"Operation & Management of Microgrid Using Back to Back Connected Voltage Source Converters with the Utility Mains"

A Dissertation Submitted in the Partial Fulfilment for the Degree of

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in

Power System Engineering

Submitted By

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CERTIFICATE

It is certified that **Mr. Nitin** Roll No. **09/P.Sy./09**, student of **M.Tech. Power System Engineering**, Department of Electrical Engineering, Delhi Technological University, has submitted the dissertation entitled **“Operation & management of microgrid using back to back connected voltage source converters with the utility mains”** under my guidance towards partial fulfilment of the requirements for the award of the degree of Master of Technology (Power System Engineering).

The dissertation is a bonafide work record of project work carried out by him under my guidance and supervision. His work is found to be outstanding and his discipline impeccable during the course of the project.

I wish him success in all his endeavours.

Dr. Vishal Verma

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ABSTRACT

Grid Coupled distributed generation Systems (DGs) are gaining wide popularity and acceptance these days. There is a need for faster and reliable systems for operation particularly when dealing with grid connected distributed generation systems (DGs). But most of the state-of-the-art systems are not so cost-efficient, faster and reliable. The objective of this project is to develop a new, highly efficient and cost-effective algorithm for the distributed generation (DG) interface for grid interactive applications. This thesis proposed a solution for arrangement of electrical power, generated by distributed generators (DG), catering to local loads as well as the grid. The interface design is capable of accomplishing the following tasks: (a) the generated power is feed to the local as well as main grid through the back to back voltage source converters (VSCs). (b) In case of generated active power being more than the local load, the difference is fed to the grid, and when it is less than the local load, additional power is drawn from the grid. (c) Islanding of the system for its protection in case of absence of the grid. (d) Load Scheduling. In case the grid gets disconnected from distributed generation systems (DGs), the proposed system detects this condition quite easily. At the time of grid disconnection, if the power fed by the DG is insufficient, then the load is scheduled according to the need and supply. At the time of reconnection to grid, the voltage source converters are synchronized and allow transferring with in short time. The DGs are made to operate in the islanding mode even after the grid is detected and is synchronized with the grid first. After the synchronization is complete, the operation is successfully transferred from islanding to normal mode.

A combination of the above two techniques (normal operation and islanding operation) with the option of selecting the one suiting and fulfilling the need accordingly at the particular time can be highly cost-efficient, fast and reliable.

The work presented in thesis deals with issues related to formation of microgrid, its operation and solution to the difficulties faced by such integration with main grid. The MATLAB modeling and simulation of operation of micro grid under both grids connected and islanding mode is discussed in different chapters. The grid connected mode address to load sharing, reactive power compensation and other power quality issues, whereas, the islanded mode has been shown to deal with islanding detection, isolation from the main grid, intentional scheduling of the load and reconnection of the main grid to the microgrid. The simulation result presented in the thesis depicts performance of the proposed control method under dynamic perturbation on microgrid and grid side.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Power system plays an important role in our life. A good power system maintains reliability of power supply and also good power quality to the customer. The load demand around the world is gradually increasing, to meet the load requirements and fossils fuel are fast depleting. This is not economically convenient to generate power far from the loads thus dispensing of this bulk power generation is moving towards renewable sources. So we are moving new trend of power generation that is called distributed generation (DG). In distributed generation (DGs) power is generated near the load centre to meet the increasing load demand at distributed voltage level. Therefore, the up gradation of transmission lines and in the increase in the capacity of the remote power plants can easily be deferred to a latter date. The distributed generation (DGs) are decentralized power sources. The conventional power system is suffering from the problems of depletion of fossil fuel resources, poor energy efficiency and environmental pollution but distributed generation systems (renewable energy sources) are free from these problems. The distributed power generation systems (DPGs) have been gaining popularity due to their efficiencies and lower emission, and the technologies have already been used to share to peak generation during peak load hours when the coast of electricity is high and provide stand by generation during system outages. The development of distributed generation has to lead to a more recent concept called microgrid "A microgrid is a cluster of inter connected distributed generators, load and intermediated energy storage unit that cooperated with to each other to be collectively treated by the grid as a controlled load or generator" and compared to a single distributed generation, a microgrid has capability and controlled flexibilities to fulfil system reliability and power quality requirement. The microgrid also offers opportunities for optimizing DGs.

A microgrid supported by distributed generation sources could be connected to utility grid by back to back (BTB) voltage source converters (VSCs) which allow bidirectional power flow between microgrid and utility grid. If the power generated by DGS is more than the connected load on microgrid the extra power is fed into the utility grid, whereas if the power generated by distributed generation systems is short for the connected load than remaining power is imported flow from utility grid. This depicts the bidirectional power flow devised by

BTB VSCs . Another advantage of BTB VSCs is operation amidst two different frequencies at which the utility grid and microgrid may operate can be connected. The switching of the voltage source converters (VSCs) are controlled so that the distributed generation can inject a desired amount of real and reactive power into/from the utility grid. This back to back converter connection is essential to ensure that the operation of the two voltage source converter (VSC) do not conflict with each other. New control strategies have been developed to ensure that the both voltage source converter perform effectively.

The microgrid can operate in grid connected mode or autonomous islanding mode and benefit both the utility and the customers. “Islanding” is a condition that a portion of the microgrid which contains distributed generation (DG) and load is isolated from the reminder of the utility system but continue to provide adequate power to local sensitive loads and maintain service within the microgrid. Under normal operation, each distributed generation (DG) system in the microgrid usually works in power control mode or current control mode in order to provide a pre-set or available maximum power to the load and main grid. When the microgrid is cut off from the main grid referred as “intentional islanding”, each distributed generation systems (DGs) must detect this islanding situation and has to be switched to a voltage control mode to provide a constant voltage to local sensitive loads and maintain the stability of the microgrid.

To ensure a smooth re-connection of the microgrid back to the main grid when the grid recovers from a fault, a microgrid re-synchronization method is also required. When the main is back on, the microgrid may then be operating in the islanding mode and may have its own PCC terminal voltage magnitude, frequency and phase angle, which most likely may be different from those at the utility grid terminal. A re-synchronization scheme is thus needed before closing the separation switch. The resynchronization is to ensure the voltage magnitude, frequency and phase angle at the microgrid end and main grid end match for a smooth reconnection of the two systems.

1.2 THESIS OBJECTIVE

The broader focus of the work carried out on this thesis project is the effort to develop a compact, self-monitoring and adjusting intelligent power conditioning module that can be used to interface the distributed generation with the utility grid and develop a grid-coupled microgrids that works in both normal and islanding modes. This project concentrates on re-synchronizing the power of the utility grid and the power being produced by the distributed generation sources. Also, the problem of sudden collapse of the grid supply, which disturbs the stability of the system, is tackled by the islanding operation of the system.

1.3 STATE OF THE ART

1.3.1 Concept of Microgrid

Microgrids are small-scale, low voltage conventional/non conventional power supply networks designed to supply electricity to a small community, such as a housing estate or a suburban locality, or an academic or public community such as a university or school, a commercial area, an industrial site, a trading estate or a municipal region. Microgrid is essentially an active distribution network because it is the conglomerate of DG systems and different loads at distribution voltage level. The distributed generators employed in a Microgrid are usually conventional/non-conventional distributed energy resources (DERs) integrated together to generate power at distribution voltage. From operational point of view, the DG must be equipped with power electronic interfaces (PEIs) and controls to provide the required flexibility to ensure operation as a single aggregated system and to maintain the specified power quality and energy output. This control flexibility would allow the Microgrid to present itself to the main utility power system as a single controlled unit that meets local energy needs for reliability and security. The key differences between a Microgrid and a conventional power plant are as follows: [1]

1. The DGs are of much smaller capacity with respect to the large generators in conventional power plants.
2. Power generated at distribution voltage can be directly fed to the utility distribution network.
3. The DGs are normally installed close to the customers' premises so that the electrical loads can be efficiently supplied with satisfactory voltage and frequency profile and negligible line losses.

The technical features of a Microgrid make it suitable for supplying power to remote areas of a country where supply from the national grid system is either difficult to avail due to the topology or frequently disrupted due to severe climatic conditions or man- made disturbances. From grid point of view, the main advantage of a Microgrid is envisaged as a controlled entity within the power system. It can be operated as a single aggregated load. This ascertains its easy controllability and compliance with grid rules and regulations without hampering the reliability and security of the power utility. From customers' point of view, Microgrids are beneficial for locally meeting their electrical requirements. They can supply uninterruptible power, improve local reliability, reduce feeder losses and provide local voltage support. From environmental point of view, Microgrids reduce environmental pollution and global warming through utilisation of low-carbon technology. However, to achieve a stable and secure operation, a number of technical, regulatory and economic issues have to be resolved before Microgrids can become commonplace. Some problem areas that would require due attention are the intermittent and climate-dependent nature of generation of the DERs, low energy content of the fuels and lack of standards and regulations for operating the Microgrids in synchronism with the power utility. The study of such issues would require extensive real-time and off line research, which can be taken up by the leading engineering and research institutes across the globe.[1]

1.3.2 A Typical Microgrid Configuration

A typical Microgrid configuration is shown in Fig.1.1. It consists of electrical loads and DG system connected through an LV distribution network. The DGs have plug-and-play features. They are provided with power electronic interfaces (PEI) to implement the control, metering and protection functions during stand-alone and grid-connected modes of operation. These features also help seamless transition of Microgrid from one mode to another. The Microgrid consists of three radial feeders (A, B and C) to supply the electrical loads. It also has two conventional and two non-conventional DGs and storage devices. The DGs and storage devices are connected to feeders A and C through microsource controllers (MCs). Some loads on feeders A and C are assumed to be priority loads (i.e. requiring uninterrupted power supply), while others are non-priority loads. Feeder B, however, contains only non-priority electrical loads. The Microgrid is coupled with the main medium voltage (MV) utility grid (denoted as 'main grid') through the PCC (point of common coupling) circuit breaker CB4 as per standard interface regulations. CB4 is operated to connect and disconnect the entire Microgrid from the main grid as per the selected mode of operation. Feeders A, B and C can however be connected and disconnected by operating breakers CB1, CB2 and CB3, respectively.

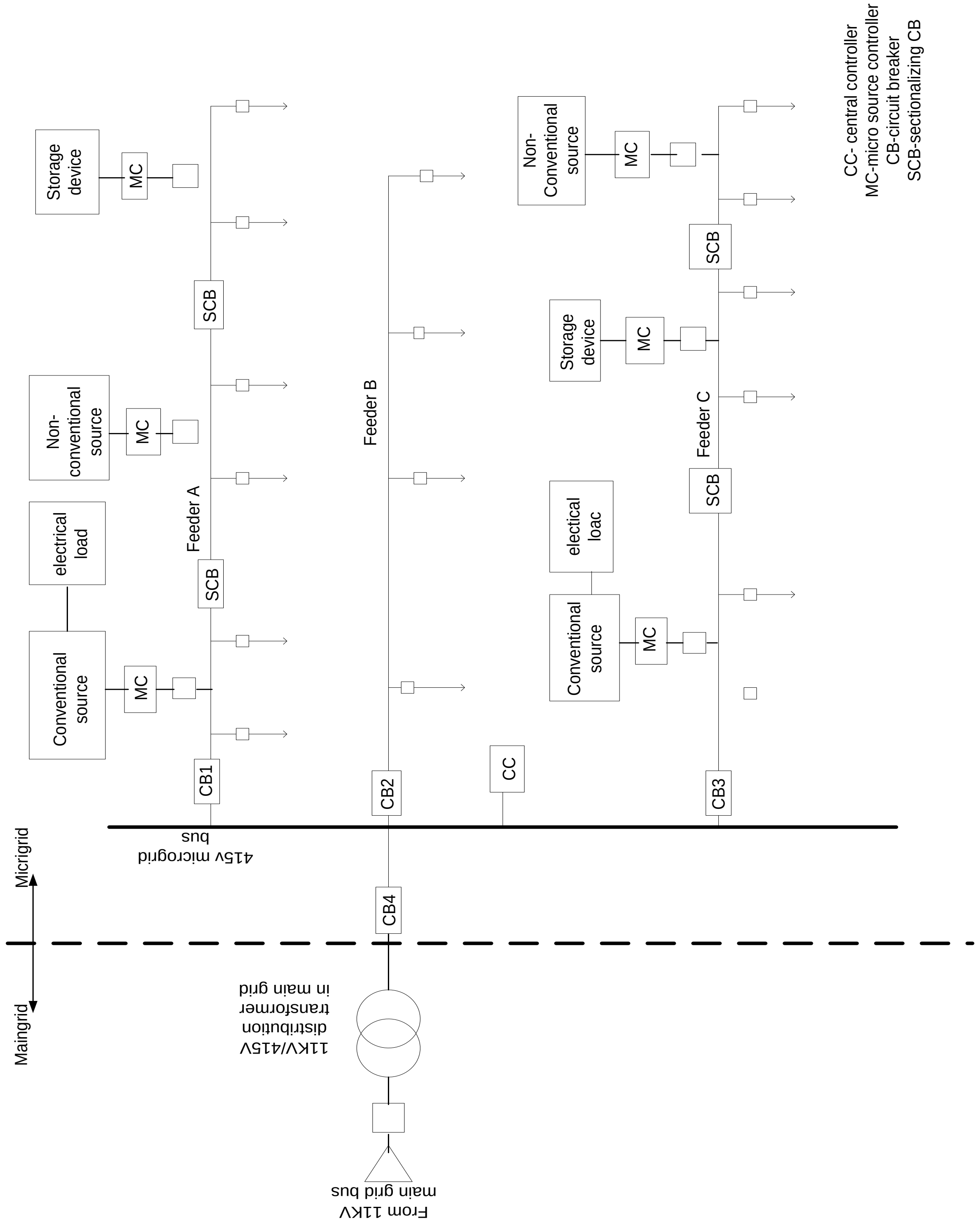

Fig.1.1 A Typical Microgrid Configuration

The DG system on feeder A and C are placed quit apart from the Microgrid bus to ensure reduce in the losses, provide good voltage profile and optimal use of waste heat. The control of power flow and voltage profile along radial feeders is quite complicated when several DGs are connected to a common radial feeder and not to a common generator bus, this configuration is necessary to avail the plug-and-play feature of the DGs. The Microgrid is operated in two modes: (1) grid-connected and (2) standalone. In grid-connected mode, the Microgrid remains connected to the main grid either totally or partially, and imports or exports power from or to the main grid. In case of any disturbance in the main grid, the Microgrid switches over to stand-alone mode while still feeding power to the priority loads. This can be achieved by either (i) disconnecting the entire Microgrid by opening CB4 or (ii) disconnecting feeders A and C by opening CB1 and CB3. For option (i), the Microgrid will operate as an autonomous system with all the DGs feeding all the loads in feeders A, B and C, whereas for option (ii), feeders A and C will supply only the priority loads while feeder B will be left to ride through the disturbance.[1]

1.3.3 Interconnection of Microgrid

Since Microgrids are designed to generate power at distribution voltage level along with utilization of waste heat (in case it is generated), they have restricted energy handling capability. Therefore, their maximum capacity is normally restricted to approximately 10 MVA as per IEEE recommendations. Hence, it is possible to supply a large load pocket from several Microgrids through a common distribution network, by splitting the load pocket into several controllable load units, with each unit being supplied by one Microgrid. In this way, Microgrids can be interconnected to form much larger power pools for meeting bulk power demands. For interconnected Microgrids, each central controller (CC) must execute its control in close co-ordination with the neighbouring CCs. Thus, an interconnected Microgrid would achieve greater stability and controllability with a distributed control structure. It would also have more redundancy to ensure better supply reliability.[1]

1.3.4 Technical and Economical Advantages of Microgrid

The development of Microgrid is very promising for the electric energy industry because of the following advantages:[1]

(1) Environmental issues – It is needless to say that Microgrids would have much lesser environmental impact than the large conventional thermal power stations. Physical proximity of customers with DGs may help to increase the awareness of customers towards judicious energy usage.

(2) Operation and investment issues – Reduction of physical and electrical distance between DG system and loads can contribute to:

(i) Improvement of reactive support of the whole system, thus enhancing the voltage profile.
(ii) Reduction of T&D feeder congestion.
(iii) Reduction of T&D losses to about 3%.
(iv) Reduction/Postponement of investments in the expansion of transmission and generation systems by proper asset management.
(3) Power quality – Improvement in power quality and reliability is achieved due to:
(i) Decentralization of supply.
(ii) Better match of supply and demand.
(iii) Reduction of the impact of large-scale transmission and generation outages.
(iv) Minimization of downtimes and enhancement of the restoration process through black start operations of DGs.
(4) Cost saving – The following cost savings are achieved in Microgrid:
(i) A significant saving comes from utilization of waste heat in combined heat and power (CHP) mode of operation. Moreover, as the CHP sources are located close to the customer loads, no substantial infrastructure is required for heat transmission. This gives a total energy efficiency of more than 80% as compared to a maximum of 40% for a conventional power system.
(ii) Cost saving is also effected through integration of several DG system. As they are locally placed in plug-and-play mode, the T&D costs are drastically reduced or eliminated. When combined into a Microgrid, the generated electricity can be shared locally among the customers, which again reduces the need to import/export power to/from the main grid over longer feeders.
(5) Market issues – The following advantages are attained in case of market participation:
(i) The development of market-driven operation procedures of the Microgrids will lead to a significant reduction of market power exerted by the established generation companies.
(ii) The Microgrids may be used to provide ancillary services.
(iii) Widespread application of modular plug-and-play DGs may contribute to a reduction in energy price in the power market.
(iv) The appropriate economic balance between network investment and DG utilisation is likely to reduce the long-term electricity customer prices by about 10%.

