# CHAPTER 1

# INTRODUCTION

## 1.1 GENRAL INTRODUCTION

With increasing demand of electric power around the worldand diminishing of fossil resources the conventional fossil- fuel based power plants are being discarded for poor energy efficiency and environmental pollution [1]. The non-conventional renewable energy sources like solar panels, wind etc., and other conventional sources like fuel cells. are now encouraged at distribution level and in near future these renewable resources will provide major contribution towards energy development. Amongst the various renewable resources wind and solar have proved quite promising for distributed generation in remote and residential areas with and without grid interconnection. Integrating these intermittent capacity renewable sources with grid may affect the traditional power system working as major fuels in India being radial in nature. The assimilation of renewable energy sources poses a challenge because their output is intermittent and volatile in terms of time and magnitude. Moreover this intermittency mayproduce a fluctuation in grid voltage due to mismatch in demand or supply. It may also severely affect the conventional power system protection as these protections are developed keeping line current flow in one direction only. But with these renewable sources power may flow in any direction.So in all situations it is necessary to regulate voltage within permissible IEEE standard as ±5% of grid voltage. The problem become more aggravated with wind speed may too low and sometimes may high which may caue to low or high voltage fluctuations.To tackle such situations wind plants employ cut in and cut out speeds for generation. Moreover to tackle the situation of less generation some extra energy resources as captive power is being used in conjunction with renewable sourcesto cater uninterrupted power demands with full reliability. There are various ways to integrate captive power, like the battery, ultra capacitor, flywheel, diesel generator etc. This chapter shall make a thorough investigation in finding out means and ways to curb intermittency in power reflected as fluctuation in voltage through minimal use of storage sources.

## 1.2 Distribution System

With increased power demand and limited stock of conventional sources of energy and with need of high quality and for better power reliability, the concept of distributed energy generation came forward. Moreover, to avoid the losses that may be occurring due to centralized generation during transmission of power and also to the renewable sources at best of their capacity, it is now encouraged to use various renewable sources nearer to the load side only to cater the demand. The interconnection of these various source at load side either in grid connected or islanded mode invoke the concept of distribution generation(DG's) and their integration with various energy sources. It offers significant socio-economic benefits, with reduced losses in power network and utilizing the renewable energy resources to their max.

With the concept of DG's and enhancement in the utilization of distributed energy resources, new concept of microgrid came forward. Microgrid is defined as the cluster of distributed energy resources with regional loads, which can be connected or disconnected from the main network under emergency conditions or as per needed condition. The main advantage of microgrid is it's higher energy efficiency and reliability of the deliver of electric energy. In microgrid, distributed energy sources and energy storage devices are inter-connected with various types of loads ,basically three methods may be adopted,
(a) Interconnection of DC system (b) interconnection of AC system (c) interconnection through high frequency AC system are then interface to power frequency. The interconnection of sources at DC system is the simple, as this system has no frequency and phase control requirements moreover it has high efficiency and high reliability compared to the AC interconnection bus. In future technology will move towards DC transmission and distribution system as most of the load like fan, refrigerator, motors, and lights is now working on dc after converting it from AC.

The DC-grid system has advantages compared to AC conventional ac-grid system:
**1)** Power supplies connected to dc gird are easily operated in conjuction with various dc sources because connection on DC do not require phase and frequency synchronization.
**2)** Even in case of abnormal or fault conditions this dc-grid or microgrid system may be switched to islanded mode where local loads get supplies from the power generated throughit.

From the viewpoint of the system reliability, extendibility and maintainability, the followings things are requisite for various power units connected with the microgrid:

**a)**The units may be connected to, or disconnected from, the active dc grid.

**b)** Other units with different power ratings may be connected to the dc gird in the near future.

**c)**Signal and data communication among various sources not required among the existing various units.

In the thesis, augmentation of various DG's with minimize storage support is considered; havingemphasis on regulation of voltage and power intermittency in grid connected and islanded operation.

