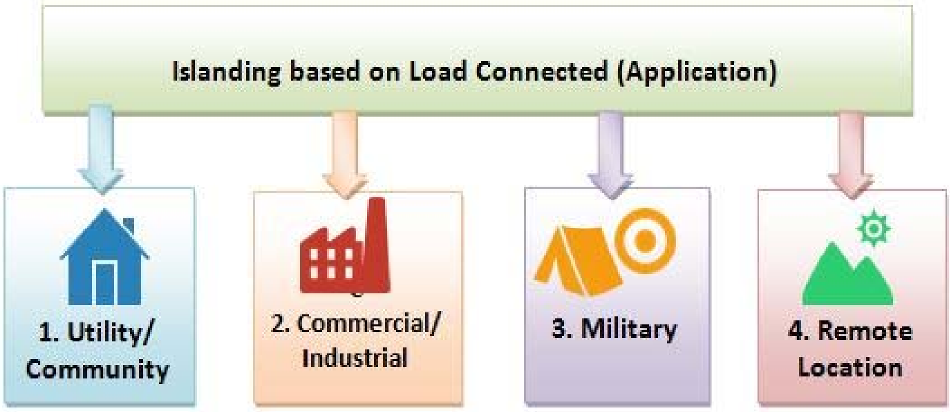


Fig.6

1. Utility:
During the islanding the microgrid predominately supplies Utility loads such as home, offices, schools, colleges and hospitals. It is of greater importance that the controller should optimize the islanded grid based on the social value rather than economic value. Islanding based on utility can have different marking based on emergency, to ensure power to the emergency loads such as hospitals.

2. Commercial & Industrial:
It represents the islanding in which the Microgrids supplies to commercial and Industrial loads. The controller should optimize the power to the industrial loads in such way that the critical loads in industry are taken care of.

3. Military:
The vulnerability of utility grid to hackers, terrorist as well as natural disasters can have disastrous consequences on military establishment. This has created the need for independent, secure, smart, reliable and robust micro grids that incorporate renewable energy sources [8].

4. Remote Location:
Electric supply to remote location, such as island or mountain with traditional grid is of great challenge. The challenge predominant because of the physical distance and the nature of terrain and it calls huge investment for developing transmission and distribution lines, in the backdrop of carbon emission and pollution. Remote location can be powered by distributed energy sources and they can operate independently [9]-[10].

C. Based on Power conversion stages
Islanded microgrid consists large number of Distributed Renewable Energy Resources (DRES) and they produces low voltage which cannot be directly connected to the high voltage AC or DC grid. Therefore DRES uses no of power electronic converter for shaping (Power conditioning) the power flow ino the Grid. Based on the power conversion stages Islanded Microgrids are classified as

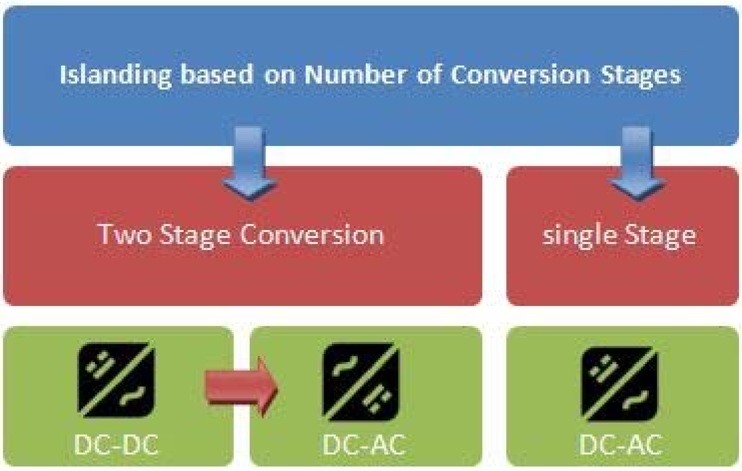


Fig.7

1. **Single stage:** PV Connected microgrid uses single stage power converter to step up the voltage as well as convert to DC voltage into AC Voltage [11]. They are compact and have low cost. The main drawback such converters are low gain and efficiency compared to two stage converters.
2. **Two Stage Converter:** In this type of converter, the first stage has high voltage gain booster inverter followed by H Bridge Inverter [12]. They have low switching losses and thus provide higher efficiency.