1.3.5 Challenges in Microgrid Development

In spite of potential benefits, development of Microgrids suffers from several challenges and potential drawbacks as explained.[1]

(1) High costs of distributed energy resources – The high installation cost for Microgrids is a great disadvantage. However this can be reduced by arranging some form of subsidies from government bodies to encourage investments.

(2) Technical difficulties – These are related to the lack of technical experience in controlling a large number of plug-and-play DGs. This aspect requires extensive real-time and off line research on operation, protection and control aspects of Microgrids and also on the choice, sizing and placement of DGs. The seamless switching between operating modes is still a major challenge since the available solutions for reclosing adaptive protection with synchronism check are quite expensive.

(3) Absence of standards – Since Microgrid is a comparatively new area, standards are not yet available for addressing operation and protection issues. Power quality data for different types of sources, standards and protocols for integration of DGs and their participation in conventional and deregulated power markets, safety and protection guidelines, etc., should be laid down.

1.3.6 Operational Issues of Microgrid

Major operational issues related to a Microgrid are as follows:[1]

(1) For maintaining power quality, active and reactive power balance must be maintained within the Microgrid on a short-term basis.

(2) A Microgrid should operate stand-alone in regions where utility supply is not available or in grid-connected mode within a larger utility distribution network. Microgrid operator should be able to choose the mode of operation within proper regulatory framework.

(3) Generation, supply and storage of energy must be suitably planned with respect to load demand on the Microgrid and long-term energy balance.

(4) Supervisory control and data acquisition (SCADA) based metering, control and protection functions should be incorporated in the Microgrid central controllers (CCs) and microsource controllers (MCs). Provisions must be made for system diagnostics through state estimation functions.

(5) Economic operation should be ensured through generation scheduling, economic load dispatch and optimal power flow operations.

(6) System security must be maintained through contingency analysis and emergency operations (like demand side management, load shedding, islanding or shutdown of any unit). Under contingency conditions, economic rescheduling of generation should be done to take care of system loading and load-end voltage/frequency.

(7) Temporary mismatch between generation and load should be alleviated through proper load forecasting and demand side management. The shifting of loads might help to flatten the demand curve and hence to reduce storage capacity.

(8) Suitable telecommunication infrastructures and communication protocols must be employed for overall energy management, protection and control.

1.3.7 Dynamic Interactions of Microgrid With Main Grid

The capacity of Microgrid being sufficiently small, the stability of main grid is not affected when it is connected to the main grid. However, in future, when Microgrids will become more commonplace with higher penetration of distributed energy resources (DERs), the stability and security of the main grid will be influenced significantly. In such case, the dynamic interactions between Microgrid and the main grid will be a key issue in the operation and management of both the grids. However, as of now, since the DERs in Microgrids are mainly meant to ensure only local energy balance within a small load pocket, the effects of DER penetration are likely to have a low impact on the main grid. Nevertheless, Microgrids need to be designed properly to take care of their dynamic impacts on main grid such that overall stability and reliability of the whole system is significantly improved.[1]

1.4 ORAGNIZATION OF THESIS

Chapter-2, Describes the literature survey of the project.

Chapter-3, Describes the general modeling of the system and its control scheme.

Chapter-4, Describes the performance evaluation of grid connected as well as decoupled microgrid

Chapter-5 Present conclusion and future scope of the project.

CHAPTER - 2

LITERATURE SURVEY

2.1 GENERAL

With restructuring and technological changes in the utility sector, electric utilities have begun to include fuel cell, micro turbine, wind farms and PV parks as a power source. The issues with the integration of these new power sources with utility grid are Branch power flows and node voltages, Protection scheme and its ratings, Harmonic distortion and flicker, Power system dynamics and dynamic stability, Reactive power control and voltage control, Frequency control, grid synchronization, slow transient effect (including cloud transients), fast transients effects (switching event, islanding, fault and lightning surge), power storage problems in islanding mode with PV and voltage regulation with wind energy.

2.2 TYPES OF DISTRIBUTED GENERATION

The common types of energy sources that can be utilized in DG systems and the salient features of these types are briefly introduced in the following subsections.

2.2.1 Micro-turbines

They are small capacity combustion turbines, which can operate using natural gas, propane and other types of fuels. In a simple form, they consist of a compressor, combustor, recuperator, small turbine, and generator [2]-[3]. Sometimes, they have only one moving shaft, and use air or oil for lubrication. Micro-turbines are small scale of 0.4-1.0 m3 in volume and 20-500 kW in size. Unlike the traditional combustion turbines, micro-turbines run at less temperature and pressure and faster speed (up to 150,000 rpm), which sometimes require no gearbox. The small size is a big advantage of these systems due to the use of high-speed turbines with airfoil bearings. Due to the low price of natural gas, low installation cost, and low maintenance cost, micro-turbines are one of the most promising DG energy sources today [2]-[4]. A micro-turbine generator is interfaced to the gird or load via a power electronic converter; usually a voltage source inverter [5]. Being a dispatchable source, micro- turbines do not cause intermittent generation problems.

2.2.2 Fuel Cells

The fuel cell is a device used to generate electric power and provide thermal energy from chemical energy through electrochemical processes. It can be considered as a battery supplying electric energy as long as its fuels are continued to supply. Unlike batteries, fuel cells do not need to be charged for the consumed materials during the electrochemical process since these materials are continuously supplied [6]-[7]. Fuel cell capacities vary from 1-kW to few MW for portable and stationary units, respectively. It provides clean power and heat for several applications by using gaseous and liquid fuels. Fuel cells can use a variety of hydrogen-rich fuels such as natural gas, gasoline, biogas or propane. They operate at different pressures and temperatures, which vary from atmospheric to hundreds of atmospheric pressure for a wide range of temperatures. A fuel-cell generator is interfaced to the gird or load via a power electronic converter; usually a voltage source inverter [5]. Being a dispatchable source, fuel cells do not cause intermittent generation problems.

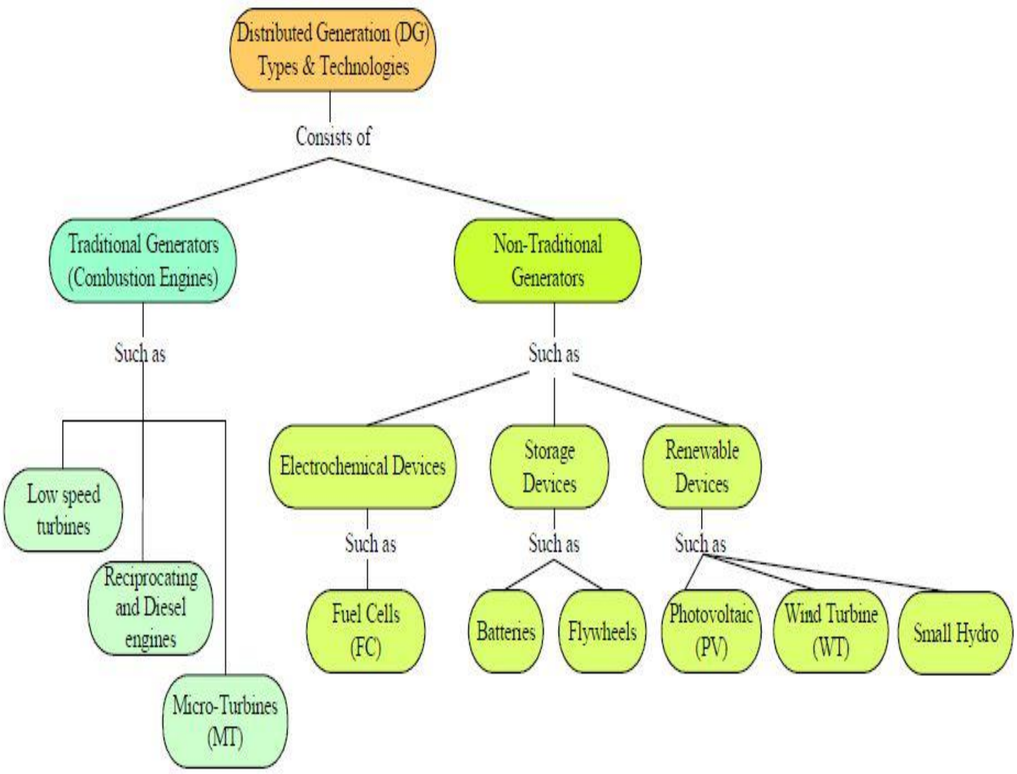

Fig.2.1: Distributed Generation Energy Types and Technologies.

2.2.3 Wind Turbines

Wind energy is not a new form; it has been used for decades in electrical energy production. A wind turbine consists of a rotor, turbine blades, generator, drive or coupling device, shaft, and the nacelle (the turbine head) that contains the gearbox and the generator drive. Modern wind turbines can provide clean electricity as individuals or as wind farms. Wind turbine blades usually are two or three blades. Electricity capacity is limited by the amount of wind, so the wind plants should be installed in windy areas. It has expected electrical efficiency of 20-40%, and the expected power sizes are in the range of 0.3 kW to 5 MW [8]-[9]. There are four types of wind turbines; they are: Type A, B, C and D. Types A, B, and C are connected to the grid or to the load via a rotary machine, normally, an induction generator. Type D, utilizes a full-scale power electronic converter, usually, a voltage source inverter, for grid interfacing. Wind farms have been found in areas with heavy wind profile. Large ratings such as 640 MW have been reported [10]. Due to the large penetration of wind turbines and the chaotic nature of wind power generation, the impact of the wind generation on system performance is remarkable. Extensive research efforts are running in addressing and mitigating the impact of wind turbines on system operation [11], stability [12], planning and reliability [13], power quality [14], pricing and market [15], etc.

2.2.4 Photovoltaic (PV) Systems

The basic unit of a PV array is a cell that may be square or round in shape, made of doped silicon crystal. Cells are connected to form a module or panel and modules are connected to form an array to generate the required power from the sunlight. Current ratings of PV arrays vary from 0.3 kW to few MW. However, larger sizes of PV generation units are limited. This is because the high cost of land, weak solar intensity in many areas around the world, and climate changes leading to unreliable sun exposure [16], [17]-[18]. Approximately, one acre of land would be needed to provide 150 kW of electricity [16]. Currently, the cost per kW of a PV system is around $6000, whereas it is $900 in micro-turbine generation. The cost per kW of other DG sources can be found in Fig.2.2. Until the 1990s, the creation of photovoltaic farms (in analogy to wind farms) has been considered the preferred solution to increase the penetration of PV arrays. However, cost issues and the relatively low power generation of these farms made the concept of PV farms un-economical. Small scale distributed PV panels (1-100 kW) yield cost effective solutions with higher reliability. Recently, under the green energy policies adopted by many countries, some interest in large scale PV farms appears. In general, the impact of PV generation profile on the system level, mainly voltage fluctuations and possible harmonic injection, is weak and it can be mitigated by injecting a controlled-reactive power through the PV inverter itself [19]-[20] or via nearby controlled reactive power sources. Therefore, the majority of PV studies are directed either towards the internal controls of the PV generation system for better energy processing and precise power tracking [21] or towards the development of more exotic solar cell technology for greater efficiency and to lower the overall generation cost [22]. It is worth to mention that large wind and PV farms are normally connected at the sub-transmission or transmission levels, where the grid stiffness is higher and the impacts are less pronounced. Therefore, studies related to these farms in the context of distribution systems are not practical and will lead to flawed results. A PV generator is interfaced to the gird or load via a power electronic converter; usually a voltage source inverter [5].

2.2.5 Other DG Sources

Other renewable energy sources, such as micro-hydro power, bio-energy, geothermal power, ocean thermal power, and ocean wave power can be utilized in DG systems. Currently, these sources are not commonly used due to economical reasons.

2.2.6 Energy Storage Devices

Current technologies enable efficient means of energy storage. Common among these are: batteries, super-capacitors, flywheels, and super-conducting magnetic energy storage [23]. Energy storage devices can have important roles in DG systems, such as enabling fast load pick-up, enhancing the reliability, and flatting the generation profile in non dispatchable sources [24].

Energy storage generators are interfaced to the gird or load via a power electronic converter; usually a voltage source inverter [5].

2.2.7 Hybrid Systems

To improve the efficiency and generation characteristics, hybrid DG energy sources have been proposed. Recently, a solid oxide fuel cell has been combined with a gas microturbine to form a combined cycle power plant. The combined plant has an electrical efficiency of greater than 70% with ratings range from 250 kW to 2.5 MW [16], [25]. High efficiency, such as 75%, can be achieved with combined heat plants as well. Also, the wind energy sources have been utilized with other DG energy sources, such as fuel cells, PV, micro-turbines, energy storage devices or diesel-fired generators, particularly in weak and isolated networks [26]. Figure 2.2 illustrates the salient feature of common energy sources in DG system, from the point of view of rating, capital cost, grid-interfacing technology, efficiency, and fuel type. Most of this information has been published by the U.S. Department of Energy in [26].

In current standards, e.g. IEEE Standard 1547-2003 [27] and IEEE Standard 929-2000 [28], DG units are normally disconnected from the ac line when the grid is not present. However, in coming few years where higher penetration of DG will be there, it will be meaningless to discard these backup sources when the grid is not present. Therefore, DG units should be able to work in the islanded mode of operation serving sensitive loads; yielding to remarkable boosts in system reliability. Moreover, in rural and remote areas, where a public grid is not researchable, islanded operation mode is necessary.

	Micro-turbines	Fuel Cells	Wind–Turbines	Photovoltaic Arrays	Fossil Fuels
Rating	20 - 500 kW	1 kW - 5 MW	0.3 kW - 5 MW	0.3 kW - 2 MW	Up to 100 MW
Capital Cost ($/kW)	900	2,800	3,000	5,500	500-900
Grid/load Interfacing Technology	Power Electronic Converter	Power Electronic Converter	Induction Generator and Power Electronic Converter	Power Electronic Converter	Synchronous Generator
Efficiency	20-30%	40-60%	20-40%	5-15%	33%
Fuel Type	natural gas, hydrogen, biogas, propane, diesel	hydrogen, natural gas, propane	wind	sunlight	Oil, diesel, natural gas, coal, etc.

Fig.2.2: Salient Features of Common Energy Sources in DG System.

2.3 PROBLEMS WITH GRID CONNECTED SYSTEMS

When wind turbines are connected to a weak grid, or a large amount of power connected to a more robust grid, it may cause stability problems. The time variation of power output due to wind speed variation. These variations, giving rise to fluctuations in voltage, frequency and phase angle could lead to interference & problems with grid connection. Integrating renewable energy source which are often connected via power electronics interfaces into the power grid can sometimes face a challenging task just from a pure technical point of view. Stability and power quality problems exist due to intermittent nature of the wind. This problem becomes evident, especially, when the amount of wind power integrates to the system is significantly large. The output voltage variation of a wind farm occurs due to two main reasons (i) the wind gusts & frequent gradual wind speed variations and (ii) mechanical disturbances such as swings in wind turbine, wind shear effect an tower shadow effect [29, 30].Wind farms are located at remote locations which tend to be weak points in the electrical power system and require special consideration in connecting wind power plants (WPP) to the grid.

Short circuit power control: Since wind farms are usually situated in remote areas, long transmission lines are required to connect them and hence the fault levels are generally low and the grid is said to be weak grid. The usual practice is that installed capacity of the connected wind power plants (WPP) should be about 10 % of the short circuit power. If the short circuit power is high, the voltage variation due to changes in power production/ consumption at the connection point is low and vice versa. If a wind power plant (WPP) is connected to a weak grid, there may exist the problems of power surge. In such cases, it is necessary to reinforce the grid in order to carry the fluctuating power from WPP. [32]

Voltage Control: Generally, the voltage increases at the point of interconnection of the wind farm and on the feeder to which the wind farm is connected. It should be ensured that the voltage does not exceed the maximum limit values. Voltage control depends on WPP type connected to the grid. Variable speed WPPs (DFIG) can generate reactive power and contribute to voltage control. Difficulty in controlling voltage regulation is aggravated when the WPP is located in a remote area and connected to the distribution network through transmission lines originally designed to be only as a distribution network. As a general rule, WPPs are not permitted to disconnect as long as the voltage and frequency limits are not exceeded. During voltage swells or voltage sags and short circuit currents during and after faults the WPP is disconnected. These are also disconnected when the voltage dips are higher than 10% to 20% as their disconnection does not cause much voltage instability. The current output must increase or else the WPPs will overspeed and cause mechanical failures. Hence with greater wind power penetration, WPPs must comply with ‘low voltage ride through’ capabilities.[31]

Reactive Power Control: WPPs should share the responsibility to define the voltage and frequency of the grid by controlling their real and reactive power as the conventional power plants. For steady state conditions, reactive power produced should be equal to reactive power consumed. In power system networks other components such as lines, transformers and loads also consume reactive power. WPPs are required to import and export reactive power over a full range of system voltages to improve the quality of power injected into the grid. During transient faults reactive power has to be fed into the grid to support the system voltage. In order to provide this voltage control, the WPPs are expected to meet a certain range of reactive power exchange at full active power. The value of reactive current has to be limited to a specified for each individual case to avoid tripping of the protection equipment. If the voltage reaches 1.2 p.u. at point of common coupling (irrespective of the voltage level) the wind has to start performing voltage reduction within 100 ms of detection [33]. Voltage reduction can be achieved by switching in reactors to increase the reactive power demand of wind farm. A grid network contains energy storage elements like capacitors the reactive power thus oscillates between them. All generators in WPPs which are connected to the grid network either with inverters or with synchronous generators are capable of providing reactive power. In DFIG, the reactive power is controllable as they provide considerable reactive power support due to Power Electronic Converters (PECs).