Microgrid operate in two modes **(i)** Grid Connected operated Mode **(ii)** Islanded operatedMode

### I. Grid-connected mode -

In the grid-connected mode, the DG's connected a common DC bus are connected to the AC grid via grid tied power converter. The grid-tied power converter control the regulationof DC link voltage. The total power by distributed generation system is fed to the local suppliers and the excess remaining power is supplied back to the utility grid. In case of deficiency the local dc load, the deficit required power may be drawn from the utility grid via a power converter. During excess generation, the wind generation may be utilized to charge from battery storage etc. so that in case of deficiency the power could be retrieved to support the grid via power converter so the microgrid operate efficiently with full reliability

### Islanded mode -

When the proposed configuration of DG get disconnected from the utility grid or when the grid collapse in some emergency it is operated in islanded mode. In this mode the grid-tied power converter control the DC link voltage level, and the same is switched to storage devices for voltage regulation of DC bus in islanded operation. The task of controlling the AC side voltage lie with some inverter and dc voltage is maintained by managing the operation of storage device. Since individualsource of distributed generation which are intermittent in behaviouris used for optimal control of its belonging source, only the energy storage elements are free to regulate the DC link voltage level. During the islanded mode, the battery plays the main role in regulating the

DC link voltage level, and the supercapacitor if used plays a secondary role in responding of the sudden power requirement as an auxiliary source or in case of sag or swell of voltage

## 1.3 RENEWABLE ENERGY SOURCES:-

Renewable sources(wind and solar) have their merits and demerits andthe technology to be used for these sources dependslargelyon their application and on the system where they re located. Among different renewable sources,wind turbines are the most obvious solution for large scale applications - such as for production of commercial scale power for the national grid. Large scale wind turbines are efficient by nature, and can be installed in different locations. Earlier the large turbines compared to modern turbines are virtually silent and the largest systems can generate in upto 2 megawatts of power which is large enough to supply power over 2,000 homes.On smaller scale, turbines may be a good support compared to solar power, but such hybrid integration would require adequate battery support.

Small wind turbines have disadvantages as they are site specific. Compared to large turbineswhich used by the power industries, small wind turbines are not highly efficient and need to be situated in an area where the speed of wind is average to generate reasonable amounts of power.

Wind turbines work in best manner where average wind speeds are highbest near the coast, or in open exposed areas. Ideally, turbines are mounted high up, typically a small turbines or 5-10kW are mounted 8-10 meters high to get sufficient wind power with taking in considerationthat it should be placed away from buildings. Roof mounting of turbine is not ideal condition as the building itself generates turbulence, creating a loud and annoying vibrating sound.The height may also cause problems if it is sited near to neighbouring properties. Integration of small turbine with a solar electric system, generates a few watts of power at lower wind speeds which can be consumed locally and is usually better than a large turbine that generates lots of power at high wind speeds.

As far as set up consideration, where voltage is taken in consideration, both solar panel and wind generator systems are quite similar. The wind generator may be grid tied or off grid, same also holds for solar panels. Both the solar and wind generator require a battery bank due to intermittency of power if they are used on an off grid system.Both if these renewable energy sources(RES) will produce clean energy and help the environment. Out of the two such RES,wind energy offer more intermittency, thus poses daunting task before the controller, and have being selected for study in the thesis.

### 1.3.1Wind Turbine Generator System

The main advantage of wind generator is that they can produce electricity all time based on availability of wind and need less space on land to produce sufficient electricity. They are able to produce more electric for the same price for example if $1,000.00 is spend on wind generator it may produce 1kW – 2kW, whereas with PV panels only 0.5kW – .75kW is produced; when same amount is invested. Wind generators have moving parts, so there is always concurrence wear and tear on it leading to system bearings which may not work properly, propeller blades can be struck by objects, and heat may be generated. Wind generator is installed on a tower to gain height so that when there is more wind, enhacing the vulnerability to strike on the wind generator. As wind hits the propeller blades there will be noise and also produce shadows flickering.

#### 1.3.1.1 SMALL CAPACITY TURBINES-

With the use of renewable resources in transmission and distribution system, wind energy is used worldwide and its capacity is doubled in last decades. Basically wind turbines are categorized according to their rated capacity. Small wind turbines may be used in residential, agricultural, small commercial and small industrial applications. In the given applications, turbine are providing energy to the local user to offset the use of grid power. Large wind turbines have rated capacities ranging from 660 kW to 1,800 kW (1.8 MW) and are designed use in generating power plants. Large turbines are designed as such to provide bulk electricity production for delivery on the local transmission network.

Often small/micro wind turbines operate with low voltage(415V), and intermittent power injection in such low voltage, low capacity line tend to pose the problem of several voltage fluctuation. It is therefore an alternative solution in repusitive for connectiong number of turbines probably in cascaded connection, to enhance the voltage level to reduce the effect of voltage fluctuations. Moreover, it may be pertinent to devise free configuration in such a way that large bank of battery could be awaited for connecting them in series to have higher voltage for their connectivity to reduce the intermittency in power and voltage.