D. Based on Method of connection
This classification is based on how the distributed energy resources are connected to the islanded Microgrids either through conventional electrical connection or through electronic connection through converters.

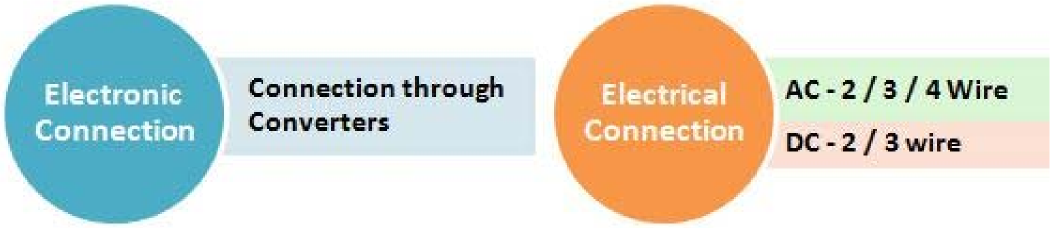


Fig.8

1. Electronic Connection:
The connection between the islanded Microgrids and distributed energy resources is achieved through power electronic converters.

2. Electrical connection:
The connection between the distributed energy resources is established through the Single phase / three phase for AC Islanded or through Two Wire/Three Wire connection in case of DC powered Islanded Microgrids.

E. Based on Controller
Islanded microgrid needs a separate controller to control the system voltage and frequency. Without such controller large circulating current will flow between the DRES and it will lead to grid failure.

Fig.9

1. Single Master Slave Control (SMSC)
Each and every Distributed Renewable Energy Source has a local controller (Slave Inverter) they are in turn connected to the central controller (Master Inverter), which provides the reference parameters[13]. The Master provides the necessary control signals to the Slaves (PQ Control), when the grid is disconnected (islanded) from the main grid through bidirectional communication link.

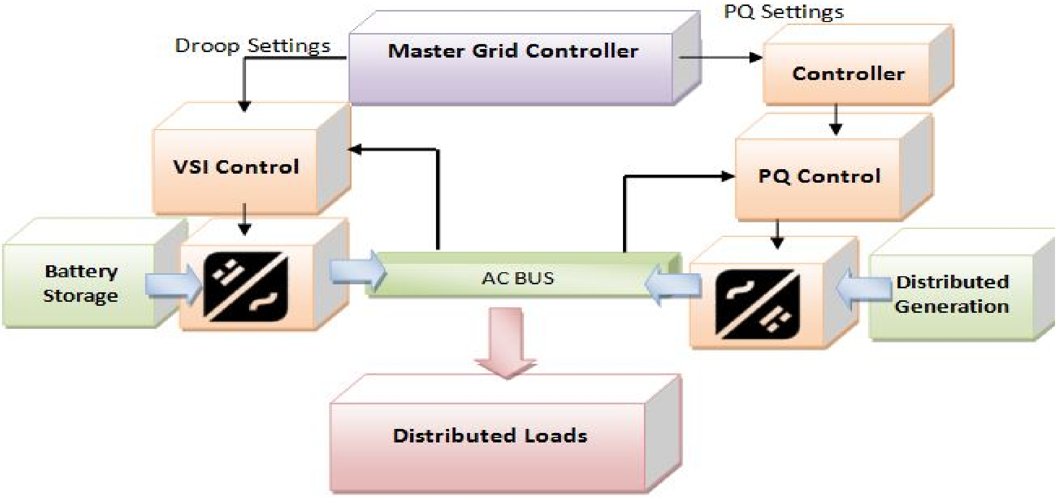


Fig.10

2. Multi Master Slave Control (MMSC)
This system has Multi Master Controllers (MMC) which is basically all the PQ controlled inverters which are in turn co-exist with the Master Voltage Source Inverter. In MMSC control all the PQ controlled inverter (Slaves) can change or modify the reference point for frequency and voltage and their by provides flexibility in setting operating point for smooth control of islanded Microgrids.