Flicker Control: Flicker problem is typical in constant speed type induction generators. Each time the wind turbine rotor blade passes the tower gives rise to short lived wind variation in power output resulting infrequencies above 1 Hz and its multiples. In these WPPs, the variation in aerodynamic power are directly translated into output power fluctuations and passed on to the grid, as there is no energy buffer between mechanical input and electrical output. Depending on the strength of the grid, the power fluctuations of the active and reactive power in the WPPs may result in grid voltage fluctuations, which can cause flicker. There are various ways of dealing with this issue in the design of wind turbine, mechanically, electrically and using power electronics. Flicker is not much of an issue with DFIG where power electronic converters (PEC) take care of it.[31]

Harmonics Control: Harmonics are of concern due to potential damage to both utility distribution and customer load equipment. However, advanced PECs used in modern WPPs produce very little harmonic distortion in the output. With addition of harmonic correction devices and current trends towards the use of advanced power electronics in variable speed WPPs, harmonics are no longer a significant grid concern.[31]

Photovoltaic systems: PV systems are unidirectional so power flow from PV system to the grid. In grid connected PV systems, when the load connected to the PV systems is short than extra power flow in grid. In case load demand is increased from its rated capacity than extra power flow from grid so for grid connected PV systems, grid behaves like a source and storage device. Due to fault the grid is disconnected from the PV systems than we need to dissipate the generate power by connecting the bleeder because PV systems continuously generating power. We can not store this large power.

PV generation can be integrated into a utility system in substantial amounts without creating any unusual problems in system operation and control. The most severe condition observed by PV generation results the sudden change in PV generator output when the entire array is completely covered or uncovered by a fast moving cloud bank[37]. This appears to the system to be very much like the large, sudden load change associated with industrial rolling mills or electric furnaces. These large load changes can be tolerated but, as their size increases, any system will begin to experience control problems as the disturbance size approaches about 10 percent of the connected load. Because the PV generation is uncontrolled and appears to the system to be part of the load, this same kind of limitation is observed for large PV penetrations. [34, 36]

One effect of primary concern is voltage regulation at the point of common coupling (PCC) any injection of power into a utility grid will cause a voltage rise at the point of connection and in the surrounding network. Due to cloud or in night the power import from utility grid, the voltage at the PCC reduces which is not a desirable feature in grid connected PV system.

The large penetration of PV systems with utility grid will also increase the level of harmonics in the utility supply. The change in intensity of sun light the power generate by the PV system also change so the utility grid dynamics, which seriously affect the utility grid. [35]

2.4 SOLUTION

Some issues for distributed energy source when connected to main grid described earlier in the section needs effective solution. The problem of grid connected in the distributed systems, may be resolved by connecting many small capacity distributed generation system in parallel with some storage devices and the system should feed local load rather than connect bulk power distributed system from grid. Such distributed generation and distributed consumption points to a new technology batter known as microgrid. A microgrid has capability and controlled flexibilities to fulfil system reliability and power quality requirements at such systems. The microgrid also offers opportunities for optimizing distributed generation systems (DGs).

2.5 CONTROL METHODOLOGY

There are two methods to control active and reactive power:

(1) Direct current control

(2) Indirect current control

2.5.1 DIRECT CURRENT CONTROL

The control algorithm requires a low processing time and needs the measurement of variables like the three phase AC source voltages, currents both on load side and that of the VSC output together with DC link voltage. In order to pump the desired amount/shape of current into the microgrid it is needed to estimate and synchronise with mains which requires a low pass filter for sensed AC voltage to obtain the fundamental d-q components. The active power balance on the DC link estimates the component of current corresponding to real power to be drawn from AC source. The use of a PI controller allows a smooth regulation of both AC and DC voltage by keeping a fast the system dynamic response. The main block diagram of the system operation is shown in Fig.2.3.

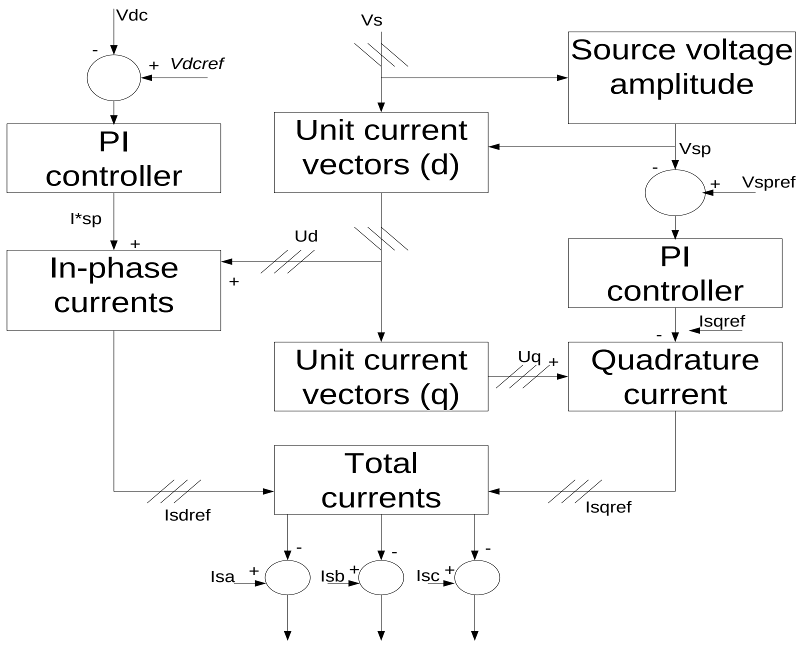

Fig.2.3: Generation of Reference in Direct Current Control Strategy

The rms source voltage amplitude, *Vsp*, is calculated from the source phase voltages

$$V_{sp} = \sqrt{\frac{2}{3}\left(v_{sa}^2 + v_{sb}^2 + v_{sc}^2\right)}$$

$$u_{sa} = v_{sa} / V_{sp}$$

$$u_{sb} = v_{sb} / V_{sp}$$

$$u_{sc} = v_{sc} / V_{sp}$$

The direct (or in-phase) unit current vectors u_{sn} (n=a,b,c) are obtained from the source phase voltages and the rms amplitude of the source voltage, *Vsp*.

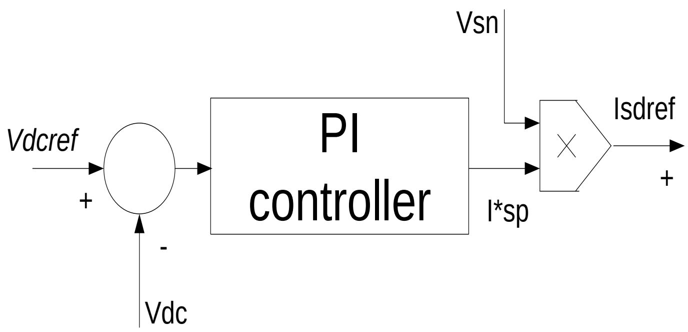

Fig. 2.4: Block Diagram for the Calculation of the Reference Current

The actives components of the reference currents on the AC source, i_{sdref} (i^*_{sad}, i^*_{sbd}, i^*_{scd}), are calculated through a PI controller as shown in Figure 2.4. The proportional and integral gains determine the controller behaviour in dynamic and steady static operation. The correct estimate of amplitude of active component, I^*_{sp}, of the AC source current is determined from the power balance in the DC link. The current reference is then generated with the unit current vectors in phase with the source phase voltage for star connected system.

$$i^*_{sa} = I^*_{sp}\ u_{sa}$$
$$i^*_{sb} = I^*_{sp}\ u_{sb}$$
$$i^*_{sc} = I^*_{sc}\ u_{sc}$$

For the modulation stage (Fig.2.5) the total reference currents are subtracted from the source current to obtain a current error on which the controller triangular carrier to produce PWM signals. The purpose of using the PWM generator is to stabilize the converter switching frequency by forcing it to be constant and equal to the frequency of the triangular carrier signal. Since the current error signal is always kept within the negative and positive peaks of the triangular waveform, the system has an inherent over current protection. The PWM output is augmented with the introduction of an appropriate dead time to the control signals of the inverter transistors.

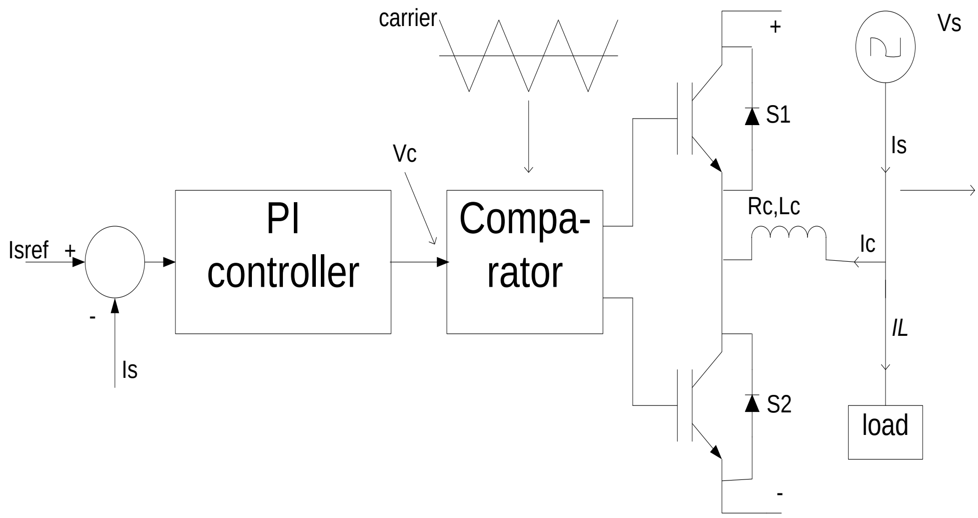

Fig.2.5: Current Control and PWM Stage

2.5.2 INDIRECT CURRENT CONTROL

A typical indirect current control scheme is shown in Fig.2.6. The hysteresis controlled back to back voltage sources converter (VSCs) is connected to microgrid, local load as well as the main grid. The purpose of the indirect current control algorithm is to control the flow of real and reactive power in particular VSC and keeping the microgrid alleviated from power quality problems and control real power flow across the link.

The control of the system is obtained by sensing the load current, source currents and estimating the real power component of the load current and source currents. And based on their difference the quantum of DC power flow across the BTB link is computed, which VSC has to absorb/release. Synchronous reference used to implement this control.

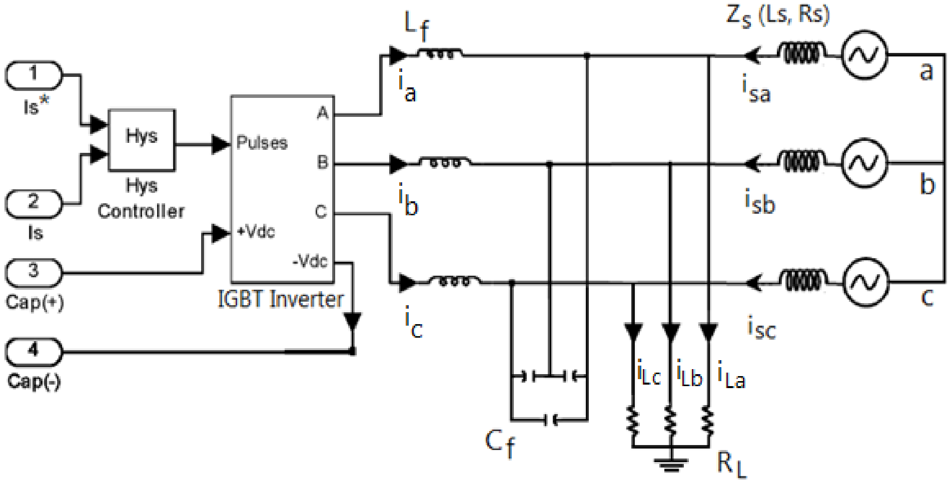

Fig.2.6: The Grid Interface System

As a DC link capacitor is used for maintaining bus voltage to a constant value, the same can also be used for reactive power compensation. Reactive power compensation is done for the fundamental component only, but the control algorithm differs in the sense that the reactive current from the VSC is not a constant but varies with the grid requirement. This value of current saturates at the maximum possible reactive compensation which can be provided by the given VSC.

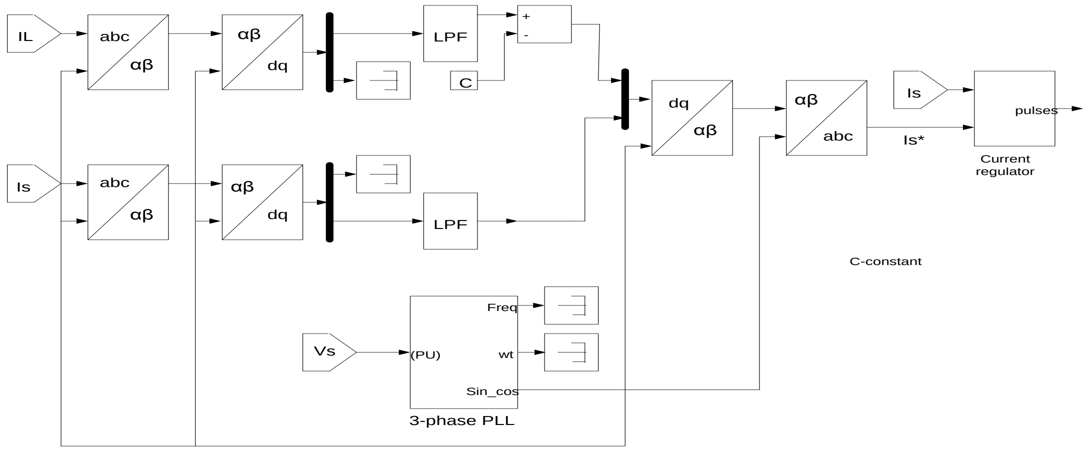

Fig.2.7: Control Scheme for Operation

In order to find the reference source current at fundamental frequency, the synchronous reference frame (SRF) theory based extraction of fundamental component from source current is performed. The control scheme is depicted in Fig.2.7. The SRF isolator extracts the fundamental component of the source current by transformation of i_{sa}, i_{sb} and i_{sc} into d–q reference frame.

In the synchronously rotating reference frame, the components at fundamental frequency (ω1), are transformed to dc quantities and all harmonic components undergo a frequency shift of ω1 (50 Hz). The following are basic equations for these transformations:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos(\omega_1 t) & -\sin(\omega_1 t) \\ \sin(\omega_1 t) & \cos(\omega_1 t) \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

SRF isolator extracts the dc quantities by low pass filters (LPF) for isd from the load current sensor sensing i_{La}, i_{Lb} and i_{Lc} while i_{sq} extraction is done from the grid current sensor (reactive power compensation of the grid) sensing i_{sa}, i_{sb} and i_{sc}.

The dc components i_{sdcD} and i_{sdcQ} are transformed back into a–b–c coordinates to obtain the fundamental components of source currents as shown:

$$\begin{bmatrix} i_{s1\alpha} \\ i_{s1\beta} \end{bmatrix} = \begin{bmatrix} \cos(\omega_1 t) & \sin(\omega_1 t) \\ -\sin(\omega_1 t) & \cos(\omega_1 t) \end{bmatrix} \begin{bmatrix} i_{sdcD} \\ i_{sdcQ} \end{bmatrix}$$

$$\begin{bmatrix} i_{s1a} \\ i_{s1b} \\ i_{s1c} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{s1\alpha} \\ i_{s1\beta} \end{bmatrix}$$

The source current is controlled to follow this reference current by switching the voltage source inverter, through hysteresis current controller. i_{s1a}, i_{s1b} and i_{s1c} together form the reference current is*.

2.6 Problem statement

The configuration of the problem shall consider a distributed energy source (DES) connect to main grid through back to back voltage source converter for bidirectional power flow. An advanced control algorithms which would enable the distribution systems to withstand grid faults, grid connection, power flow control, load sharing, islanding detection, grid synchronization shall be developed and proposed. The proposed algorithm shall provide a variety of flexible control options of power flow control.

A simulation study on microgrid shall be proposed with spread emphasis to

(1) Active and reactive control

(2) Islanding issues and load matching

(3) Grid synchronization

(4) Active load sharing with utility grid

2.7 CONCLUSION

Two main methods exist for controlling *Ps* and *Qs* in the VSC system. The first approach that is known as *voltage-mode control* has been dominantly utilized in high-voltage/-power applications such as in FACTS controllers [38, 39], although its industrial applications have also been reported [41]. In a voltage-controlled VSC system, the real and reactive power are controlled, respectively, by the phase angle and the amplitude of the VSC AC-side terminal voltage relative to the point of common coupling (PCC) voltage [40]. If the amplitude and phase angle of *Vtabc* are close to those of *Vsabc*, the real and reactive power are almost decoupled and two independent compensators can be employed for their control. The voltage-mode control is simple and has a low number of control loops.

