Literature Review :

Theortical Background

Due to the environmental and economical conditions and the need to provide a clean environment and decrease the carbon emissions in the atmosphere and due to decrement in the fossil fuels,recent technological developments in micro-generation is micro-grid is the future of efficient and fast restoration of power system .

**Micro-grid**

“A group of interconnected loads and distributed energy resources(DERs)with set electrical boundaries that act as single controllable entity with respect to grid that can connect and disconnect itself from the grid based on the mode required”

Fig(1)

The term micro-grid dates back to 1882 when Edison installed 50 DC micro-grid before the operation of the utility grid .Withe the utilization of utility grid and benefiting from economic and increasing transmission process leading to fade away of micro-grids. Certainly in the past years with advancement in technologies of power electronics and DER and more engagement with the electricity consumer the micro-grid concept started seeing the light again.

There are three assorted features if we compromised the DER installations could be considered as a micro-grid :There must be a master controller to control the system components as a single controllable entity, and the installed generation capacity must exceed the peak critical load thus when we can disconnect from the grid and must importantly clearly defined electrical boundaries

The above mentioned characteristics thus present the micro-grid as a small-scale power supply network for small community, it allow the penetration of distributed generation into system. One of its major advantage is that its ability to work alone during utility grid disturbance or outage; in means that micro-grid can operate in two modes

i)ON-grid ii)OFF-grid(Islanded)

ON-grid mode is when the micro-grid is connected to the main utility grid and work in synchronization with it, this mode enables bidirectional power flow and if any disturbance happens to the main grid the micro-grid will switch to off-grid mode or what’s known as standalone grid (islanded) it acts as main provider to the specified geographical area working autonomously with high quality service by acting as local voltage and frequency regulator [1](An overview on micro-grid control).Micro-grid aren’t backup generation; backup generation have been around for quite a while providing temporary supply to local loads when there is a disturbance in the main utility grid supply ,however, micro-grids has wide range of benefits and noticeably more flexible than backup generation.

The Micro-grid main components include Loads, DERs, master controller, smart switches, protective devices, as well as communication, control and automation system.

Micro-grid load are known to be of two categories critical and non-critical (fixed and flexible);critical load (Fixed )must be satisfied at all conditions and isn’t altered whilst the non-critical load (flexible) can differ and be adjusted based on the economic incentives or the status of the grid (islanded requirements).

DERs consist of distributed generation units(DG) and Energy Storage System (ESS) which can be installed on the utility or consumer premises. The distributed generation units are either dispatchable or nondispatchable ;dispatchable units can be controlled by main controller and are subjected to technical constraints depending on the unit type.Nondispatchable cannot be controlled by the micro-grid controller as its input is changeable and unrestrained such units are like Solar and wind mainly renewable sources .The intermittency shows that generation is not always available ,the unpredictability reveal that the generation tends to be unstable in different time scales .Those stated characteristic effect our nondispatchable units negatively and usually increase the forecast error a good solution is always to reinforce those units with energy storage system (ESS).

As we know the demand of electricity varies based on the time of day and time of year .while in traditional power system we aren’t capable of storing electricity and this lead to a gap between supply and demand. Micro-grid having a mixed power generation will allow as to fill in the mismatch as some generations have large response time and others have little flexibility and some generations can start real quickly to provide more or less depending on demand .Provided the late reasons the energy storage system is quite beneficial in managing such system .ESS synchronize with DGs as assurance to micro-grid generation capability. Its inclusion within the micro-grid system allows the excess energy generated to be stored or in the typical scenario could be put into the utility grid

The master controller in the micro-grid perform the scheduling in the dual-mode of the micro-grid based on economic and security considerations, usually the master controller is responsible for interaction with utility grid ,the decision to switch between on-grid and islanded.

With that been said micro-grids benefits are :improve reliability by introducing self-healing at local distribution network, managing local loads due to higher power quality ,carbon emission reduction due to diversification usage in renewable energy sources , economically reducing the Transmission and distribution (T&D) costs[](S. Parhizi et al.: State of the Art in Research on Microgrids: A Review)

**Technical challenges of Micro-grid**

Integration of DERs units and micro-grid introduce a number of technical challenges that require to be addressed in control design and protection system to ensure the level of reliability isn’t effected and the potential benefits of DG are fully harnessed.Some of this challenges are stability issues arising while at transmission level and other are assumptions applied to distribution sytems.