## 1.4Different possibilities of connection of Windfarm

### i) Permanent Magnet Synchronous Generator(PMSG) connection with uncontrolled rectifier-

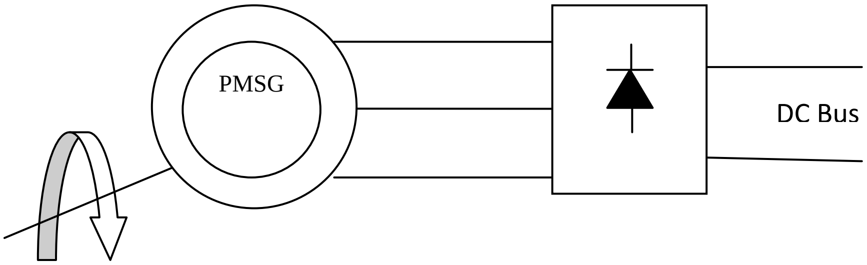


Fig1.1 PMSG connected with uncontrolled rectifier

Fig.1.1 show small/ micro PMSG wnd having conversion system. Wind being intermittent,the PMSG output voltage keep varying.. Due to fluctuation in voltage magnitude, it will further led to the distortion of flux in PMSG. The distorted flux willcause losses in system. This will cause decrease in power generation($P_{gen}$).Further the decrease voltage due to less generation may make diode rectifier out of operation due to varying power. So this configuration will work only when speed is constant, but not fluctuatingin  nature.

### ii) PMSG connection with controlled rectifier using Vector controlled method

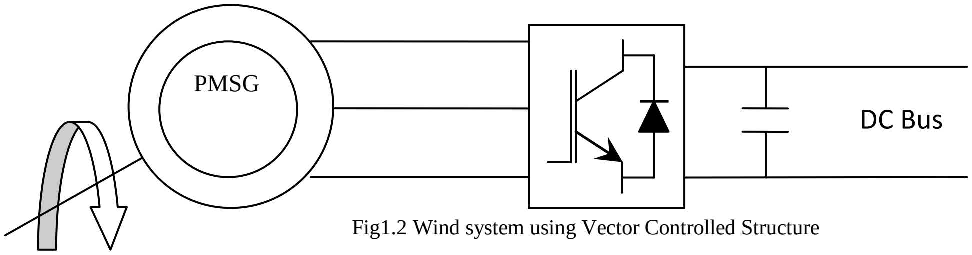


Fig1.2 Wind system using Vector Controlled Structure

Fig1.2 shows the PMSG connection with controlled rectifier using Vector controlled method is shown. Wind being very variant in nature so to regulate the voltage at DC bus, Vector controlled method is one of the possible configuration to maintain constant voltage even though the intermittent of wind is high. Itis one of the fast and excellent control method to handle the transients but the problem exist with this system is fluctuation in power,assystem is more complex and is costly.

### iii) PMSG control using controlled back-to-back converter system with Solid State Transformer

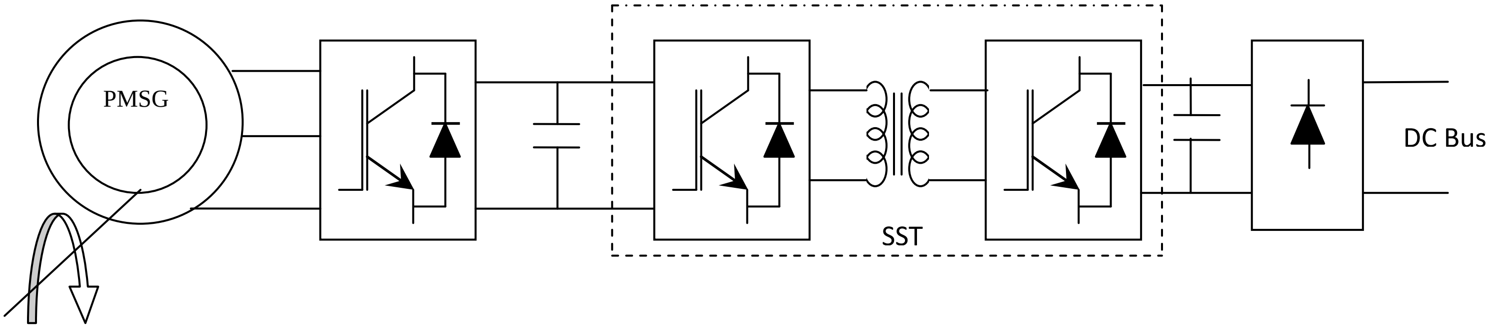


Fig1.3 Wind system using SST Technology

Wind being intermittent in nature and to regulatethe dc link there is need of voltage for bidirectional power transfer via conventional transformer,but due to bulky size conventional transformer is challenged by solid state transformer technique for such bidirectional power transfer. Apart from facilitating bidirectional power transfer, the SST overcome the issue of transfer of disturbance(active and reactive power)from one side to other side as seen in conventional transformer i.e. it led to transfer these disturbances to other side. Further SST isolates fault, regulate voltage, insusceptible to harmonics and easily integrated with renewable sources. The magnitude of power transfer will vary the magnitude depending on delta(δ) angle between converter2 (C2) and converter3(C3) gating pulses.