However, the main shortcoming of the voltage-mode control is that there is no control loop closed on the VSC line current. Consequently, the VSC is not protected against over currents, and the current may undergo large excursions if the power commands are rapidly changed or faults take place in the AC system. The second approach to the control of the real and reactive power in the VSC system is referred to as the *current-mode control*. In this approach, the VSC line current is tightly regulated by a dedicated current-control scheme, through the VSC AC-side terminal voltage. Then, the real and reactive powers are controlled by the phase angle and the amplitude of the VSC line current with respect to the PCC voltage. Thus, due to the current regulation scheme, the VSC is protected against over current conditions. Other advantages of the current-mode control include robustness against variations in parameters of the VSC system and the AC system, superior dynamic performance, and higher control precision [42]. It is also concluded that BTB VSC shall be used for system under study for Microgrid interface to utility mains.

CHAPTER -3

MODELING OF GRID CONNECTED SYSTEMS

3.1 GENERAL

An accurate and simple modeling of an electrical system is a prerequisite as it enables engineers and researches to get an insight of the system. The system behavior and dynamics can be observed in mathematical equation. In this chapter a mathematical model of the proposed system is presented to address the concerns mentioned above. This mathematical model has simple equation which can be solved as per the system requirement. We can not work directly to the real system because we do not know the behavior and dynamics of system. How behaves it's in transient condition and also do not know the stability of the system in transient condition. Without the modeling of the system we may get the unpredictable result and condition that's why we need the modeling of the system.

3.2 MODELING OF SYSTEM

Fig.3.5 illustrates a circuit model of VSC feeding through Δ/*Y* transformer emulating the DGS studied in this chapter, and each such DGS model consists of a DC voltage source, a three-phase PWM inverter, an *L–C* output filter, a Δ/*Y* transformer, and a load. of course, a DC voltage source may come from one of various generation sources: combustion engine, small hydro, photovoltaic arrays, fuel cells, micro-turbines, or battery energy storage systems.

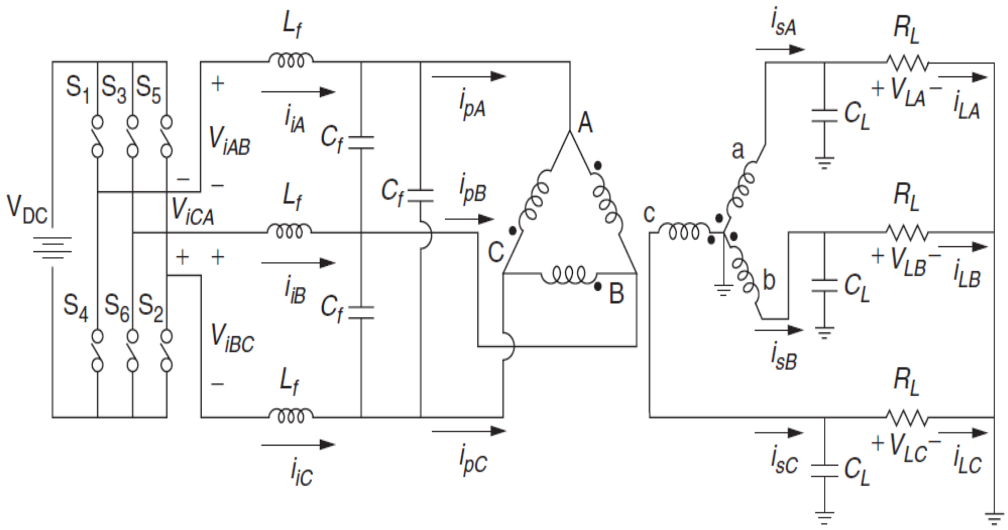

Fig.3.1 Each DGS Circuit Model.

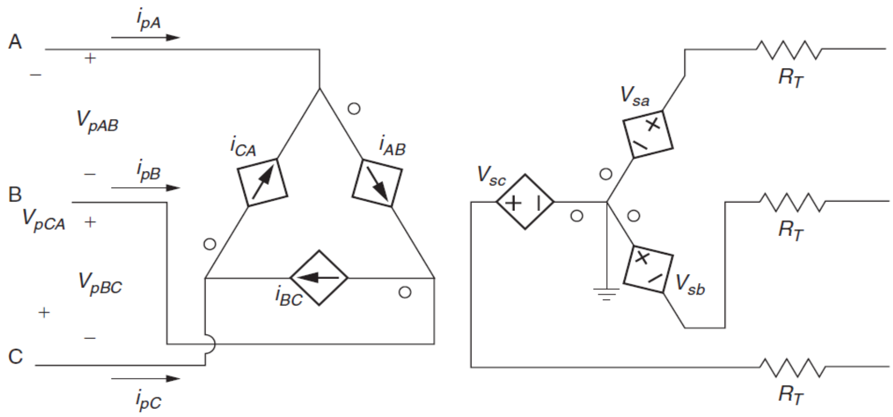

Fig.3.2: Δ/*Y* Transformer Model.

Particularly, the three-phase (Δ/*Y* type) transformer is further modelled using a controlled voltage source, a controlled current source, and equivalent phase impedances with the resistorR_T and the inductor L_T as shown in Fig. 3.2. The power rating of each transformer is 150 kVA, and turn ratio between the primary side (*Np*) and secondary side (*Ns*) is 11000:415. The primary side and secondary side voltages are 11kv (RMS, line to line) and 415 (RMS, line to line), respectively. The circuit system defined in Figs. 3.1 and 3.2 uses the following quantities to describe its behavior. The inverter output line-to-line voltage is represented by the vector $V_i = [V_{iAB} \quad V_{iBC} \quad V_{iCA}]^T$. The three-phase inverter output currents are i_{iA}, i_{iB}, and i_{iC} . Based on these currents, a vector can be defined as$I_i = [i_{iAB} \quad i_{iBC} \quad i_{iCA}]^T$ $I_i = [i_{iA} - i_{iB} \quad i_{iB} - i_{iC} \quad i_{iC} - i_{iA}]^T$. The transformer primary side line-to-line voltage is represented by the vector $V_p = [V_{pAB} \quad V_{pBC} \quad V_{pCA}]^T$.The transformer primary side is Δ connected and the line current vector is defined as$I_p = [I_{pA} \quad I_{pB} \quad I_{pC}]^T$. The transformer secondary side is *Y* connected and the phase voltage and current vectors are represented by $V_s = [V_{sa} \quad V_{sb} \quad V_{sc}]^T$and $I_s = [I_{sa} \quad I_{sb} \quad I_{sc}]^T$, respectively. At the output terminal, the load voltage and current vectors can be represented by $V_L = [V_{La} \quad V_{Lb} \quad V_{Lc}]^TandI_l = [I_{la} \quad I_{lb} \quad I_{lc}]^T$, respectively. The three phase (Δ/*Y* type) transformer has *Np* turns in the primary side windings and *Ns* turns in the secondary side windings. Based on Fig. 3.2, the voltage relation between the two sides of the transformer can be described by [43]

$$V_{sa} = \frac{N_s}{N_p} V_{pAB} , \qquad V_{sb} = \frac{N_s}{N_p} V_{pBC} , \qquad V_{sc} = \frac{N_s}{N_p} V_{pCA} . \qquad 3.1$$

similarly, the current relation is

$$i_{AB} = \frac{N_s}{N_p} i_{sa} \,, \qquad i_{BC} = \frac{N_s}{N_p} i_{sb} \,, \qquad i_{CA} = \frac{N_s}{N_p} i_{sc} \,. \tag{3.2}$$

From Fig. 3.2, it also can be observed that

$$i_{pA} = i_{AB} - i_{CA} \,, \; i_{pB} = i_{BC} - i_{AB} \,, \; i_{pC} = i_{BA} - i_{BC} \,. \tag{3.3}$$

On the primary side of the transformer, the *L–C* filter yields the following current equations:

$$i_{iA} + C_f \frac{dV_{pCA}}{dt} = C_f \frac{dV_{pAB}}{dt} + i_{pA} \,,$$

$$i_{iB} + C_f \frac{dV_{pAB}}{dt} = C_f \frac{dV_{pBC}}{dt} + i_{pB}$$

$$i_{iC} + C_f \frac{dV_{pBC}}{dt} = C_f \frac{dV_{pCA}}{dt} + i_{pC} \,. \tag{3.4}$$

From Eqs. (3.2)–(3.4), it is easy to derive

$$\frac{dV_{pAB}}{dt} = \frac{i_{iAB}}{3C_f} + \frac{1}{3C_f}\frac{N_s}{N_p}(2i_{sa} - i_{sb} - i_{sc}),$$

$$\frac{dV_{pBC}}{dt} = \frac{i_{iBC}}{3C_f} + \frac{1}{3C_f}\frac{N_s}{N_p}(-i_{sa} + 2i_{sb} - i_{sc}),$$

$$\frac{dV_{pCA}}{dt} = \frac{i_{iCA}}{3C_f} + \frac{1}{3C_f}\frac{N_s}{N_p}(-i_{sa} - i_{sb} + 2i_{sc}). \tag{3.5}$$

Rewrite Eq. (3.5) into matrix form:

$$\frac{dV_p}{dt} = \frac{1}{3C_f} I_i - \frac{1}{3C_f} T_i I_s \,, \tag{3.6}$$

Where

$$T_i = \frac{N_s}{N_p}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \qquad 3.7$$

Equation (3.1) can be rewritten as

$$V_s = \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} = \frac{N_s}{N_p}\begin{bmatrix} 1 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} V_{pAB} \\ V_{pBC} \\ V_{pCA} \end{bmatrix} = T_v V_p \ . \qquad 3.8$$

It is easy to write the *L*–*C* filter voltage equations as follows:

$$L_f \frac{d i_{iA}}{dt} - L_f \frac{d i_{iB}}{dt} = V_{iAB} - V_{pAB} \ ,$$

$$L_f \frac{d i_{iB}}{dt} - L_f \frac{d i_{iC}}{dt} = V_{iBC} - V_{pBC} \ ,$$

$$L_f \frac{d i_{iC}}{dt} - L_f \frac{d i_{iA}}{dt} = V_{iCA} - V_{pCA} \ . \qquad 3.9$$

Rewrite Eq. (3.9) into matrix form:

$$\frac{dI_i}{dt} = \frac{1}{L_f} V_i - \frac{1}{L_f} V_p . \qquad 3.10$$

The load current equation can be written as

$$\frac{dV_L}{dt} = \frac{1}{C_L} I_s - \frac{1}{C_L} I_L . \qquad 3.11$$

The voltage equation of the secondary side circuit is

$$\frac{dI_s}{dt} = -\frac{R_T}{L_T} I_s - \frac{1}{L_T} T_v V_p - \frac{1}{L_T} V_L \ . \qquad 3.12$$

Equations (3.6), (3.10), (3.11), and (3.12) are the four state equations for each DGS circuit model or, say, the control plant of the proposed feedback system in this chapter. The state variables of the system are V_p, I_i , V_L , and I_s , the control input is the inverter output line-to-line voltage V_i, and the disturbance is the load current I_L .

The three-phase system represented by the above state space model can be transformed from the *abc* reference frame into stationary *qd*0 reference frame using Eq. (3.13).

$$f_{qd0} = K_s f_{abc} \qquad 3.13$$

Where

$$K_s = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & -\sqrt{3}/2 & \sqrt{3}/2 \\ 1/2 & 1/2 & 1/2 \end{bmatrix}, \quad f_{qd0} = [f_q \quad f_d \quad f_0]^T, \quad f_{abc} = [f_a \quad f_b \quad f_c]^T,$$

and *f* denotes either a voltage or a current variable.,

Rewrite the previous state equations [(3.6), (3.10)–(3.12)] into the stationary *qd*0 reference frame defined above:

$$\frac{dV_{pqd}}{dt} = \frac{1}{3C_f} I_{iqd} - \frac{1}{3C_f} T_{iqd0} I_{sqd0}, \qquad 3.14$$

$$\frac{dI_{iqd}}{dt} = \frac{1}{L_f} V_{iqd} - \frac{1}{L_f} V_{pqd}. \qquad 3.15$$

$$\frac{dV_{Lqd0}}{dt} = \frac{1}{C_L} I_{sqd0} - \frac{1}{C_L} I_{Lqd0}. \qquad 3.16$$

$$\frac{dI_{sqd0}}{dt} = -\frac{R_T}{L_T} I_{sqd0} - \frac{1}{L_T} T_{vqd0} V_{pqd} - \frac{1}{L_T} V_{Lqd0}. \qquad 3.17$$

Where

$$T_{iqd0} = [K_s \quad T_i \quad K_s^{-1}]_{row\ 1,2} = \frac{N_s}{N_p}\frac{3}{2}\begin{bmatrix} 2 & 0 & 0 \\ 0 & 2 & 0 \end{bmatrix}$$

and

$$T_{vqd0} = [K_s \quad T_v \quad K_s^{-1}]_{col\ 1,2} = \frac{N_s}{N_p}\begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix}.$$

All the above vectors with *qd* subscriptions are two dimensional vectors where the zero sequence elements are not included. Because the transformer is Δ/Y type with the neutral point of the secondary side grounded, the secondary side circuit may carry unbalanced three-phase current (e.g., load unbalanced fault can cause zero sequence current). The transient behavior of the zero sequence circuit is uncontrollable in that the circuit is not accessible for the control inputs V_{iq} and V_{id} .

3.3 CONTROL SCHEME

3.3.1 Utility Side Controller

Fig.3.3 Shows the MATLAB model of utility side controller (USC). Here we are using the utility side controller for dc bus controlled and reactive power compensation of utility side loads under grid connected mode. The utility side controller having PLL block for sin(wt) and cos(wt) generation, abc to dqo transformation block, dqo to abc transformation block for current transfomation and a hysteresis current cotroller block which generates switching pulse for utility side converter to regulate dc bus and reactive compensation for grid side load.

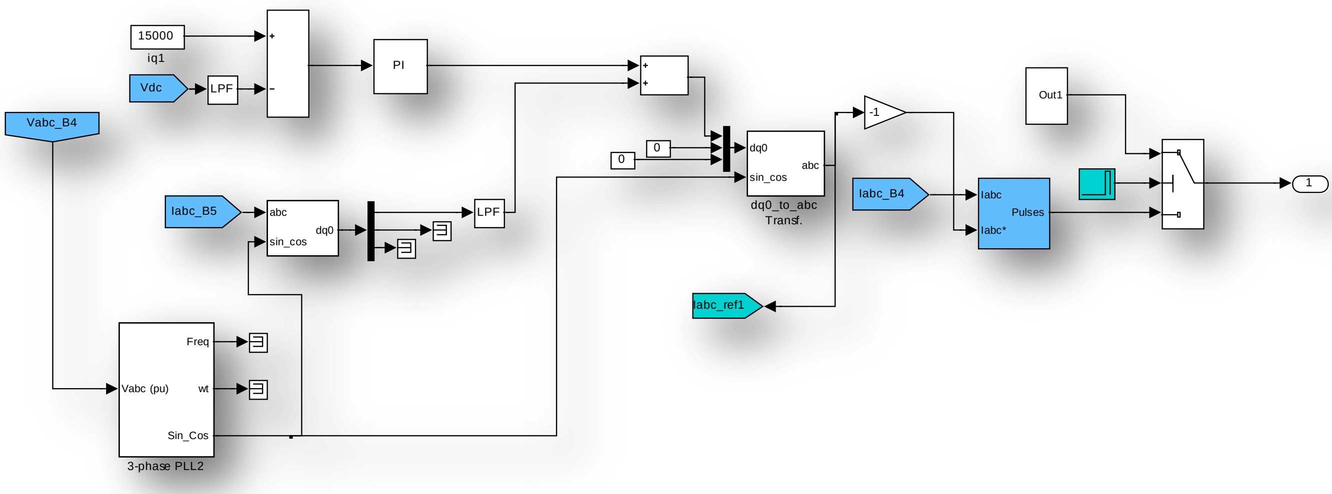

Fig.3.3 Control Scheme of Utility Side Converter

3.3.2 Microgrid side controller

Fig.3.4 Shows the MATLAB model of microgrid side controller (MSC). The microgrid side controller controls the flow of power and in grid connected mode. It is also used for reactive power compensation of microgrid side load. In islanding mode the MSC controller takes over the DC bus control from USC and continuos to support reactive power compensation on microgrid. The microgrid side controller having PLL block for sin(wt) and cos(wt) generation, abc to dqo transformation block, dqo to abc transformation block and a hysteresis current controller block which generates switching pulse for microgrid side converter to control power across the link and reactive compensation for microgrid side load in grid connected mode and tacking DC bus control in islanding condition.