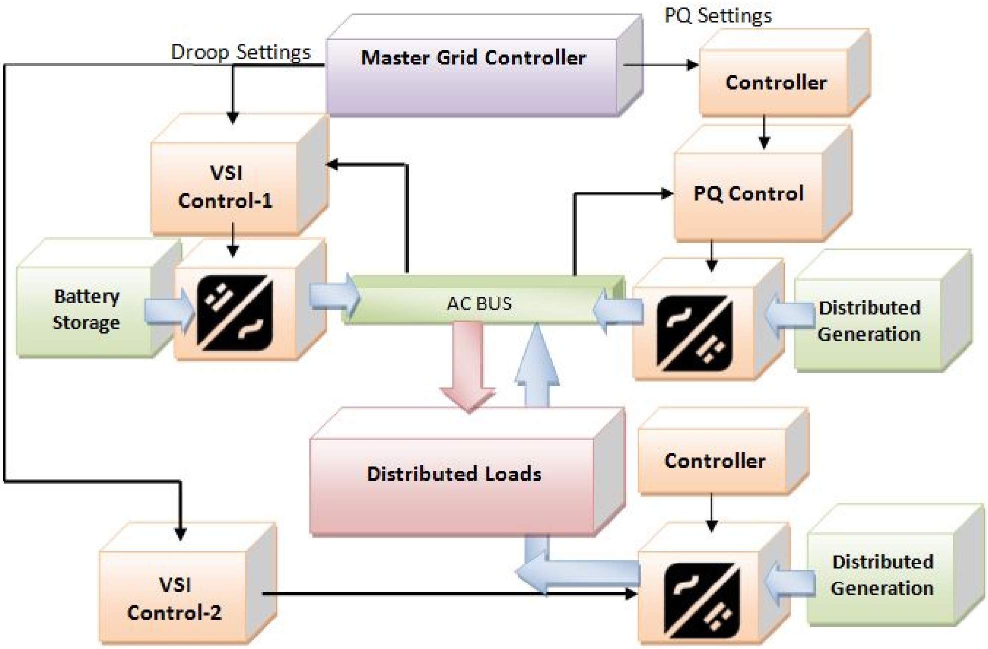


Fig.11

3. Load Frequency Control (LFC)

Load Frequency control is one of the key objectives for any control strategy in an Islanded Microgrid [14]. This is achieved with the help of storage devices, which would keep on injecting or absorbing active power whenever there is a frequency deviation.

V. MAJOR CONTROL CHALLENGES IN ISLANDED MICROGRIDS

Controlling real and reactive power in an Islanded microgrid is not straight forward due to following reasons.

1. They do not have dominant sources of energy and consists only of small Distributed Renewable Energy Sources (DRES) such as photovoltaic, wind turbine and fuel cells.
2. Intermittent nature of different DRES, load demand cannot be pre specified to meet the load requirement.
3. Without autonomous control for voltage and frequency, direct controlling DGs based on preset reference points leads to large circulating current and grid failure.

Some of the key challenges or issues in islanded micro grids are

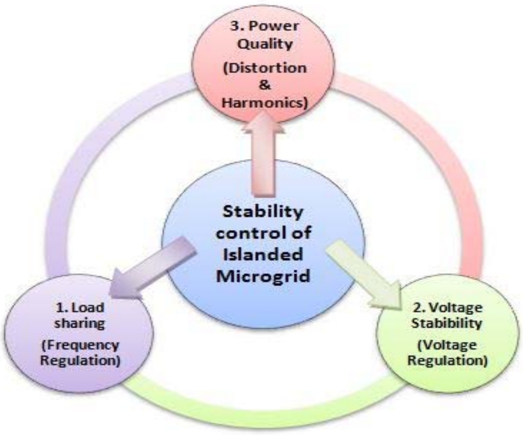


Fig.12

1. Load Sharing (Frequency Regulation):

Load balancing in islanded Microgrids is one of the major challenges because most of the microgrids employs distributed renewable energy resources rather than a dominant source of energy such as synchronous generator. Therefore it is very important to ensure proper load sharing among the distributed generation units because of different size. An Islanded microgrid uses Voltage Source Inverter to provide frequency reference points for load sharing [15]. Even with VSI Reactive power sharing is difficult, because the output voltage of each inverter is different due to different line impedance.