If such small wind energy conversion system(WECS) are connected in parallel and interface into the HV distribution grid, in case of intermittency the voltage regulation would become difficult to attain. To alleiviate the problem of such intermittency BESS and STATCOM must be incorporated at the same level, making system utilizing higher number of storage source to make the system costly . Moreover, the voltage regulation will be poorer. So as to have better voltage regulation and with an unnecessary connection to grid through inverter, a number of such units may be connected in cascade to make it plausible for its connection to higher and differential voltage for battery or storage units. The differential voltage of storage or bacttery element will take care of voltage fluctuation produced by WECS units supplying sufficient voltage, offering better voltage regulation, when connected to the HV grid by single configuration in cascaded mode.

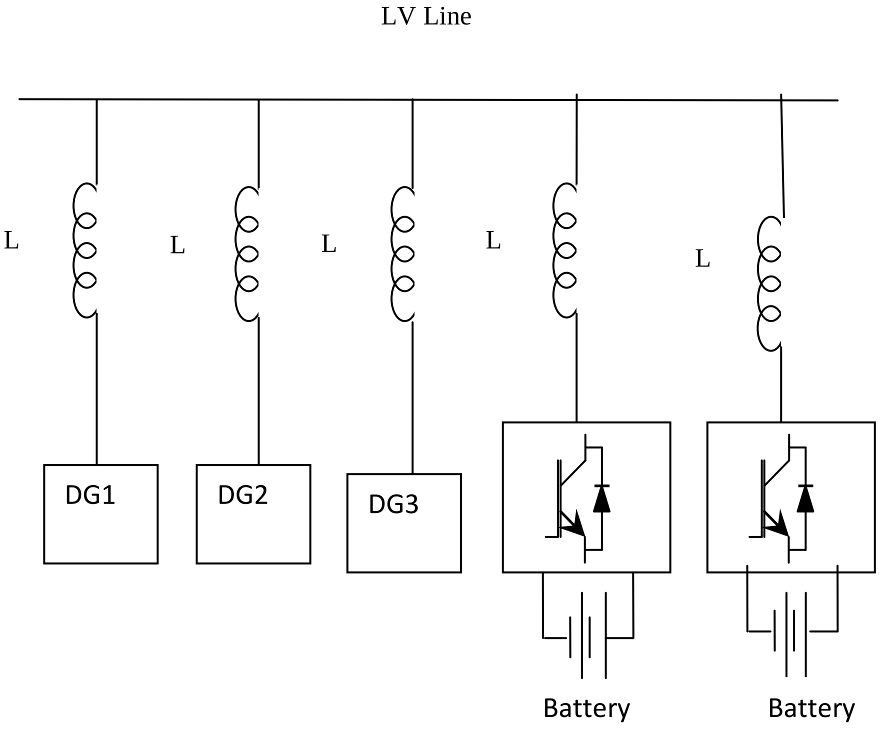


Fig1.4 Shunt connected Distributed Generator with Battery as storage

To put in a simple language for connection to 11kV,the DC bus voltage of battery energy storage system(BESS) would typically require 15kV, which would employ 1250 number batteries of 12V each.