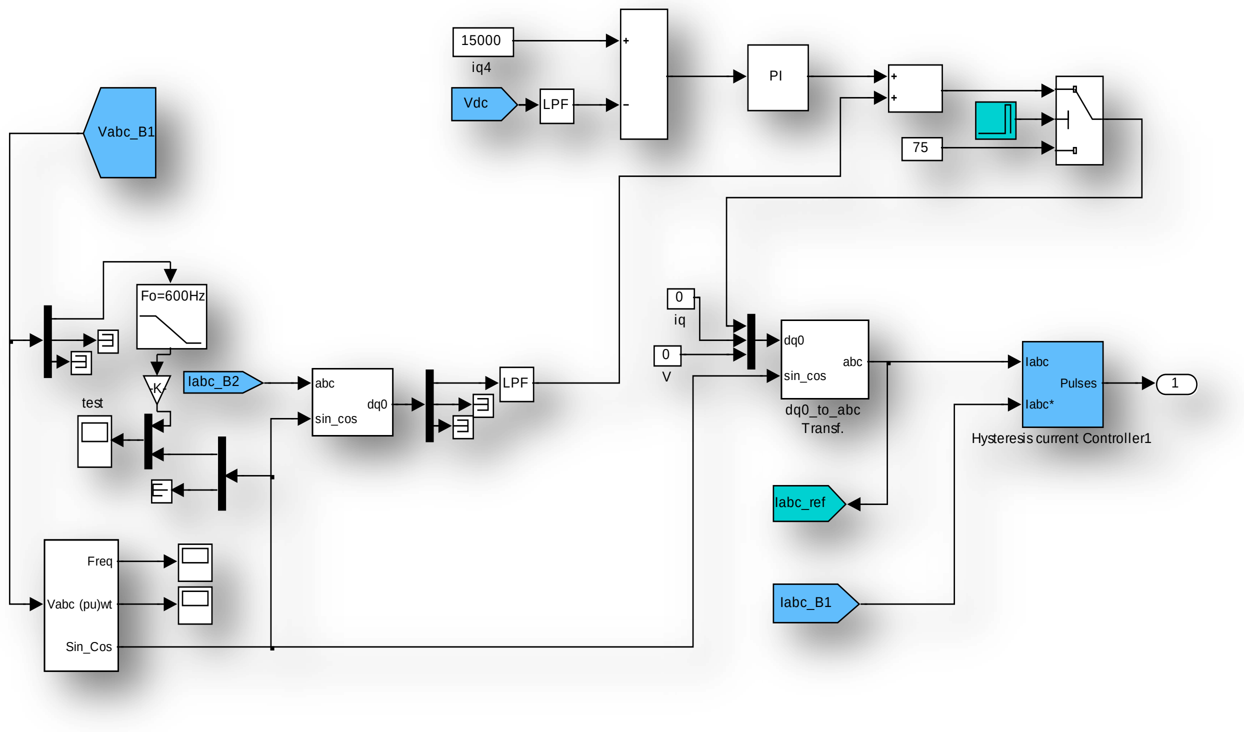

Fig.3.4 Control Scheme of Grid side Converter

3.4 ISLANDING

In a distribution system, when a Utility grid is disconnected for any reason, the distributed generation still supplies the required power to any section of local loads. This phenomenon is called "Islanding Phenomena". When an islanding occurs, the voltages and frequencies in the islanded area cannot be controlled by the grid system. This may lead to damage of electrical equipments and pose a danger to the working personnel. To avoid the occurrence of islanding phenomena, many control schemes have been proposed and devised to sense the islanding.

Islanding can be classified into two types namely:

(i) Unintentional Islanding
(ii) Intentional Islanding

(i) Unintentional islanding: As the name suggests is an undesirable islanding caused in a power grid. It occurs when a part of the distribution system becomes electrically isolated from the whole power grid and is still being energized by the distributed generators. The reason for such occurrence of islanding is due to several reasons such as inverter misinterpreting the voltage and frequency harmonics of utility grid, ground fault on the feeder from grid etc. During a steady state, the real and reactive power produced by the distributed generators and the utility grid should match with the consumption. Any mismatch in real power gives rise to frequency deviation [44]. A part of the grid with balanced load and generation may become islanded when there is a sudden opening of switch or a circuit breaker. Also when such islanding takes place, the working personnel are not aware of the power present in the microgrid and therefore may have a danger of being electrocuted. Also the distributed generators in the islanded microgrid can be damaged if the island is reconnected to the utility grid as the distributed systems usually tend to operate at a different frequency in the islanded mode and could be out of synchronism with the utility grid. This may also give rise to high starter currents which in turn may once again result in tripping of the utility system.

(ii) Intentional Islanding: Intentional islanding can be explained as a purposeful islanding of a microgrid from the remaining power grid system. When there is a power outage, many distributed generators may go out of synchronous with one another and therefore it is required to have specific islands at points where there is a slight mismatch between load and generation. Circuit breaking operations are executed to develop islanded systems.

3.4.1 ISSUES WITH ISLANDING:

Although there are some benefits of islanding operation there are some drawbacks as well. Some of them are as follows:

(1) Line worker safety can be threatened by DG sources feeding a system after primary sources have been opened and tagged out.

(2) The voltage and frequency may not be maintained within a standard permissible level. Islanded system may be inadequately grounded by the DG interconnection.

(3) Instantaneous reclosing could result in out of phase reclosing of DG. As a result of which large mechanical torques and currents are created that can damage the generators or prime movers [45] Also, transients are created, which are potentially damaging to utility and other customer equipment. Out of phase reclosing, if occurs at a voltage peak, will generate a very severe capacitive switching transient and in a lightly damped system, the crest over-voltage can approach three times rated voltage. [46]

(4) Various risks resulting from this include the degradation of the electric components as a consequence of voltage& frequency drifts.

Due to these reasons, it is very important to detect the islanding quickly and accurately.

3.4.2 REVIEW OF ISLANDING DETECTION TECHNIQUES

The main philosophy of detecting an islanding situation is to monitor the DG output parameters and system parameters and/ and decide whether or not an islanding situation has occurred from change in these parameters. Islanding detection techniques can be divided into remote and local techniques and local techniques can further be divided into passive, active and hybrid techniques as shown in Figure 3.5

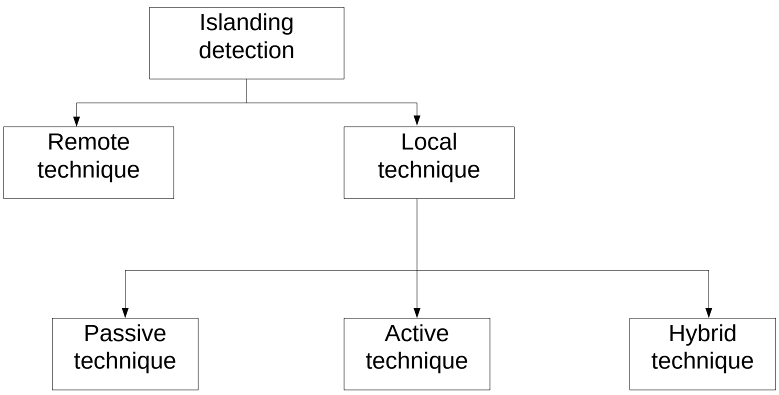

Fig.3.5**:** Islanding Detection Techniques

3.4.2.1 Remote islanding detection techniques:

Remote islanding detection techniques are based on communication between utilities and DGs. Although these techniques may have better reliability than local techniques, they are expensive to implement and hence uneconomical .Some of the remote islanding detection techniques are as follows:

Power line signalling scheme: These methods use the power line as a carrier of signals to transmit islanded or non-islanded information on the power lines. The apparatus includes a signal generator at the substation (25kV) that is coupled into the network where it continually broadcasts a signal as shown in figure (3.6). Due to the low-pass filter nature of a power system, the signals need to be transmitted near or below the fundamental frequency and not interfere with other carrier technologies such as automatic meter reading. Each DG is then equipped with a signal detector to receive this transmitted signal. Under normal operating conditions, the signal is received by the DG and the system remains connected. However, if an island state occurs, the transmitted signal is cut off because of the substation breaker opening and the signal can not be received by the DG, hence indicating an island condition.

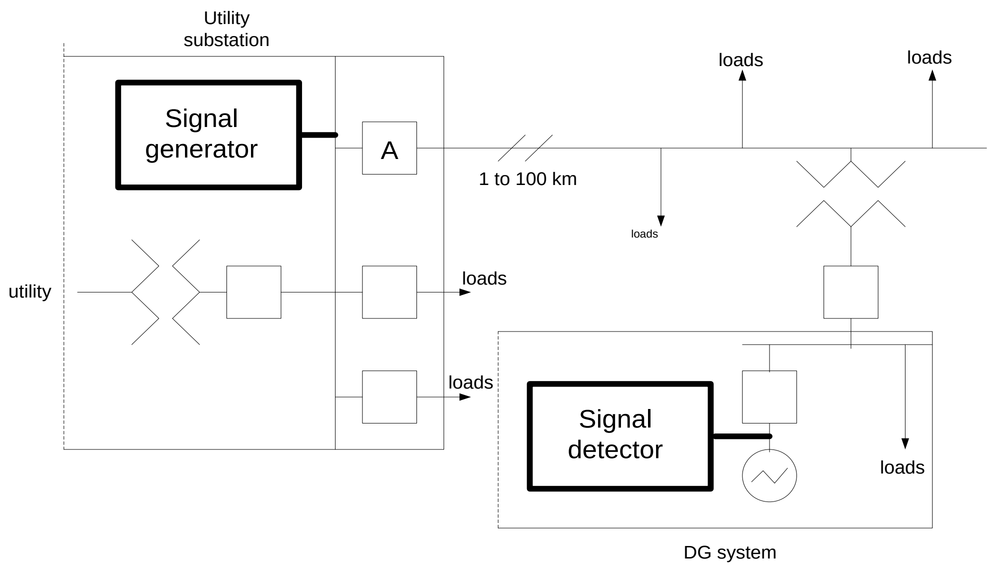

Fig.3.6: Distributed Generation Power Line Signalling Islanding Detection

This method has the advantages of its simplicity of control and its reliability. In a radial system there is only one transmitting generator needed that can continuously relay a message to many DGs in the network. The only times the message is not received is if the interconnecting breaker has been opened, or if there is a line fault that corrupts the transmitted signal.

There are also several significant disadvantages to this method, the first being the practical implementation. To connect the device to a substation, a high voltage to low voltage coupling transformer is required. A transformer of this voltage capacity can have prohibitive cost barriers associated with it that may be especially undesirable for the first DG system installed in the local network. Another disadvantage is if the signalling method is applied in a non radial system, resulting in the use of multiple signal generators. This scenario can be seen in Fig.3.7 where the three feeder busses connect to one island bus. The implementation of this system, opposed to a simple radial system, will be up to three times the cost.
Another problem for power line communication is the complexity of the network and the affected networks. A perfectly radial network with one connecting breaker is a simple example of island signaling; however, more complex systems with multiple utility feeders may find that differentiation between upstream breakers difficult.

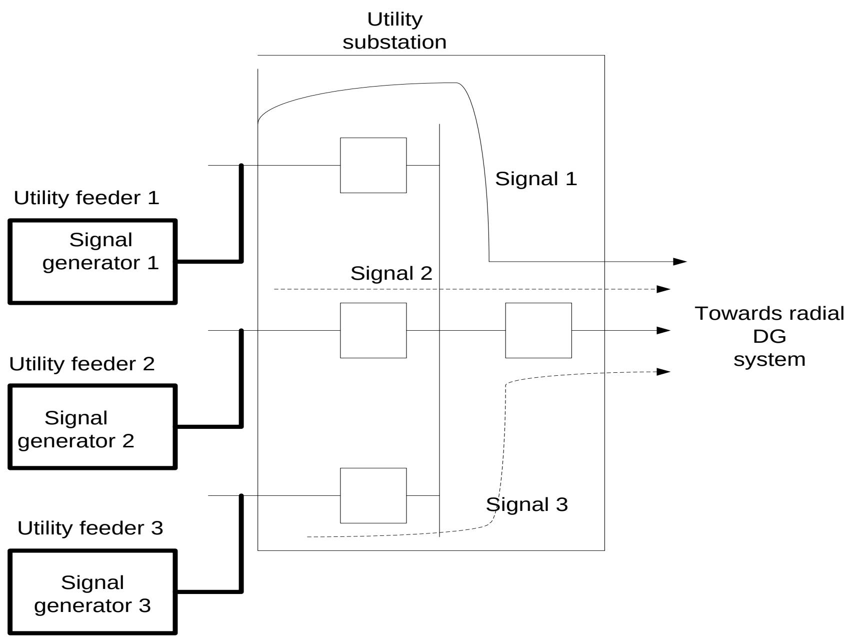

Fig.3.7: Distributed Generation Multi Power Line Signalling Islanding Detection Issue

Transfer trip scheme: The basic idea of transfer trip scheme is to monitor the status of all the circuit breakers and reclosers that could island a distribution system. Supervisory Control and Data Acquisition (SCADA) systems can be used for that. When a disconnection is detected at the substation, the transfer trip system determines which areas are islanded and sends the appropriate signal to the DGs, to either remain in operation, or to discontinue operation. Transfer tip has the distinct advantage similar to Power Line Carrier Signal that it is a very simple concept. With a radial topology that has few DG sources and a limited number of breakers, the system state can be sent to the DG directly from each monitoring point. This is one of the most common schemes used for islanding detection [47].This can be seen in fig.3.8**.** The weaknesses of the transfer trip system are better related to larger system complexity cost and control. As a system grows in complexity, the transfer trip scheme may also become obsolete, and need relocation or updating.

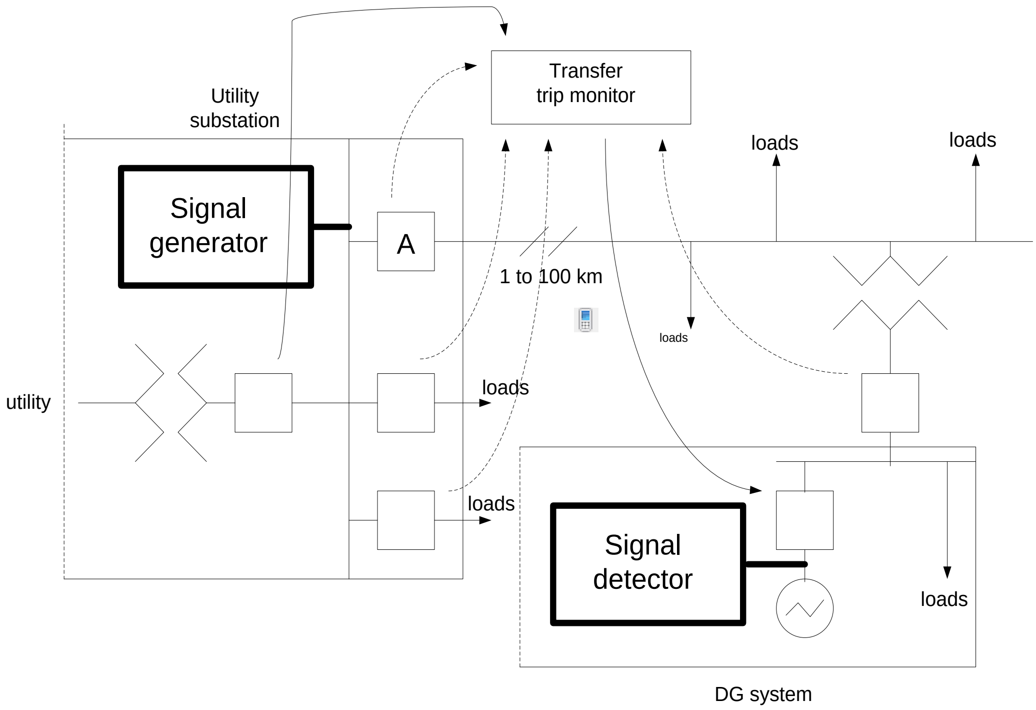

Fig.3.8: Distributed Generation Transfer Trip Islanding Detection

Reconfiguration of this device in the planning stages of DG network is necessary in order to consider if the network is expected to grow or if many DG installations are planned. The other weakness of this system is control. As the substation gains control of the DG, the DG may lose control over power producing capability and special agreements may be necessary with the utility. If the transfer trip method is implemented correctly in a simple network, there are no non-detection zones of operation.

3.4.2.2 Local detection techniques

It is based on the measurement of system parameters at the DG site, like voltage, frequency, etc. It is further classified as:

(a) Passive detection techniques

Passive methods work on measuring system parameters such as variations in voltage, frequency, harmonic distortion, etc. These parameters vary greatly when the system is islanded. Differentiation between an islanding and grid connected condition is based upon the thresholds set for these parameters. Special care should be taken while setting the threshold value so as to differentiate islanding from other disturbances in the system. Passive techniques are fast and they don't introduce disturbance in the system but they have a large non detectable zone (NDZ) where they fail to detect the islanding condition.

There are various passive islanding detection techniques and some of them are as follows:

Rate of change of output power: The rate of change of output power, dp/dt , at the DG side, once it is islanded, will be much greater than that of the rate of change of output power before the DG is islanded for the same rate of load change[48]. It has been found that this method is much more effective when the distribution system with DG has unbalanced load rather than balanced load. [49]

Rate of change of frequency The rate of change of frequency, df/dt , will be very high when the DG is islanded. The rate of change of frequency (ROCOF) can be given by [50]

$$\text{ROCF,} \frac{df}{dt} = \frac{\Delta p}{2HG} \times f \qquad 3.18$$

WhereΔP is power mismatch at the DG side

H is the moment of inertia for DG/system

G is the rated generation capacity of the DG/system

Large systems have large H and G where as small systems have small H and G giving larger value for *df/dt* ROCOF relay monitors the voltage waveform and will operate if ROCOF is higher than setting for certain duration of time. The setting has to be chosen in such a way that the relay will trigger for island condition but not for load changes. This method is highly reliable when there is large mismatch in power but it fails to operate if DG's capacity matches with its local loads. However, an advantage of this method along with he rate of change of power algorithm is that, even they fail to operate when load matches DG's generation, any subsequent local load change would generally lead to islanding being detected as a result of load and generation mismatch in the islanded system.