Most relevant challenges in protection and control are bidirectional power flow, stability issues , modeling, low inertia , uncertainty. [] OLIVARES et al.: TRENDS IN MICROGRID CONTROL .

Along with the above the micro-grid must be able to guarantee reliable and economical operation of micro-grid while overcoming the aforementioned challenges .Henceforth, this are some of the required features in control system :output control , power balance, DSM,economic dispatch ,transition between mode of operation [] OLIVARES et al.: TRENDS IN MICROGRID CONTROL .

Furthermore we can summarize microgrid issues into three points

1. **Islanded mode**

This mode represent a future of interconnected grid with a high density of DG.The control strategies of islanding mode are quite essential for the micro-grid to operate in autonomous mode.

Two kind of control strategies of islanding are used to operate the grid .The PQ inverter controls active and reactive power set point .furthermore, the VSI control maintains the voltage and frequency feeding the load.

Henceforth the following issues occur within the islanded mode : As beginning as DG supply the load demand equal sharing is required but due to various unequal capacities of the DG load sharing tend to be impossible. Along with the harmonics and compensation effort for unbalance and nonlinearity of the load. Secondly losing a DG in this mode allow the using of load shedding and battery unit to be explored in order to fulfill the critical load. Finally guaranteeing stability in islanded mode is quite challenging with presence of non-linear load. (An overview on microgrid control strategy).

1. **Stability**

Stability issues may arise in a micro-grid due to various causes such as islanding the micro-grid and grid reconnection, change in parameters ,faults , mismatch in the generation demand, sudden connection of DG or disconnection ,this leading to changes in the voltage and frequency of the system.

Henceforth usage of voltage and frequency controllers or regulators was suggested along with power electronic DGs to give flexibility to the micro-grid. Along with ensuring the both voltage and frequency are within predefined limit around set point values in order to adjust active and reactive power generated or consumed .

1. **Protection**

Certain conditions has to be taken into consideration when designing a micro-grid its ability to operate under unbalanced conditions such as spacing of overhead transmission and unbalanced impedance from three phase load any type of fault within our power system. As the protection of micro-grid is vital a new scheme has been introduced that uses abc-dq transformation of the system voltage to detect any faults or short circuit by comparing measurements at different locations thus associating with micro-grid network the faults varieties at different zones.

Unrestrained excess generation result in the voltage profile distortion in islanded micro-grid therefore, we should take into consideration the characteristic difference between various DG to develop control strategies in order to regulate the power output ,in cases where active power isn’t consumed power oscillations can be used especially in islanded mode.

**Control hierarchy in micro-grids**

To be able to understand how the micro-grid is controlled and how it can operate in the two modes on-grid and islanded.Two opposite approaches are identified with regard to the architecture of power system control which are centralized and decentralized .

A centralized control that is characterized by having one main central controller responsible for collecting all the required data for decision making from the various DERs by performing the required calculations and conclude the control actions for each unit at this single point.

On other hand, we have the decentralized control in which we have a local controller for each DERs unit receiving only local information without being aware of any other system action.

Interrelated power system are usually characterized by covering large geographical areas which means a fully centralized approach is quite infeasible due to the computation needs and communication needed. At the same time decentralized approach is not possible either due to its need of minimum level of coordination and cannot be achieved by using only local variables. Therefore, a cooperation between centralized and decentralized control schemes is found in means of hierarchical control scheme that consist of three control levels :primary,secondary, and tertiary.These control level vary in their (i) speed of response (ii) infrastructure requirments.

[Hierarchy diagram]

Fig (2)

1. **Primary Control**

Is the local control that is first level in our hierarchy featuring fastest response .it being in the first level its control is based on local measurements and does not need communication .Given the speed requirements and reliance on local measurements, islanding detection, inverter output control and power sharing balance are all in this level.

* 1. **Inverter Output Control**

This usually contain the outer loop for voltage control and an inner loop for current regulation. Using PI controllers is the typical approach in designing the control loops supported with feed forward compensation to enhance the current regulator performance; we will have a look at those control loops further in Chapter 3.