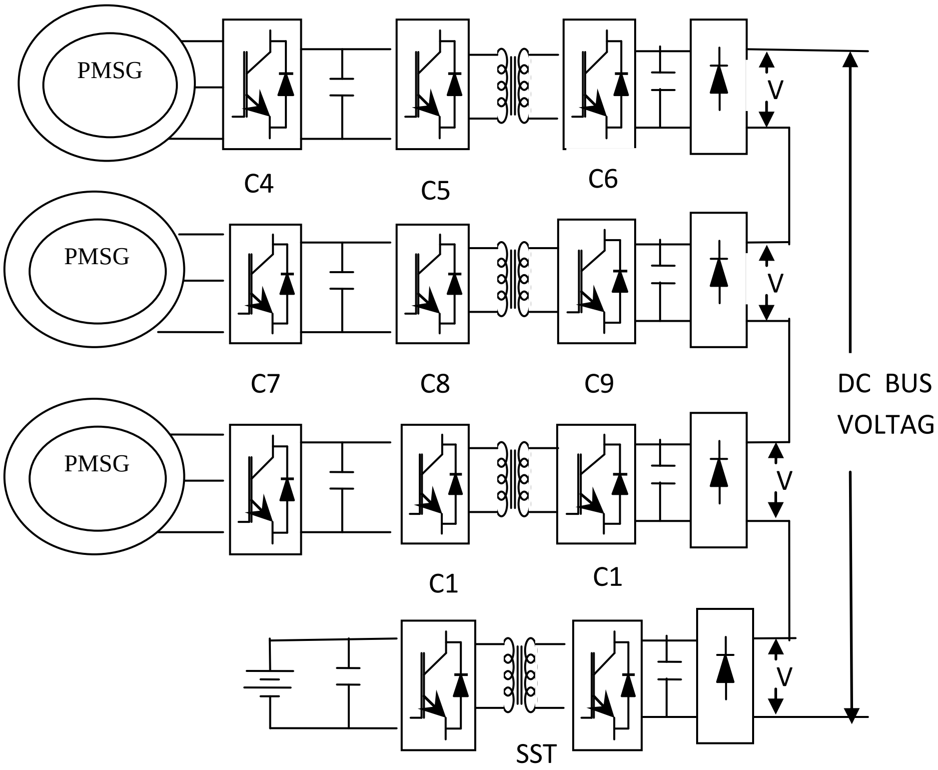


Fig1.5 Cascaded Structure of variable wind turbine with different magnitude of voltage source(VS) using SST

## 1.5 PROBLEM STATEMENT

With the rapid development and reduction in cost of renewable energy generation and power electronics technology, the renewable sources such as wind farms with power electronics interfaces find major applicationsin the microgrid system.Wind being intermittent, its generation via PMSG, may not operate satisfactorily to meet the load demand. Therefore some additional sources are required in conjunction with wind generation to balance the fluctuating nature of the wind via proper power electronics interface. As discussed before, in the proposed system the various wind generating units are connected in cascade with small unit of BESS. All the wind generating units are connected with DC grid via. SST.The battery is used as energy storage to counterbalance the intermittency in wind generation for monitoring the DC grid voltage. Integratingsuch large network system of DG'sto microgrid envisaged to provide higher security and reliability in electricity supply.But there are technical constraints that may degrade the network overall performancethat may be check out by proper control and regulation of the microgrid have been proposed. The adverse effects may include:-

- Voltage and current transients during connection and disconnection of microgrid or due to sudden lost of grid power.
- Increased in power quality problem beyond the level of acceptance for other customers especially THD.

## 1.6 OBJECTIVES OF THE RESEARCH

The primary objective of this researchwork is to regulate the voltage and maintain the demand supply management even under intermittentoperation ofwind generating unit by developingproper control strategies for a Wind energy system under different configuration and operating modes. They are

**i)** Islanded mode
**ii)** Grid connected mode, in order to maintain stable and reliable operation in the system.

Thus the objectives are-

**1.** To design and simulate the various wind energy conversion system, generatingat different voltages which are cascaded to form high DC link voltage in conjuction with battery energy storage system.

**2.**To develop a control algorithm for dual active bridge(DAB) for bi-directional power transfer between battery and the DC link working on different voltages by sensing DC voltage

**3.** To develop control algorithm to transfer power from wind generating units to DC grid via. and integrating to either stand alone DC or AC microgrid or in distribution system

A comprehensive model for energy sources: wind and battery energy storage system is modelled in MATLAB/SIMULINK to study powercontrol strategies in an islanded microgrid and a grid connected system. The focus is on regulating the DC link voltage and balancing the power flow irrespective of fluctuating wind conditions and load demands. The simulation of wind energy system at different voltages with energy storage is cascaded to maintain the dc voltage. The batterywith dual active bridge is responsible for bi-directional power flow control depending on quantum of terminal with fluctuation on DC link. It also control deep-discharging and overcharging by maintaining dc link voltage at a specified value. Furthermore, the effectiveness of the controller is also tested under change in the wind generation and load perturbation.

## 1.7THESIS ORGANIZATION

The thesis is organized into six chapters. Following the chapter on introduction, the thesis is outlined as follows.

Chapter 2 explains the survey of various literature and researches by researchers who have presented various techniques related to SST with concept of bi-directional power flow, wind energy generation, etc., in microgrid.

Chapter 3 represents the designing of solid state transformer by considering various parameters with its advantages and application

Chapter4explainthe designing of dual active bridge for bi-directional power transformer with detailed concept of it. It also discussed the overall configuration of the microgridsystem.Along with the operation of the grid and modelling and control of the used converters aredescribed.

Chapter 5presents the simulation and results which are found using MATLAB/SIMULINK program.