Rate of change of frequency over power: df/dp in a small generation system is larger than that of the power system with larger capacity. Rate of change of frequency over power utilize this concept to determine islanding condition .Furthermore, test results have shown that for a small power mismatch between the DG and local loads, rate of change of frequency over power is much more sensitive than rate of frequency over time. [51]

Voltage unbalance: Once the islanding occurs, DG has to take change of the loads in the island. If the change in loading is large, then islanding conditions are easily detected by monitoring several parameters: voltage magnitude, phase displacement, and frequency change. However, these methods may not be effective if the changes are small. As the distribution networks generally include single-phase loads, it is highly possible that the islanding will change the load balance of DG. Furthermore, even though the change in DG loads is small, voltage unbalance will occur due to the change in network condition. [52-53]

Harmonic distortion: Change in the amount and configuration of load might result in different harmonic currents in the network, especially when the system has inverter based DGs. One approach to detect islanding is to monitor the change of total harmonic distortion (THD) of the terminal voltage at the DG before and after the island is formed [54].The change in the third harmonic of the DG's voltage also gives a good picture of when the DG is islanded.

(b) Active detection techniques

With active methods, islanding can be detected even under the perfect match of generation and load, which is not possible in case of the passive detection schemes. Active methods directly interact with the power system operation by introducing perturbations. The idea of an active detection method is that this small perturbation will result in a significant change in system parameters when the DG is islanded, whereas the change will be negligible when the DG is connected to the grid.

Reactive power export error detection: In this scheme, DG generates a level of reactive power flow at the point of common coupling (PCC) between the DG site and grid [55] or at the point where the Reed relay is connected [56]. This power flow can only be maintained when the grid is connected. Islanding can be detected if the level of reactive power flow is not maintained at the set value. For the synchronous generator based DG, islanding can be detected by increasing the internal induced voltage of DG by a small amount from time to time and monitoring the change in voltage and reactive power at the terminal where DG is connected to the distribution system. A large change in the terminal voltage, with the reactive power remaining almost unchanged, indicates islanding.[57] The major drawbacks of this method are it is slow and it can not be used in the system where DG has to generate power at unity power factor.

Phase (or frequency) shift methods: Measurement of the relative phase shift can give a good idea of when the inverter based DG is islanded. A small perturbation is introduced in form of phase shift. When the DG is grid connected, the frequency will be stabilized. When the system is islanded, the perturbation will result in significant change in frequency. The Slip-Mode Frequency Shift Algorithm (SMS) [58] uses positive feedback which changes phase angle of the current of the inverter with respect to the deviation of frequency at the PCC.

A SMS curve is given by the equation

$$\theta = \theta_m \sin\left(\frac{\pi}{2}\frac{f^{(k-1)} - f_n}{f_m - f_n}\right) \qquad 3.19$$

Where θm is the maximum phase shift that occurs at frequency fm. fn is the nominal frequency and f (k−1) is the frequency at previous cycle.

(c) Hybrid detection schemes

Hybrid methods employ both the active and passive detection techniques. The active technique is implemented only when the islanding is suspected by the passive technique. Some of the hybrid techniques are discussed as follows:

Technique based on positive feedback (PF) and voltage imbalance (VU): This islanding detection technique uses the PF (active technique) and VU (passive technique). The main idea is to monitor the three-phase voltages continuously to determinate VU [59] which is given as

$$VU = \frac{v+sq}{v-sq} \quad 3.20$$

V+Sq and *V-Sq* are the positive and negative sequence voltages, respectively. Voltage spikes will be observed for load change, islanding, switching action, etc. Whenever a VU spike is above the set value, frequency set point of the DG is changed. The system frequency will change if the system is islanded.

Technique based on voltage and reactive power shift: In this technique voltage variation over a time is measured to get a covariance value (passive) which is used to initiate an active islanding detection technique, adaptive reactive power shift (ARPS) algorithm [60].

$$\text{Co-variance}(\mathrm{T_{av}}, \mathrm{T_v}) = \mathrm{E}\ \mathrm{T_{av}^{(n)}} - U_{av} T_v^{(n)} - U_v \quad 3.21$$

Tav' is the average of the previous four voltage periods.

Uav is the mean of Tav'

Tv is the voltage periods

UV is the mean of TV

The ARPS uses the same mechanism as ALPS, except it uses the d-axis current shift instead of current phase shift. The d-axis current shift, **idk** or reactive power shift is given as

$$\boldsymbol{i}_d^k = \boldsymbol{k}_d \left(\frac{\boldsymbol{T}_{av'} - \boldsymbol{T}_v^{(k)}}{\boldsymbol{T}_v^{(k)}} \right) \quad 3.22$$

kd is chosen such that the d-axis current variation is less than 1 percent of q-axis current in inverter's normal operation. The additional d-axis current, after the suspicion of island, would accelerates the phase shift action, which leads to a fast frequency shift when the DG is islanded. There is no single islanding detection technique which will work satisfactorily for all systems under all situations. The choice of the islanding detection technique will largely depend on the type of the DG and system characteristics. Recently, hybrid detection techniques have been proposed and it seems that the hybrid detection technique is the way to go with passive technique detecting the islanding when change in system parameter is large and initiating the active technique when the change in system parameter is not so large for the passive technique to have an absolute discrimination.

Here In our project discussed intentional islanding. When main grid is disconnect from the distributed generation system, this condition detects quick as possible and a signal send to grid side converter to seize the pulse so the flow of power from the grid is obstruct. At that time a signal is send to load circuit breakers to disconnected the load and keeping the critical load according to the capacity of distributed generation system.

3.5 GRID SYNCHRONIZATION

In our work distributed generation systems can operate in both islanding or grid connected mode, when main grid is disconnected from main grid than microgrid goes in islanding (autonomous) mode and distributed generation systems operated in voltage control mode from current controlled mode . To ensure a smooth re-connection of the microgrid back to the main grid when the grid recovers from a fault, a microgrid re-synchronization method is also required. When the main is back on, the microgrid has been operating in the islanding mode and has its own PCC terminal voltage magnitude, frequency and phase angle, which most likely are different from those at the main grid terminal. A re-synchronization scheme is thus needed before closing the separation switch. The resynchronization is to ensure the voltage magnitude, frequency and phase angle at the microgrid end and main grid end match for a smooth reconnection of the two systems.

3.5.1 Prevalent Techniques of Phase Locked Loop

PLL structures can be broadly classified into the following categories.

Zero Crossing Detection (ZCD):

In this PLL, the phase angle is detected by synchronizing the PLL rotating reference frame and the utility voltage vector. Setting the direct axis reference voltage (Vd*) to zero results in the lock in of the PLL output on the phase angle of the utility voltage vector. In addition, the instantaneous frequency and amplitude of the voltage vector are also determined. The feed forward frequency command is introduced to improve the overall tracking performance of the PLL. The tuning of the feedback gains requires the determination of an equivalent linear model,

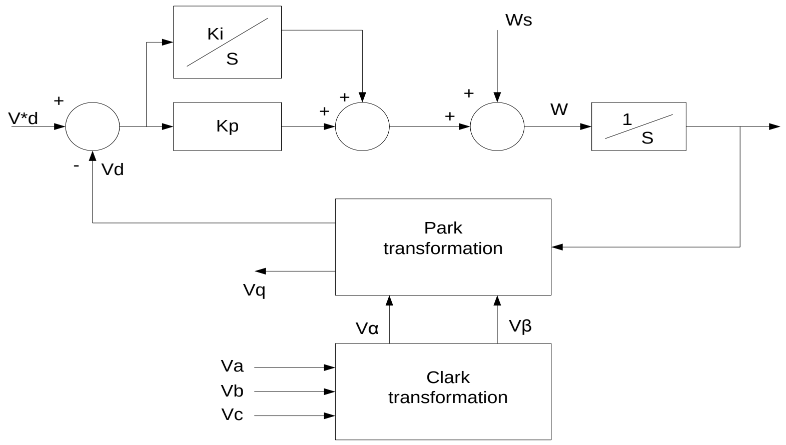

Fig.3.9: Three-Phase PLL Structure

shown in Fig.3.10. From this small signal model, one can derive the state space representation of the three-phase PLL topology.

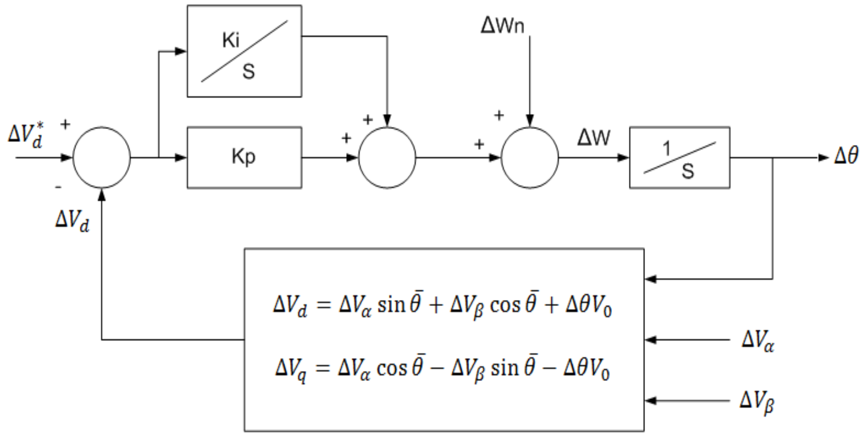

Fig.3.10: Small Signal Model of the PLL

Following the determination of an equivalent linear model, it is necessary to adopt some criteria in order to impose an adequate dynamic behaviour on the three-phase PLL topology: By imposing an acceptable distance between the fastest pole and the sampling frequency of the DSP, one can guarantee the affective application of the PLL tracking commands. A better robustness of the three-phase PLL is achieved by imposing an adequate distance between closed-loop poles. The behaviour of the PLL under distorted utility conditions is determined from the analysis of the dynamic stiffness of this topology. The closed-loop disturbance rejection characteristic of the three-phase PLL depends on the intended application. In systems where the fundamental component of the utility voltage vector must be tracked, it is necessary to elevate the dynamic stiffness figures in order to better reject undesired harmonic components. On the other hand, there are systems where the distortions present in the utility voltages might be known (e.g. for compensation actions) and thus the dynamic stiffness characteristics has to be shaped accordingly.

3.5.2 Synchronous Reference Frame (SRF)

Operation of a three phase SRF based PLL can be schematically shown in the Figure 3.11.

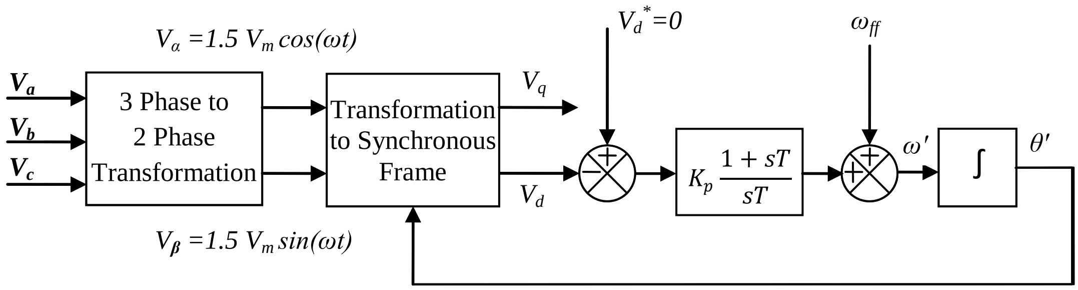

Fig.3.11: Schematic Diagram of SRF Based PLL

Basic structure of SRF PLL three phase voltage signals (Va, Vb and Vc) are transferred into stationary two phase system. Where,

$$V_a = V_m \cos(\omega t)$$

$$V_b = V_m \cos(\omega t - \frac{2\pi}{3})$$

$$V_c = V_m \cos(\omega t - \frac{4\pi}{3}) \qquad 3.23$$

Now phase angle (θ) can be obtained by either synchronizing the voltage space vector (**V**, Fig.3.12) along q axis or along d-axis of synchronously rotating reference frame. Let us assume that the voltage space vector is to be aligned with q axis (Fig. 3.12).

$$\theta = \omega t - \frac{4\pi}{3} \qquad 3.24$$

Then position of d axis (θ) is related to it by integrating estimated frequency (ω′) which is the summation of output of PI controller and the feed-forward frequency (ωff). The voltage vectors in synchronously rotating reference frame can be found out using θ′ from following equations.

$$V_d = -\frac{3}{2} V_m \sin(\theta - \theta')$$

$$V_q = \frac{3}{2} V_m \cos(\theta - \theta') \quad 3.25$$

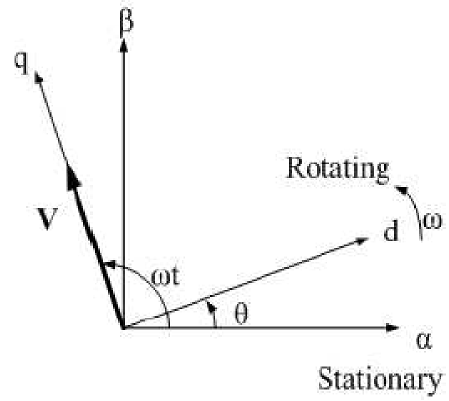

Fig.3.12. Vector Diagram Showing the Stationary ($\alpha\beta$) and Rotating (Dq) Reference Frames

The controller gains are designed such that Vd follows reference value which will result in estimated frequency (ω′) to lock to system frequency (ω) and estimated phase angle (θ′) to be equal to the phase angle θ. Now if θ = θ′ then space vector of voltage gets aligned to q axis. The voltage vector along synchronously rotating d-axis can be expressed as follows.

$$V_d = -\frac{3}{2} V_m (\theta - \theta') \quad 3.26$$

So, overall system in Fig.3.11 can be simplified to that shown in Fig.3.13. Detailed analysis and design of PI controller gains can be found.

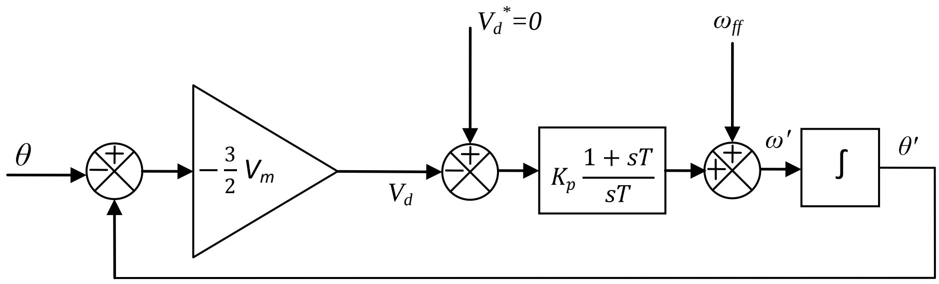

Fig.3.13 Block Diagram of SRF Based PLL Model

3.5.3 Double Synchronous Reference Frame (DSRF)

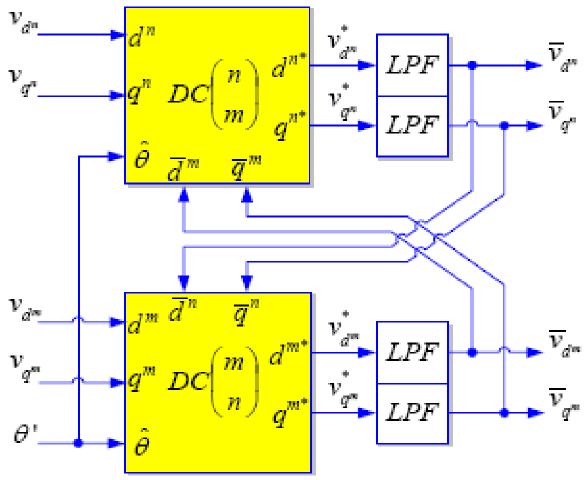

Fig.3.14: Decoupling Cell to Cancel the Effect of $\boldsymbol{V}{-}\mathbf{1}$ on the $\boldsymbol{dq}{+}\mathbf{1}$ Frame Signals

A voltage vector consisting of two generic components rotating with +ω and -ω frequencies respectively can be expressed on the αβ stationary reference frame as: [61]

$$V_{(\alpha\beta)} = \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = V^{+1}_{(\alpha\beta)} + V^{-1}_{(\alpha\beta)} \qquad 3.27$$

$$= V^{+1}\begin{bmatrix} \cos(\omega t + \varphi) \\ \sin(\omega t + \varphi) \end{bmatrix} + V^{-1}\begin{bmatrix} \cos(-\omega t + \varphi) \\ \sin(-\omega t + \varphi) \end{bmatrix}$$

ω is the fundamental utility frequency.

