Literature Review :

Theoretical Background

The environmental and economic conditions, the need to provide a clean environment, and decrease the carbon emissions in the atmosphere and the need to decrease fossil fuels made technological advancements a need. Recent technological developments in micro-generation showed that micro-grids are the future of efficient and fast restoration of the power system.

**Micro-grid**

“A group of interconnected loads and distributed energy resources(DERs)with set electrical boundaries that act as a single controllable entity concerning the 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. With the utilization of utility grid and benefiting from economic and increasing transmission process leading to fade away of micro-grids. Indeed, in the past years, with advancements in power electronics and DER technologies and more engagement with the electricity consumer, the micro-grid concept started seeing the light again.

There would be three different 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. The installed generation capacity must exceed the peak critical load; thus, when we can disconnect from the grid and, most importantly, clearly defined electrical boundaries.

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

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

The on-grid mode is when the microgrid is connected to the primary utility grid and work in synchronization with it. This mode enables bidirectional power flow, and if any disturbance happens to the primary grid, the micro-grid will switch to the off-grid mode or what is known as a standalone grid (islanded). In this mode, the microgrid acts as the primary 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 is not a backup generator; a backup generator has 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 a wide range of benefits and noticeably more flexible than a backup generator.

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

The micro-grid load is known to be of two categories; critical and non-critical (fixed and flexible). Critical load (Fixed) must be satisfied at all conditions and is not altered. In contrast, 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 non-dispatchable. Dispatchable units can be controlled by the central controller and are subjected to technical constraints depending on the unit type. Non-dispatchable 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. Simultaneously, unpredictability reveals that the generation tends to be unstable at different time scales. Those stated characteristics affect our non-dispatchable units negatively and usually increase the forecast error. The right solution is always to reinforce those units with an energy storage system (ESS).

As we know, electricity demand varies based on the time of day and time of year. While in the traditional power system, we are not capable of storing electricity, which leads 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 significant response times, and others have little flexibility. 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 an 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 that could be put into the utility grid.

The master controller in the micro-grid performs the scheduling in the microgrid's dual-mode based on economic and security considerations. Usually, the master controller is responsible for interaction with the utility grid, the decision to switch between on-grid and islanded.

With that been said micro-grids benefits are: improving 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% parhizi2015state

**Technical challenges of Micro-grid**

The integration of DERs units and micro-grid introduces several technical challenges that require addressing the control design and protection system to ensure the level of reliability is not affected. The potential benefits of DG are fully harnessed. Some of these challenges are stability issues arising while at transmission-level, and others are assumptions applied to distribution systems.

The most critical challenges in protection and control are bidirectional power flow, stability issues, modeling, low inertia, uncertainty. % olivares2014trends.

Along with the above, the micro-grid must guarantee the reliable and economical operation of micro-grid while overcoming the challenges above. Henceforth, these are some of the required features in the control system: output control, power balance, DSM, economic dispatch, the transition between mode of operation %olivares2014trends

Furthermore, we can summarize microgrid issues into three points.

1. **Islanded mode**

This mode represents 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 kinds of control strategies of islanding are used to operate the grid. The PQ inverter controls active and reactive power setpoint .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 allows the use of load shedding and battery unit to be explored to fulfill the critical load. Finally, guaranteeing stability in islanded mode is quite challenging with the 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, an immediate connection of DG, or disconnection, and this leads 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 the micro-grid flexibility. Along with ensuring both voltage and frequency are within predefined limit around setpoint values to adjust active and reactive power generated or consumed.

1. **Protection**

Certain conditions have 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 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 circuits. It achieves this by comparing measurements at different locations, thus associating with micro-grid network the faults varieties at different zones.

Unrestrained excess generation results in the voltage profile distortion in an islanded microgrid. Therefore, we should consider the characteristic difference between various DG to develop control strategies to regulate the power output. In cases where active power is not consumed, power oscillations can be used mainly in islanded mode.

**Control hierarchy in micro-grids**

To understand how the micro-grid is controlled and how it can operate in the two modes, on-grid, and island. Two opposite approaches are identified concerning the architecture of power system control, which is centralized and decentralized.

Centralized control 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 concluding the control actions for each unit at this point.

On the 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 activity.

An interrelated power system is usually characterized by covering large geographical areas. This characteristic means a fully centralized approach is entirely infeasible due to the computation needs and communication needed. Simultaneously, a decentralized approach is not possible either due to its need for a minimum level of coordination and cannot be achieved by using only local variables. Therefore, cooperation between centralized and decentralized control schemes is found in means of a hierarchical control scheme that consists of three control levels: primary, secondary, and tertiary. These control levels vary in their (i) speed of response, (ii) infrastructure requirements. %Hierarchy diagram]

Fig (2)

1. **Primary Control**

In local control, it is the first level in our hierarchy featuring the fastest response. It is at 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 at this level.

1. **Inverter Output Control**This usually contains 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 look at those control loops further in Chapter 3.
2. **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:

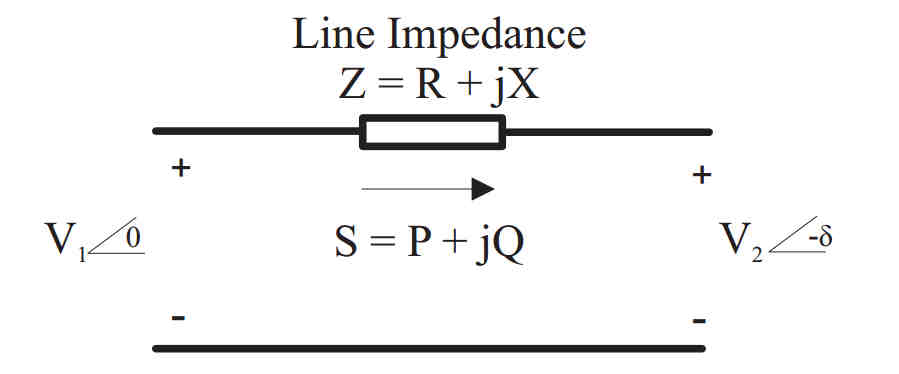
* 1. **PQ Control**

It is a public control that controls an inverter's voltage output by injecting the active and reactive power in cases the micro-grid cannot give voltage or frequency support .henceforth, and the micro-grid controller is not affected by the unstable voltage and frequency. Usually, when connected to the primary grid, it provides us by the reference frequency, unlike in private mode, it is given by another micro-grid operating on droop control.

* 1. **Droop Control**

The droop method is originally from the power balance of synchronous generators in interrelated power systems. A frequency and voltage deviation occur in our system when there is not inequity between the input mechanical power of the 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 dictates power transfer in a 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 known 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. This control level's performance gets more challenging as we switch to isolated mode(islanded) as there are 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 works 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 tends to be the highest level of control in the hierarchy for standalone micro-grids.

The centralized approach's architecture contains 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 makes decisions using either online calculation of optimal operation or databases continuously updated and pre-built with information on proper 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 controls the communication between the micro-grid and the distribution network and other microgrids, making 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 economical 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 control is the highest point in our hierarchical control level, and it works 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 primary or host grid.

It works by providing a signal to the secondary level at micro-grid and subsystems forming the full system. On the contrary, the secondary control coordinates internal primary control leading the primary control to function autonomously and react in pre-defined ways to identified signals.% olivares2014trends