Chapter 6 provides summary and conclusions of the work undertaken inthis thesis and also acknowledge about the future work. The references taken for thepurpose of research work are also the part of this chapter.

# CHAPTER 2

# LITERATURE SURVEY

The popularity of distributed generation systems has grown faster in last decade because of its higher efficiency and high penetration to the renewable sources. Distributed generation make use of several renewable source as microsources for their operation like photovoltaic cells, wind turbines, batteries, micro turbines and fuel cells etc. A lot of research has already been done and further research are going on to argument the potential of distributed generation. After extensive literature survey the problem statement of research work is finalized and efforts are being made to further add something to this new growing field i.e. distributed generation.

1. [1] Author have discussed, the drawback of induction generator which draw high reactive power, which further may led to voltage dip at the starting of generator . The performance of the induction generator disintegrateswhen connected to unbalance power supply due to which it is again re-rated depending upon the degree of unbalance supply and voltage distortions. Whereas, for fixed prime movers the surplus energy would need to be absorbed to avoid over voltage due to which battery energy storage system(BESS) was introduced. Earlier BESS is used for performing slow power regulation such as for load levelling or peak levelling. But with the introduction of fast power electronics devices in BESS, it offers wide range of area regulation, area protection, power factor correction. In all, BESS is used for enhancing the reliability, energy management, power quality of the distribution system. In this paper BESS consist of three phase IGBT.

2. [2] In this paper author have discussed, Dual Active Bridge(DAB) is used as soft switching converter to meet the required large power. The author has introduced bi-directional converter with synchronous rectifier using mechanism of two bridge type DC converter that are connected through superposition in additive polarity in series. The author has devised a converter which is capable to lower the rated voltage of switching elements by sharing voltage and load current between two converters. The concepts of

high frequency transformer which is used at high frequency to improve the efficiency by using MOSFET as switching element .

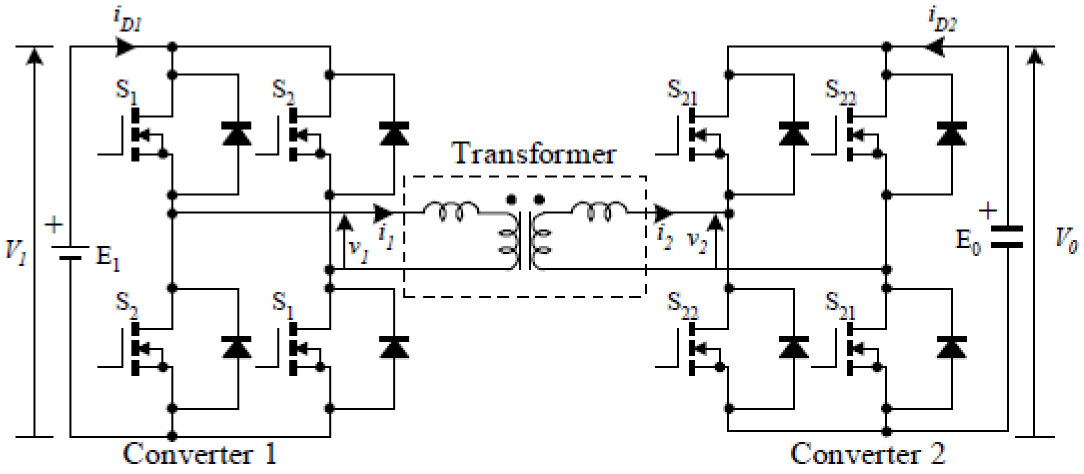


Fig.2 Bidirectional isolated dual active bridge DC-DC converter

3. [3] In this paper, author have compared the low frequeny and high frequency transformer about its weight, volume, cost and also how HFT avoid voltage and current waveform distortion caused by the core saturation of LF transformers. Different topologies of isolated bi-directional converter is discussed but eventually for biggest power capacity DAB- isolated bi-directional converter(IBDC) is considered because of their advantages of ease of realizing soft-switching, bidirectional power transfer capability, and modular and symmetric structure. In this, DAB-IBDC mainly focus on the following aspects i.e. basic characterization, control strategy, soft switching solution and optimization. Various application of DAB-IBDC which is now used at world wide is discussed ;

    - Battery energy storage and Uninterruptible Power Supply- BESS adopts DAB-IBDC instead of the traditional buck/boost circuit and line-frequency transformer, so the high power density, high-efficiency and high-power-transfer capabilitycan be achieved. The cascaded BESS based on DAB-IBDC is adopted to access high-voltage grid.