Voltage vector of (3.27) will be expressed on the generic DSRF shown in Figure 3.13. This generic DSRF is composed of two rotating reference axes, $dq{+}1$ and $dq{-}1$, who"s angular positions are +θ and -θ respectively, being θ the phase angle detected by a hypothetical PLL. If a perfect synchronization of the hypothetical PLL was possible, that is if θ = ω*t* with ω the utility fundamental frequency, the voltage vector in (3.27) could be expressed on the $dq{+}1$ and $dq{-}1$ reference frames as (3.28) shows.

$$V_{(dq^{+1})} = \begin{bmatrix} V_{d^{+1}} \\ V_{q^{+1}} \end{bmatrix} = \left[T_{dq^{+1}}\right] V_{(\alpha\beta)}$$

$$= V^{+1}\begin{bmatrix}\cos\varphi \\ \sin\varphi\end{bmatrix} + V^{-1}\cos\varphi^{-1}\begin{bmatrix}\cos 2\omega t \\ -\sin 2\omega t\end{bmatrix} + V^{+1}\sin\varphi^{+1}\begin{bmatrix}\sin 2\omega t \\ \cos 2\omega t\end{bmatrix}$$

$$V_{(dq^{+1})} = \begin{bmatrix}V_{d^{+1}} \\ V_{q^{+1}}\end{bmatrix} = \left[T_{dq^{+1}}\right]V_{(\alpha\beta)}$$

$$= V^{-1}\begin{bmatrix}\cos\varphi^{-1} \\ \sin\varphi^{-1}\end{bmatrix} + V^{+1}\cos\varphi^{+1}\begin{bmatrix}\cos 2\omega t \\ \sin 2\omega t\end{bmatrix} + V^{+1}\sin\varphi^{+1}\begin{bmatrix}-\sin 2\omega t \\ \cos 2\omega t\end{bmatrix}$$

$$\left[T_{dq^{k}}\right] = \begin{bmatrix}\cos(k\theta) & \sin(k\theta) \\ -\sin(k\theta) & \cos(k\theta)\end{bmatrix}; k = +1,-1 \qquad 3.28$$

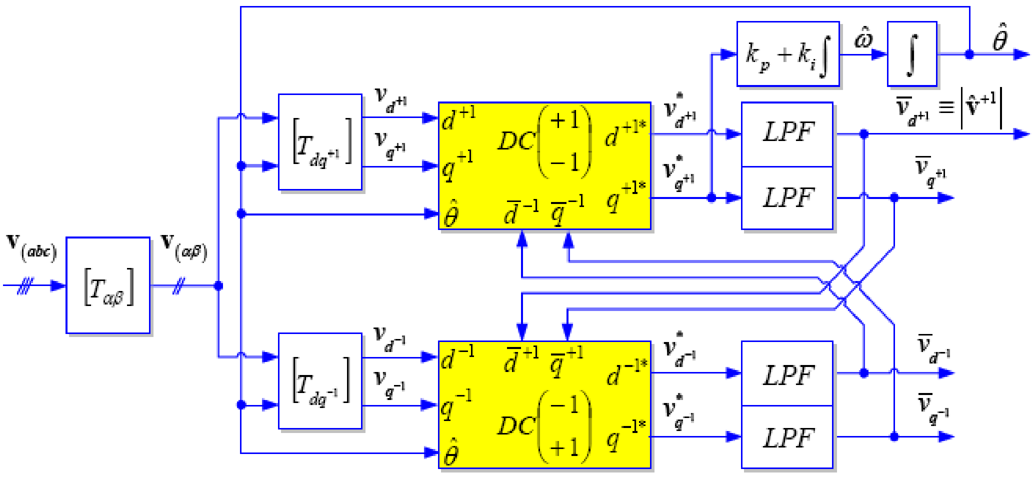

Fig.3.15: Block Diagram of DSRF PLL

In (3.28), the amplitude of the signal oscillation in the dq+1 axes depends on the mean value of the signal in the dq−1 axes, and vice versa. In order to cancel the oscillations in the dq+1 axes signals, the decoupling cell shown in Figure 3.6 is proposed. For cancelling oscillations out in the dq+1 axes signals, the same structure may be used but interchanging (-1) by (+1) in it.

In this work, the accurate detection of the parameters is achieved by means of the cross-feedback decoupling network (DN) shown in the model in Fig.3.14. In this DN the LPF block represents a first order low-pass filter with ωf (cut-off frequency). A detailed analysis of the DN was done and it was concluded that, after a stabilization period, the signal on the axes

DSRF are free of oscillations and the amplitude of the (-1) and (+1) components are accurately determined. After the analysis of the DN, it seems reasonable to set the cut-off frequency of the low-pass filter ωf around $\omega/2$, ω being the estimated fundamental utility frequency. This value for the cut-off frequency achieves a fast enough dynamic response and avoids transient oscillations in the output signals of the DN.

3.6 MATLAB MODEL OF GRID CONNECTED SYSTEM:

Fig.3.16 shows MATLAB model of grid connected system which is consist of different part.

(a) Sources: There are two types of sources in the MATLAB model of grid connected system. In which one source should be distributed generation source like wind, PV and fuel cell and another source is grid. The grid source is stiff power source and it can fulfill the increased load demand but on the other hand distributed generation system is not stiff power source.

(b) Back to Back VSCs: The distributed generation systems are not directly connected through the main grid so for the connection of DGs and main grid, we require back to back (BTB) VSCs. The BTB VSCs are provide bidirectional power flow in the system and another advantage of back to back VSCs is that through the BTB VSCs, we can connect the two different frequency source.

(c) Transformer: For the connection of main grid from microgrid, we need a step down transformer because the voltage level of microgrid is 415V and the voltage level of main grid is 11KV.The winding of low voltage side is connected in star and high side winding also in star. The rating of the transformer is 150kVA.

(d) Circuit Breaker: Circuit breakers in MATLAB model of grid connected system are use for load scheduling and grid connection.

(e) Controller: The MATLAB model of grid connected system shows the two controllers, in which one is grid side controller and other microgrid side controller both the controller generate pulse in such a manner to achieve owns task. In normal operation both controllers are performing different task. But in islanding case grid side controller should handle both tasks (reactive power control & voltage regulation of dc bus).

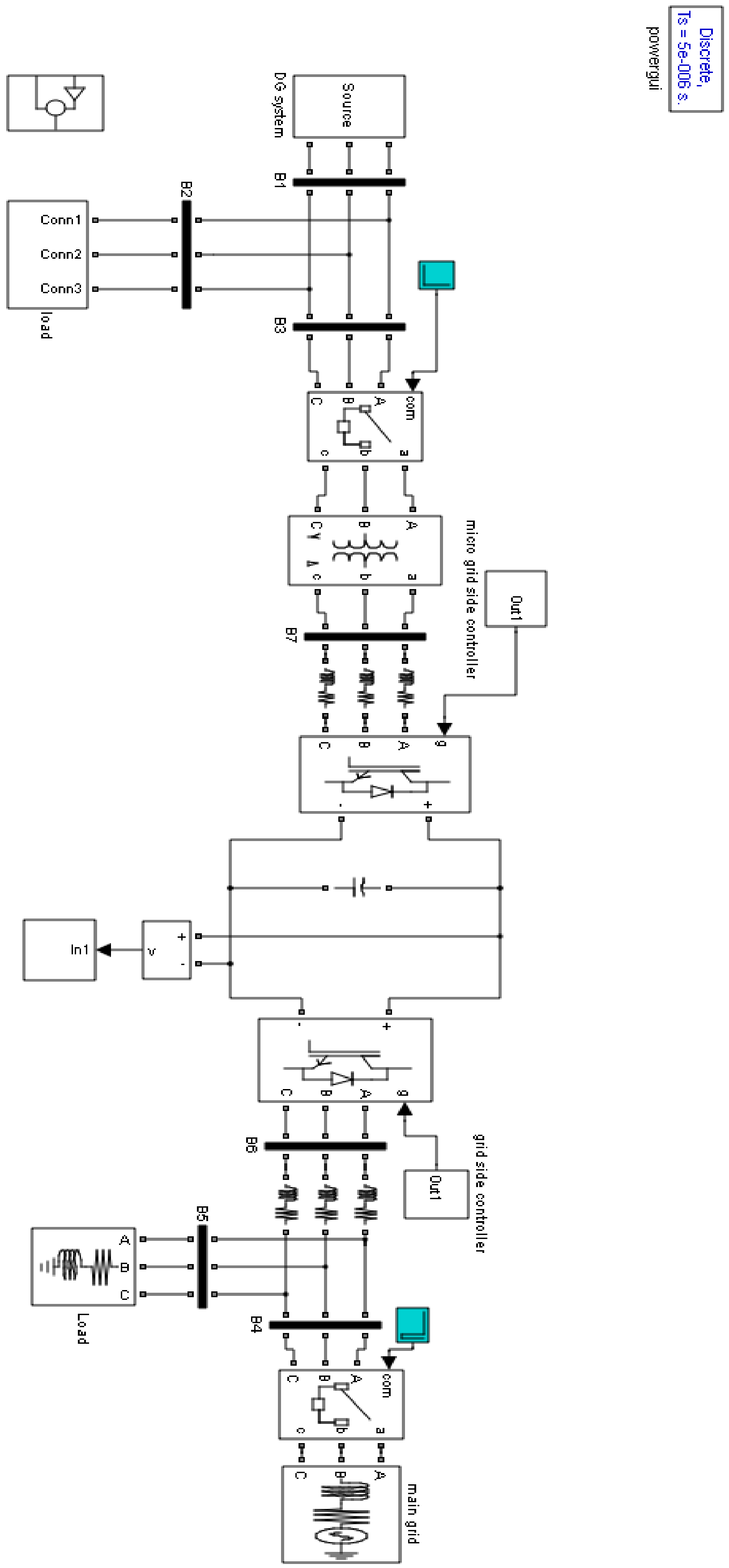

Fig: 3.16 Grid Connected Distributed Generated System

(f) Hysteresis Current Controller: Fig.3.16 shows illustrates the principle of the hysteresis band current control. The hysteresis has dead band that permit a deviation of $\Delta \boldsymbol{i}$ of the actual current from the reference wave. If an actual phase current exceeds the current reference by the hysteresis band, the upper device in the inverter leg of that phase is turned off and the lower device is turned on. This causes the phase current to decay until the current error reaches the lower limit when the switch status is reversed, causing the current to rise again. Independent control of phase current is possible in this manner if the three phase load neutral is connected to the dc bus midpoint. In a system without such a neutral connection, the current response of a phase depends not only on the switching state of the corresponding leg but also on the status of the other two inverter legs. For loads with unconnected neutrals, the instantaneous current error can taken double the hysteresis band.

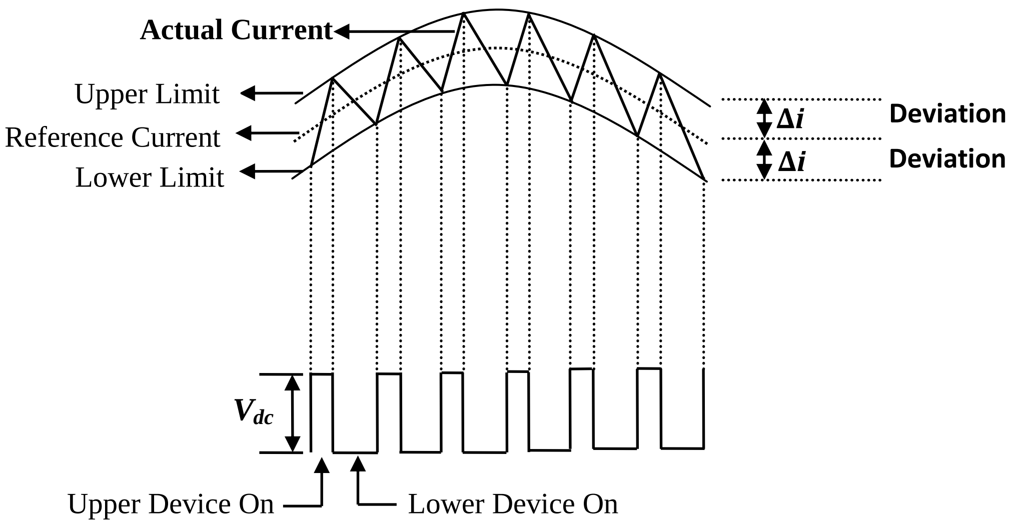

Fig.3.17 Principal of the Hysteresis Band Current Control

(g) Interface inductor: Two interface inductors are show in the MATLAB model of grid connected system. Interface inductors play an important role in the system. In the system its work as filter and filter out the harmonics in both side and it assist in power flow from ac voltage side to dc voltage side.

(h) Measurement Device and Load: There are many measurement device use in the MATLAB model of grid connected system for voltage and current measurement of different part of the system. There are also variable load connected microgrid side and these load may be restive, inductive and both.

3.7 CONCLUSION

The elaborated mathematical model for the proposed system has been presented. The control system is designed in such a manner that it can be easily implemented in MATLAB/Simulink environment. The MATLAB model of grid connected system as well as decoupled system along with their control strategies have been presented to give a detailed overview of the proposed system. The control for the grid side converter and the microgrid side converter has been presented separately to give a clear understanding of the proposed system. We are using variable step ode45 (Dormand-prince) solver is selected to study the system and keep sampling time of 5e-6. The system performance and results are evaluated in the next chapter.

FERFOMANCE EVALUATION OF GRID CONNECT MICROGRID

4.1 GENERAL

The performance of the system has been evaluated using the MATLAB Simulink for different task like bidirectional power flow, active and reactive power control, fast islanding detection, load scheduling, synchronization and power quality improvement. The results have been discussed for all the given tasks.

4.2 PERFORMANCE EVALUATION OF THE GRID CONNECTED SYSTEM

4.2.1 Microgrid side controller (MSC)

Fig.4.1 (a-d) show the dynamics of the load connected to the microgrid, while the microgrid is under both grid controlled and islanding mode. It may be observed from t=0.0 to t=.07 the connected load exactly matches with the rated capacity of the microgrid with 76 A of current. It is assumed that microgrid a photovoltaic inverter is connected to the microgrid which forms a unidirectional power source. When the load exceeds the rated load and the load current rise to 172 A earlier level of 76 A, the additional power is routed through DC link. It may be referred from 4.1(d) that 96 A of current flow during the duration t=0.07 to t=0.35 when the load exceeds the rated limits of microgrid. It may also be the seen Fig.4.1(b) that current fed by microgrid remains constant at 76 A. Further when load is reduced below the rated capacity of the grid i.e. the load current reduces to 39 A from 172 A, the extra current of 37 A on the microgrid is swiftly routed through the BTB VSC through the Dc link to utility mains, as shown in Fig. 4.1(d). During such load perturbations too, the current drawn from the microgrid mountains the status quo. It may also be observed that the voltage transient at t=0.35s, shown in Fig. 4.1(a) remains within the of 5-10% V and last only for half cycle. Further load is again increased to the level of 172 A as shown in Fig.4.1(c). The control easily reduces the current on DC bus and the current drawn from microgrid steady its rated value, while current supplied by MSC is returned back to 96 A (shown in fig. 4.1(d)). To evaluate the controller the loading is increased further during t=0.65 to t=0.85 the controller was able to support this too. Further the system is dragged into intentional islanding during t=0.8 to t=0.95. The power from utility is disconnected and microgrid is left to manage its resources locally. In such duration the MSC is entrusted to maintain the reactive power support to the microgrid and the excitation of transformer, which may be evident from Fig. 4.1(d) clearly, the demand load is scheduled to matched power rating and the current supplied by the microgrid and becomes equal. Fig.4.1(b,c) show such change. It may also be observed that till load scheduled to matched power a transient both in current and voltage exist at t=0.8s. However, the last only for 1-2 cycle and remains less than 100% of its rated value for both voltage and current. An SSR is observed between the MSC and the distribution transformer (DT) which carries excess reactive current both demanded by load and the excitation current of DT. The SSR is not observed on the low voltage side of the DT. When utility supply is restored at t=0.95 the system restores its original stable state within 3-4 cycles. The bumps in current may be observed in Fig. (4.1 b,c,d) which clarities transient conditions. The transient current amount to 10-12% increase in current which is under acceptable limits. Fig.4.1 (a) depicts similar swell in voltage which last for 3-4 cycles. The system steadily stabilizes to new stable state.

Fig.4.1(a,b.c,d) wave form of voltage and current on microgrid side.

4.2.2 Utility Side Controller (USC)

Fig.4.2 (a-e) shows the dynamics of the utility grid source, while the utility grid connects to the microgrid and disconnected. From t=0.0 to t=.05 the constant load connected to the utility side and it is supply total reactive and active demand of the load in that duration some transient are occur in voltage and current wave of the utility side. At t=0.05 utility side controller (USC) on the reactive demand of the utility side load is fulfills by the VSC so the utility grid source current is reduce. So in normal operation USC support Vdc and reactive demand of utility side load. At t=0.07 to t=0.35, when the microgrid side load exceeds the rated load and the load current rise to 172 A earlier level of 76 A, the additional power is flow from utility side through DC link and the source current of utility side is increase which is not shown in Fig.4.2 (b) because the source current of utility side in KA and the variation in this current only small range. Further when load is reduced below the rated capacity of the microgrid grid i.e. the load current reduces to 39 A from 172 A, the extra current of 37 A on the microgrid is swiftly routed through the BTB VSC to utility mains, During this period source current of utility side grid is reduce because 37A flow from microgrid side to utility side load. Further microgrid side load is again increased to the level of 172 A as shown in Fig.4.1(c). The USC is easily reveres the direction of current on DC bus and the USC is returned back to 96 A. To evaluate the controller the loading is increased further during t=0.65 to t=0.85 the controller was able to support this too. Further the system is dragged into intentional islanding during t=0.8 to t=0.95. The power from utility is disconnected and microgrid is left to manage its resources locally. In such duration the MSC is entrusted to maintain the reactive power support to the microgrid and the excitation of transformer, which may be evident from Fig. 4.1(d) clearly, the demand load is scheduled to match power rating and the current supplied by the microgrid and becomes equal. Fig.4.1 (b,c) show such change and USC pulses is switched off and the control of DC bus support is transfer USC to MSC. It may also be observed that during t=0.8 to t=0.95 the voltage and current should be zero in the utility side shown in Fig.4.2 (a,b,c,d). When utility supply is restored at t=0.95 the system restores its original stable state within 3-4 cycles and DC bus support is transfer from MSC to USC at that time a steep drop in voltage across capacitor is shown in Fig.4.2(e). It is dying out .05s and capacitor maintains a constant voltage (15000V). The bumps in the utility side current may be observed in Fig.4.2(b,c,d) which clarities transient conditions. The transient current amount to 10-12% increase in current which is under acceptable limits. Fig.4.1 (a) depicts similar swell in voltage which last for 3-4 cycles. The system steadily stabilizes to new stable state.