* 1. **Power Sharing Control**

A second stage within the primary control level is the power sharing control concept, which we will cover in two indistinct theories:

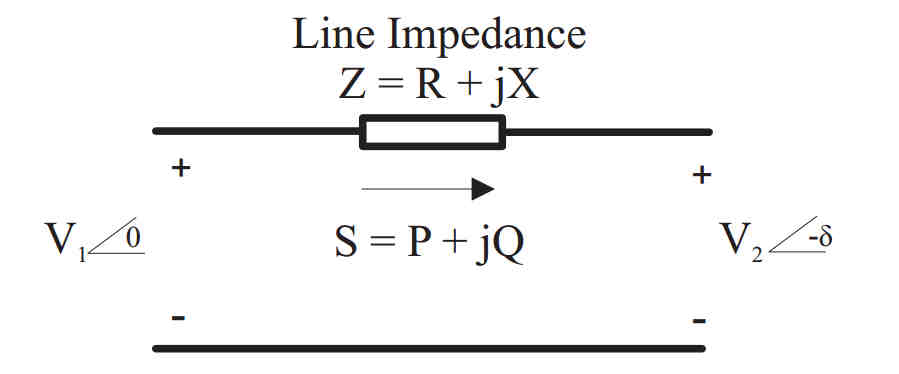
* + 1. **PQ Control**

It is a public control which control the voltage output of an inverter by injecting the active and reactive power in cases the micro-grid cannot give voltage or frequency support .henceforth the micro-grid controller is not effected by the unstable voltage and frequency. Usually when connected to the main grid it provide us by the reference frequency unlike in isolated mode it is given by another micro-grid operating on droop control.

* + 1. **Droop Control**

Droop method is originally from the power balance of synchronous generators in interrelated power systems. A frequency and voltage deviation occurs in our system when there isn’t inequity between the input mechanical power of generator and output electrical active power, likely output reactive power.

Henceforth in this unit if we drooped the frequency as a function of active output power we can then share this power of total load among the various sources. Considering the relationship that dictate power transfer in two inverter system droop control applicability is apparent Fig()



Fig(3):A system with two voltage sources

In droop control the relation between real power/frequency and reactive power/voltage can be expressed as:

Where and are the angular frequency and voltage ,respectively ,and and are measured output frequency and voltage of DG system, respectively. The coefficient and denote the droop coefficients and are determined by the following formula:

droop characteristic are shown in fig (4a) below while basic droop characteristic is shown in fig (4b)



Droop control eliminate the need for communication and its control is based on local measurments which is a noticiable flexibility ,in case we are guaranteed a balance between supply and demand there isnt any need for local controllers .Further illustration will be conducted in Chapter 3

1. **Secondary Control**

It is referred to as the Energy Management System (EMS) of the micro-grid, which is in charge of the security and reliability, and economic operation of the micro-grid in its dual mode. The performance of this control level gets more challenging as we switch to isolated mode(islanded) as there is high-variable energy sources ,in which the unit dispatch command should be high at a rate enough to keep up with the unexpected changes of load and non-dispatchable DERs.

The EMS work on finding the optimal and unit commitment (UC) and dispatch available DER units, its architecture has two main approaches :centralized and decentralized .With that being said this level tend to be the highest level of control in the hierarchy for standalone micro-grids.

The architecture of centralized approach contain a central controller that is enriched with the information of every DER and load in the microgrid and network itself as well as forecasting system information .This central controller make decisions using either online calculation of optimal operation or databases that are continuously updated and pre built with information of suitable operation.

Solving energy management related problems while guaranteeing a high level of autonomy for load and DER is one of the decentralized approach benefits .This autonomy is achieved through three levels :Distribution Network Operator (DNO),Microgrid Central Controller(MGCC) and Local Controllers(LC).

DNO control the communication between the micro-grid and the distribution networkand other microgrid which makes it part of the tertiary control .MGCC supervise the operation of DERs and load within a micro-grid and in charge of their reliable and economic operation while LC control DER units in decentralized architecture an LC can communicate with MGCC and other LC to share knowledge.

1. **Tertiary Control**

This being the highest point in our hierarchical control level it work on setting the optimal set point based on the power system. It is usually in charge of coordinating multiple micro-grids interacting with one another within the same system and communicating the needs from the main or host grid .

It work by providing signal to the secondary level at micro-grid and sub systems forming the full system, on the contrary the secondary control coordinate internal primary control leading the primary control to function autonomously and react in pre-defined ways to identified signals.[TRENDS in Microgrid Control] IEEE TRANSACTIONS ON SMART GRID, VOL. 5, NO. 4, JULY 2014