    - Solid-State Transformer (SST) - SST not only can act as a replacement for the traditional distribution transformer, but also can provide functions of voltage sag restoration, and power factor correction. Based on SST concept, the dc transformer based on DAB-IBDC is also analyzed.

- Back-to-Back (BTB) System- BTB system is also the key device in a universal flexible power management project which is to develop advanced power conversion technique to meet the future needs of electricity network, the BTB system is also used for medium-voltage motor drive applications.In this two modular converters are cascaded with PWM converters with different control strategies.

4. [4-5] In this paper, PWM technique is introduced to phase-shift bidirectional DC-DC converters, which can reduce current stresses, conduction loss and switching loss of semiconductors and can expand ZVS range. The PWM control of duty cycles can be seen as an electric transformer which regulates the amplitudes of equivalent input voltage and equivalent output voltage, so that both positive and negative amplitudes of the equivalent input voltage are equal to those of the equivalent output voltage. It has taken the Pulse Phase Shift(PPS) control technique which is the combination of both phase-shift bidirectional DC-DC converter and the advantage of PWM control and phase-shift control.

5. [5-7] In this paper, the concepts of the soft switching techniques for the efficiency improvement and the device stress reduction is presented and the unified control for a current mode controlled bidirectional DC DC converter is also discussed.

6. [13] Various topologies variations for DC-DC converters of high power applications with bidirectional power transfer have been proposed and developed through the last four decades. For the development of the efficient power, dc-dc converter they use either resonant or [8-10] soft switch control is used or [11].hard pulse width modulation(PWM).

7. [13] In this paper, the author have discussed the topology of dual active bridge cascaded with inverter (DABCI). It has discussed the significance of the dual-active-bridge (DAB) which are as follows:
    - The high-frequency transformer provide galvanic isolation and high-power density;
    - The symmetric topology through which bidirectional power flow may be achieved;
    - H-bridges with a transformer which may easily operate in a zero voltage switching mode

So the DAB cascaded with inverter (DABCI) is attractive for the interface converter between ac and dc systems.

An active power and dc-link voltage coordinative control method is proposed for the DABCI. The proposed control method shares dc-link control voltage and power control between the DAB and inverter. Without swapping control functions or sacrificing the stability, the proposed control can effectively improve the dynamic behaviour of the DABCI with better dc-link voltage maintenance and power control. The better-controlled of dc-link voltage, reduces the stress on the switching devices, which is significant to prolong system devices for life time.

8. [14] Conventionally, in an isolated dual active bridge DC-DC converter, the rated voltage of its switching elements is decided according to the DC power source voltage and load current. Therefore, as the voltage and current specifications of a DC-DC converter become higher, physical size becomes larger, conduction and switching losses increase and power efficiency reduces. In this paper, the authors had proposed the DC-DC converter which is capable of lowering the rated voltage of switching elements, by means of sharing DC power source voltage and load current between two converters. Further, the capacity of the high frequency transformer becomes small, making the DC-DC converter more efficient and smaller.

9. [15] This paper presents a high efficiency of dual-half bridge bidirectional DC-DC converter for DC micro-grid system applications. The operating principle and design consideration is discussed for bidirectional converter, with the zero-voltage-switching features and an adaptive phase-shift control method under wide-range load variations. A three-stage charging method is designed to meet the fast-charging demand and prevent battery overcharging to prolong the life-time of batteries. In this paper author have described a DC micro-grid system, in which the excess energy from renewable energy resources may be transferred to the batteries through the bidirectional DC-DC converter. On the contrary, if the renewable energy resources cannot fully supply the load demand, then the bidirectional DC-DC converter will provide the energy from batteries to DC-load.

10. In this paper, author have mentioned that with the penetration of renewable energy, wind energy prove to be close matching solution far. But being an uncontrollable or intermittent source, it becomes a great challenge to integrate large wind farms into the distribution grid with the view of power quality and protection. As the bulky step up power transformers are used to boost the voltage level needed for interconnecting wind power to the distribution grid which has some disadvantages. Earlier some reactive power compensator (like STATCOM, capacitor banks etc.) are being used to improve the power quality issues [17], [18]. With the current researches, Solid State Transformer (SST) is being considered as one the most important thing for integration in distributed energy sources. With the development of high voltage and high power level power electronic devices, researches have been started for the application of SST in high power level applications.. Two topology is proposed : One is the topology and architecture development in order to reduce the power level of the SST component and the other is the direction to find the suitability of SST in different applications [19]. SST is already found useful in the several applications such as traction/locomotives, distributed source integration (like solar farm, wind power), charge station, and smart grid where conventional low frequency transformers are dominating, in order to reduce the volume and weight of the system and improve the power quality and protection issues.[20]

11. In this paper, the benefits of SST is discussed which is much better than power transformer with its application in:

- Locomotives and other traction systems
- Offshore energy generation
- Smart Grids

The application of SST in grid is discussed how its useful are as follows-

**1. Application between generation source and load or distribution grid**

In this scenario, the SST is able to maintain constant voltage and frequency at its output even though, if the input voltage and frequency are variable. The SST allow the energy transport between source and load or grid to occur at unity power factor. This results in better utilization of the transmission lines and increased flow of active power. Another function, of SST is to improve system damping during the transient state.