2. Voltage Stability (Voltage Regulation)

Maintaining a constant voltage or within the specified limit is called voltage stability and the method of achieving the same is called voltage regulation. During Islanding micro grid consists mainly of renewable sources of energy, this leads to unbalanced reactive power, it is very difficult to regulate the voltage during the islanding [16]. Without proper controller it leads to voltage/reactive power oscillations.

3. Power Quality (Distortion and Harmonics)

Active power imbalance in an Islanded micro grid leads to frequency instability and due to large number renewable source leads to reactive power imbalance. For controlling the frequency and voltage instability power electronic converters are (Voltage Source Inverter). These switching devices creates introduces harmonics and distortion into the islanded micro grid [17]. If it is not controlled properly and regulated within the specified range, it will cause serious damage to the equipments and components in the micro grid.

VI. CONTROL TECHNIQUES FOR STABILIZING ISLANDED MICROGRIDS

When ever Microgrids moves from grid connected mode to islanded mode either by default or due to fault, it has to meet the same load demand, as compared to when it is connected to the grid but with the reduced access to resources. It is very difficult to maintain the stability of the islanded Microgrids coupled with increase in load demand, or presence of non linear loads. In order to provide stability, it is important to identify the control challenges as well as identify parameters which created the stability issue (voltage, frequency, etc).

Some of the key control techniques for stabilising the islanded Microgrids are

1. Load sharing in Islanded Microgrids

A common method of load sharing is based on droop control and it does not require communication link between distributed generations.

Active Power, P can be approximated as

$$\textbf{Real Power, } P = \frac{V_I V_B \sin\delta}{X}$$

Since δ is small, $\sin\delta \equiv \delta$, therefore

$$\delta = \frac{P X}{V_I V_B}$$

V_I – the Output voltage of voltage source inverter
V_B – AC load bus voltage.
X – Decoupling reactive impedance
δ – Power Angle

Similarly reactive power Q, can be approximated as

$$\textbf{Reactive Power, } Q = \frac{V_B\,(V_B - V_I \cos\delta)}{X}$$

δ → 0, therefore Cos **δ →1**

Substituting the same in the above equation we get

$$\Delta V = V_B - V_I = \frac{Q\,X}{V_B}$$

We can control real and reactive power (**PQ**)by controlling the power angle (**δ)** and voltage drop (**ΔV).** Swing equation gives relationship between frequency (*f*) and power angle (**δ**), therefore frequency (***f***) can be controlled by controlling the real power (**P**). This forms the basic droop control for controlling real and reactive power based on linear characteristics.

Load sharing can be achieved through following control

a. Frequency and Voltage Droop Control

Frequency and voltage droop control is conventional method of controlling the voltage and frequency. The load sharing between the DG's is simple and it is proportional to their rating.

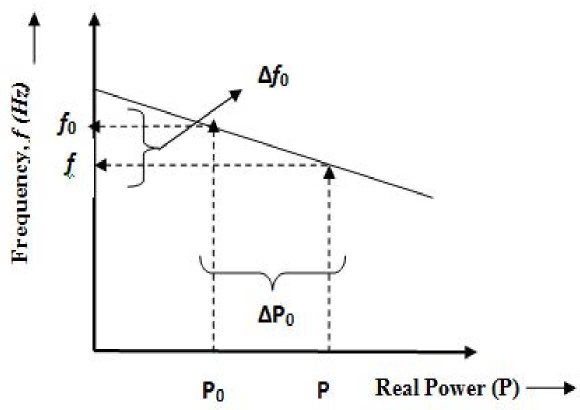


Fig.13

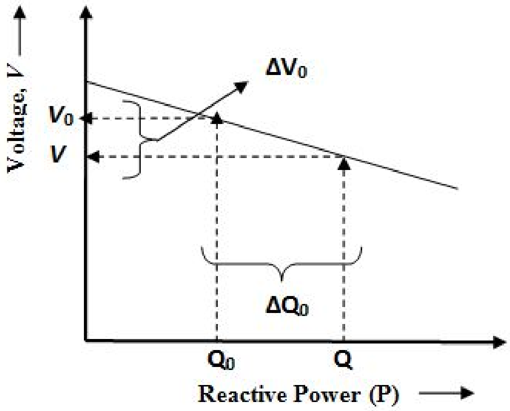


Fig.14

$f = f_0 - K_P (P-P_0)$
$V=V_0-K_Q (Q-Q_0)$
P, Q is instantaneous load power demand.
P_0, Q_0 is base load power.
f_0, V_0 are rated voltage and frequency of the DRES.
K_P, K_Q are frequency and voltage droop coefficients