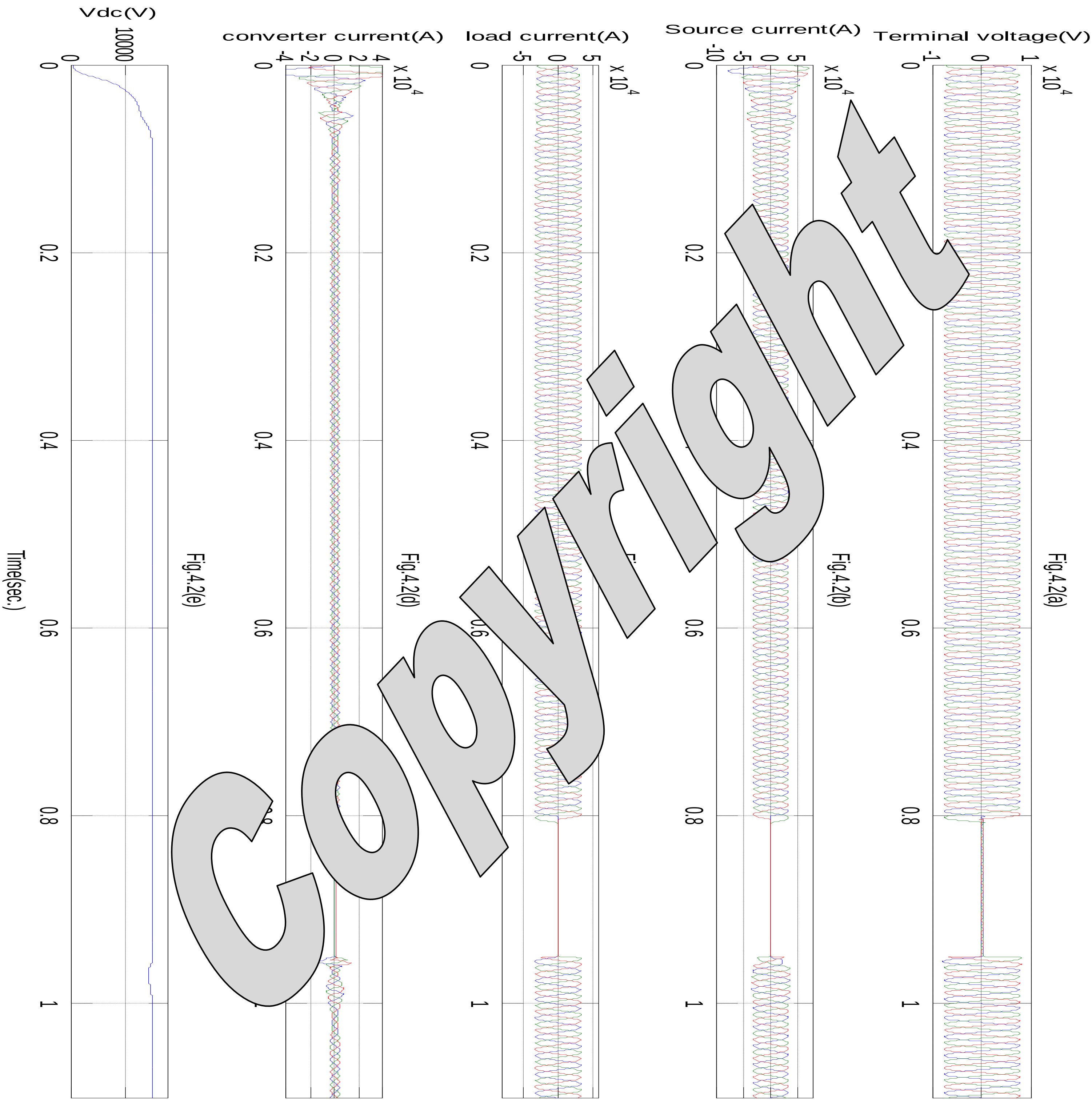

Fig.4.2 wave form of voltage and current on utility side.

4.3PERFORMANCE AND EVALUATION OF ISOLATED MICROGRID WITH STORAGE SYSTEM

A 415 V (phase to phase) system having voltage source converter (VSC) is used to configure this network. The dc bus is having 5000 microfarad capacitor. Figure 4.3(a) and 4.3(b) show the waveform for the source voltage and source current of the system. Figure 4.3(c) gives the waveform of load current. Figure 4.3(d) shows the current of the VSC. Figure 4.3(e) battery current respectively. In the starting a RL load of 16.15 ohm and 30 mH is connected to system. For this load the voltage and the current of the source are 298 volt (phase to ground) and 15.35 ampere (phase to ground) are observed as shown in figure 4.3(a) and 4.3(b) respectively. At 0.05 second the voltage source converter is switched on for the compensation of reactive power required by the load. Beyond this point the source current is observed to be in phase of the source voltage which indicates that the current has only active component. Source current is reduced to 13.8 ampere (phase to ground) as the reactive component of the current is supplied by the VSC. However, a swell in the load current is also observed at the point of switching of VSC. This is occurring due to the battery current which is installed in our system to support the capacitors. Because we have constant power source as the source reduced the voltage of source is increase which is shown in Fig.4.3 (a). At 0.2 second another resistive load of 129.16 ohm is also inserted in the system. This increases the load current demand to 20 ampere. As now the system requires more active power for this increased load, this additional power is supplied by battery connected with VSC. This active component of the current is measured equal to 3.4 ampere as shown in figure 4.3(e). The system voltage and source current are constant at this point as the active component of the current is fed from the VSC supported battery rather than the source. At 0.3 second the load is reduced to 32.29 ohm and 60 mH which decreases the load current to 8.1 ampere. This decrease in active as well as reactive power is sensed by the controller which modifies the switching of the VSC accordingly. For the present requirement of the reactive power, the switching of the VSC is such that it provides only the reactive component of current required for the load. As the source is giving constant active component of current, the difference of this component of source current and the active component of the load is additional in the system. This additional current is used for the charging of battery. The current transaction in the battery is shown in figure 4.3(e).

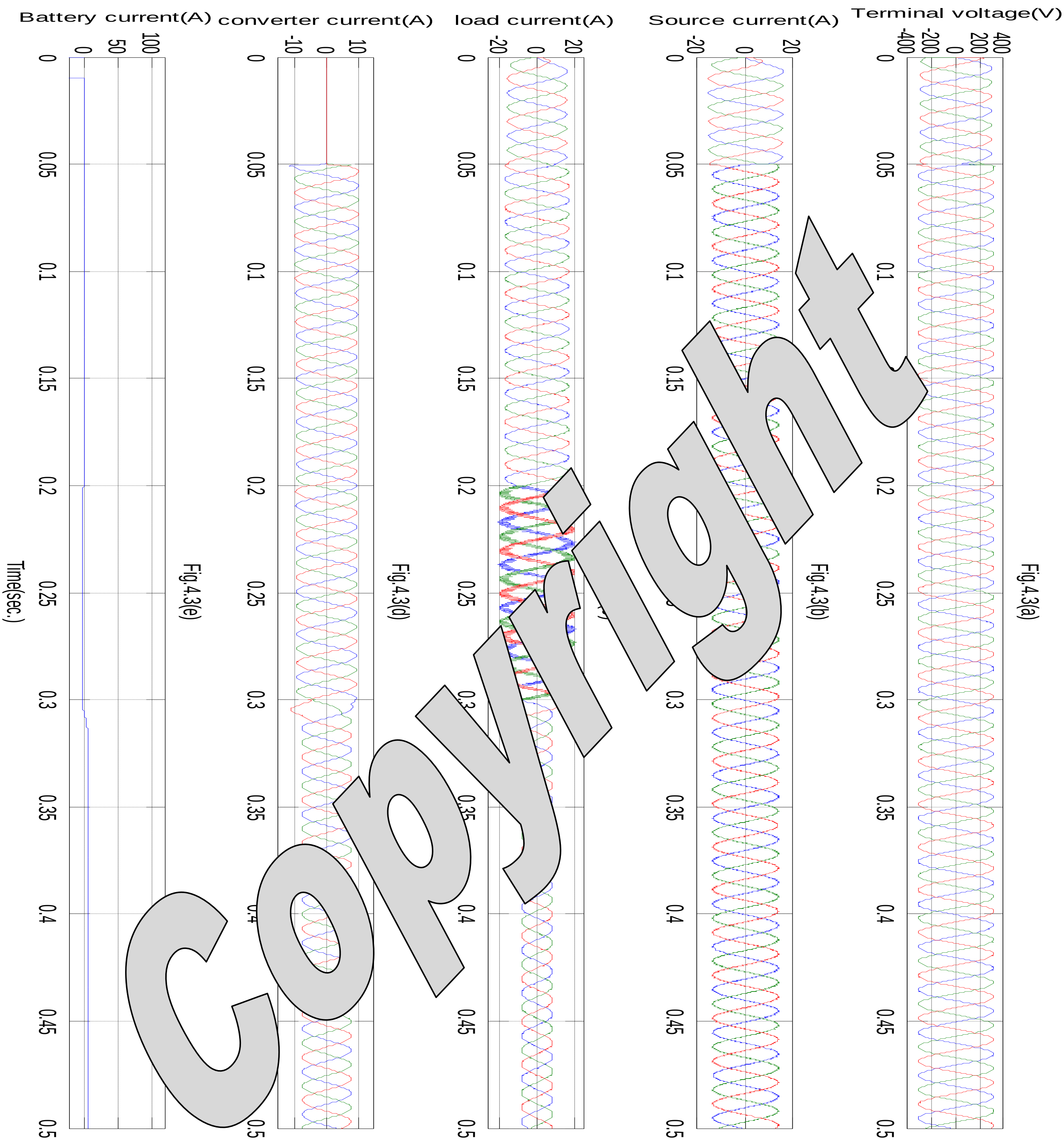

Fig.4.3(a,b,c,d,e) wave form of voltage and current of isolated microgrid with storage system

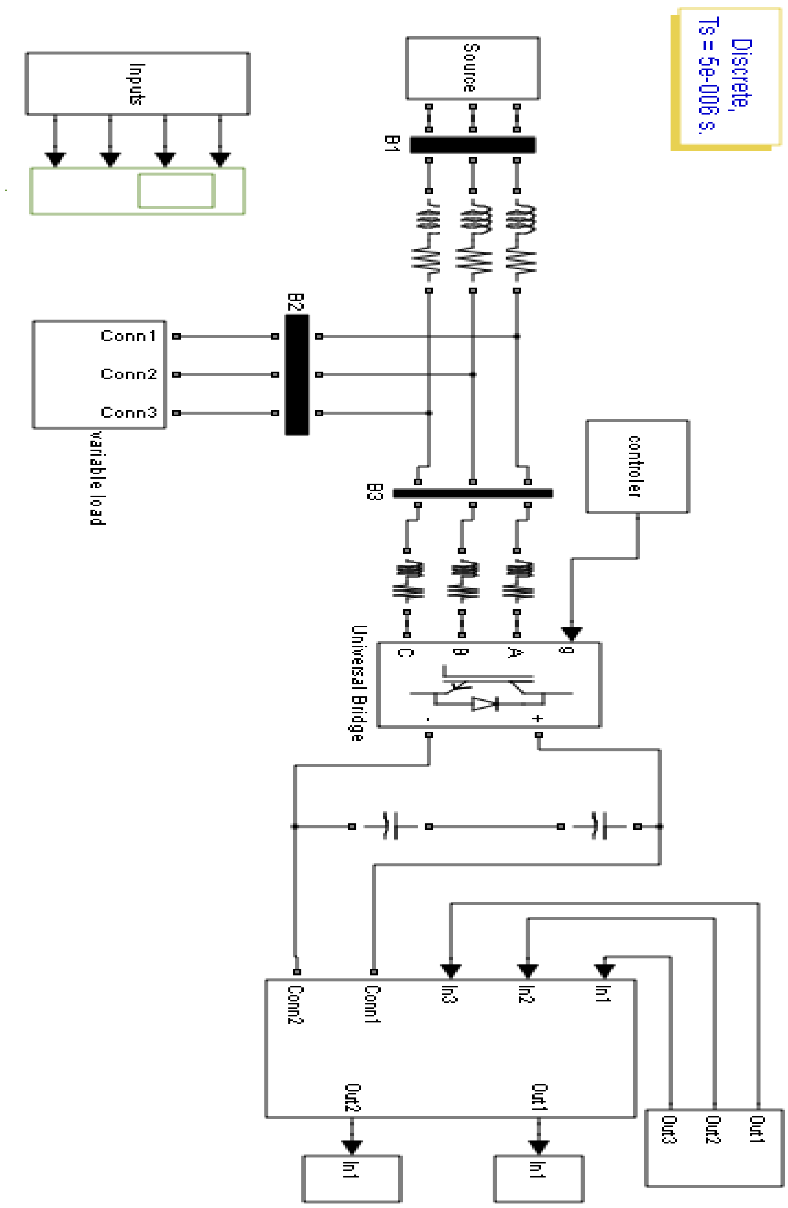

Fig.4.4 isolated microgrid with storage system.

4.4 CONCLUSIONS

The various waveforms for the proposed system have been drawn and analysed. The microgrid system as decoupled distribution system as well as coupled system (with the main grid) is analysed in accordance of system operation and control. The switching of the various loads and their effects on the system are thoroughly presented in the text and graphs. The steady state and transient behaviour of the system is also discussed. The system behaviour indicates the effectiveness of the proposed control as the various issues such as islanding, grid synchronization and reclosing are addressed successfully with the presented model.

CHAPTER-5

MAIN CONCLUTION AND FUTURE SCOPE OF WORK

5.1 GENERAL

The project did achieve the target it had started out with. The grid connected distributed generation system (DGS) is designed and simulated. The project has achieved the main aim of interfacing the grid with distributed generated system (DGS), bidirectional flow of power, real and reactive power control, islanding detection, grid synchronization and power quality improvement. The parameters of the systems are well within the IEEE 519 standards mentioning the limits of variations of various parameters of the system. The project has also shown its profitability in terms of both economy and energy utilisation and thereby its applicability to be used in new grid interface systems. The results show that the voltage and current inputs to the load are as expected.

5.2 MAIN CONCLUSION

The interface design has accomplished the following tasks: (a) The generated power from DG (AC/DC) is fed into the local load as well as the grid. (b) Grid synchronization. (c) In case of generated active power being more than the local load, the difference is fed to the grid, and when it is less than the local load, additional power is drawn from the grid. (d) Islanding of the system for its protection in case of disconnection of the grid. (e) Load Scheduling. In case the grid gets disconnected, it is isolated from the rest of the system to ensure continuous power supply to the load. At the time of grid disconnection, if the power fed by the DG is insufficient, then the load is distributed according to the need and supply. For reconnection, the system is made to operate in the islanding mode even after the grid is detected and is synchronized with the grid. After the synchronization is complete, the operation jumps from islanding to normal mode.

5.3 FUTURE SCOPE OF WORK

This project did work quite well, but the work does not end there. The intention is to do much more and achieve even more. This although could not have been done in the time allotted although. All other scope of work would be therefore done as a part of a continuation of the project. Detailed here are is the scope of future work.

1) Hardware Realization

A hardware realization of the model designed in Simulink shall be done using the rated components and utilizing D-Space for the pulse generation of the converters. This would enable a better understanding of the project, an accurate estimation of the losses occurring in the system. This would help in the calculation of the efficiency of the system at full load as well as at different levels of part loads.

2) Improving Efficiency

As stated already, the losses at smoothing reactor and transformers form a large part of the losses in the system and can knock off a large number of points from efficiency. The aim of this aspect is to decrease losses at these points in the system.

3) Islanding operation has certain drawbacks associated with it, which need to be tackled. During the islanding mode of operation when the grid is disconnected and the supply from the DG is more than that required by the load, instead of dissipating the balance power elsewhere, it can be stored in a battery and used later on when required. When adding the battery to the system, it's discharging time needs to be taken into consideration and the system set-up modified so as to synchronize the battery operation with the rest of the system. At the time of reconnection, there is interaction between the two voltage sources, i.e. the DG and the grid, which can lead to sag and dipping of the waveforms. This droop characteristics and power sharing needs to be prevented. This is a characteristic of micro-grids that are used these days.

Unintentional islanding of DG may result in power-quality issues, interference to grid-protection devices, equipment damage, and even personnel safety hazards. So, there is a need for anti-islanding.

4) Reconnection: In the present system reclosing is done for the fixed frequency of the main grid. However, this frequency is also subjected to change due to effect of various factors in the supply system. The reconnection of the main grid and the microgrid at these varying frequencies is rather cumbersome and leads to many system complications. This issue can be elaborated in the future work where an effective algorithm for the coupling of the microgrid with main grid at varying frequency may be developed.

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