When there is an increase in load, the demand for real power increases from **P_0 to P** and it is indicated by fall in frequency from ***f_0* to *f*.** This demand for real power is met by DG's with same droop characteristics by increasing their active power output. The increase in active power counters the reduction in frequency, therefore the DRES will settle in new steady state point in the droop characteristic. The droop control is provides lot of flexibility in smooth sharing of load.

b. Angle Droop Control
Conventional droop control with high gain improves the load sharing between the DGs proportional to their rating but it leads to transient oscillations. The transient oscillations can be reduced by controlling the real power based on the power angle **(δ)** [18]. The total load power demand in the micro grid can be supplied by the DGs such that no load shedding is required. The limitation of angle droop control each DGs needs the knowledge of angle of every other DGs.

c. Supplementary control,
This Control is basically a lead-lag compensator and it is used to damp the oscillations as well as to provide high gains. It also eliminates the steady state error and it is implemented along with angle droop controller [19].

d. Adaptive control

The load sharing is achieved by changing the gain value based on the load demand [20]. High value of droop gain is selected when the when the DG's goes below the rated power (**P_0**) and low value of gain is selected for above the rated power (**P_0**). The controller uses threshold value to P_{Th} and Q_{Th} and compares with the power outputs of DRES to select the gain and there by provides load sharing in an Islanded microgrid.

2. Voltage Stability in Islanded Microgrids

The voltage stability is a key parameter and it refers to maintaining the stable voltage within the grid. When a micro grid is islanded, the grid becomes unstable due to increase in load demand. Therefore it is essential to maintain the supply to critical load and proper shedding of less critical load to avoid oscillations. This reflects the inability of the grid to meet the reactive power. It is very much essential that proper control mechanism to maintain the voltage within the specified limits. The voltage stability is achieved with the help of storage devices (Batteries), also called as Energy Storage System (ESS). ESS is installed to complement the intermittent energy sources in an island by injecting or absorbing the required reactive power in order to maintain the voltage with in desired value. The power balancing capacity is limited and therefore power output battery should reduce to zero as soon as possible, to ensure maximum reserve. Basically voltage instability is local phenomena as compared to voltage collapse which is wider phenomena, its like pulling the entire grid down.

3. **Power Quality Improvement in Islanded Microgrids**

The presence of unbalanced loads in the network can cause a voltage unbalance. Inverters will control the unbalanced voltage with the help of energy storage devices either by absorbing or injecting reactive power into the islanded microgrid. The negative sequence reactive power is used to generate the reference for the compensation of voltage unbalance, which is a consequence of a linear unbalance load. In Islanded microgrids different types of Distributed Renewable Energy Sources as different dynamics and causes power oscillation. This power oscillation is the main cause of power quality degradation, losses and overloading o converters. A LCL filter at the converter output is another major cause of power oscillation. A separate series converter is provided and their by relieves overburdening of converter[.

VII.CONCLUSION

An Islanded micro grid poses stability issues with respect to voltage, frequency as well as to deliver quality power compared to traditional micro grid. The research literature are clearly indicates there is no Single controller can provide stability for multiple issues in an islanded micro grids. Balanced load sharing can be achieved by angle droop controller with high gains as well as providing an auxiliary controller will damp the oscillations. Controlling the Energy storage devices (batteries) helps in voltage stability and reactive power balancing. Power quality in an islanded micro grid is of great importance, if unregulated, it can lead damages to equipments and components. It can be improved by implementing techniques like selective harmonic elimination and distortion can be eliminated by providing harmonic impedance. The above mentioned controls can ensure stable operation of an Islanded micro grid. This paper completely discussed various aspects of Islanded micro grids, and it will be great help to the researcher to understand the various issues in islanded Microgrids and related solution which can be improved upon.

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