2. **Application between two distribution grids**

One of the features of the SST is that it does not need both grids to have same voltage magtnitude, frequency or to operate synchronously. The SST can be used to control the active power flow between both grids. It can also be used as a reactive power compensator for both grids.

3. **Connection between the MV- and LV-grid**

In contrast to the power transformer, the SST can accurately control the amount of active power flowing from the MV- to the LV-grid. This is useful if the LV-side also has generation sources such as PV-panels. The SST can limit the amount of energy that flows back and forward through certain parts of the grid, to avoid overload of transmission lines with limited current carrying capacity.

4. **Application as interface for distributed generation and smart grids**

Distributed energy sources, such as photovoltaic arrays and wind turbines, provide a variety of electric sources. These sources often have a varying voltage or frequency or can even be a DC voltage. The SST is flexible enough to allow connection of these sources to the traditional grid. [21]

12. [22] This paper is considering the overall design of the high-voltage and high-frequency (HV-HF) transformer in dc/dc converter stages of solid state transformer (SST). SST has proposed a new concept with an interfacing for direct connection between the distribution line and local customers which can be considered as another generation source as well from the local smart-grid point of view. The soft switching in DAB converter allows us to increase the switching frequency and reduce size of transformers; on the other hand, it makes the transformer as one of the power transfer elements and therefore requires more design concerns such as inductance optimization and high voltage insulation.

13. [23-24] The contribution of this paper has been focused on a new microgrid architecture that integrates the solid state transformer with zonal dc microgrids. By utilizing the dc and ac links of the solid-state transformer, both ac and dc networks can access the distribution system, which coordinate management of the power and high power supply reliability. In addition, it can minimize the effect of newly established zonal dc microgrid to the existing power grid, which promises a better stability. The photovoltaic and battery as the typical renewable energy resource and energy storage device, is used for developing a simulation for system study. In this paper, SST includes a high-voltage ac to dc power conversion to generate a high voltage dc bus, a high-frequency dc/dc converter stage to produce a regulated low voltage dc bus, and a dc/ac stage to produce a regulated low voltage ac bus. A technique is proposed ,in which SST is having a three-port energy router which is integrating with the distribution system, residential ac system, and envisioned dc system. It has also proposed the method that in order to improve the system efficiency, the dc type source and load are connected to dc port, whereas the ac type source and load are to be connected to ac port.

14. [25] In this paper, comparison of six representative topologies for the implementation of Solid StateTransformers (SST) is done. The objective is to identify the most suitable topology which is capable of supporting additional functionalities compared to a power

transformer, e.g. on-demand reactive power support to grid, voltage regulation, and current limiting. The comparison is based on switch loss, switch count, control characteristics and supported functionalities. It has been concluded that a three-stage configuration comprising distinct AC-DC, DC-DC and DC-AC stages results in the most suitable implementation.

15. [27]-[30] in this papers, different authors have discussed about microgrids having large power capacity and more control flexibility which accomplishes the reliability of the system as well as the requirement of power quality. Operation of microgrid needs implementation of high performance power control and voltage regulation algorithm.

16. [31] Author have discussed about, the microgrid concept having lower cost and improve in the reliability of small scale distributed generators. The main purpose of this concept is to accelerate the recognition of the advantage offered by small scale distributed generators like ability to supply waste heat during the time of need. From a grid point of view, microgrid is an attractive option as it recognizes that the nation’s distribution system is extensive, old and will change very slowly. This concept permits high penetration of distribution generation without requiring redesign of the distribution system itself .

17. [32-34] Authors have researched in their work that with advancement in DGs and microgrid there is development of various essential power conditioning interfaces and their associated control for tying multiple microsources to the microgrid, and then tying the microgrids to the traditional power systems. Microgrid operation becomes highly flexible, with such interconnection and can be operated freely in the grid connected or islanded mode of operation. Each microsource can be operated like a current source with maximum power transferred to the grid for the former case. The islanded mode of operation with more balancing requirements of supply-demand would be triggered when the main grid is not comparatively larger or is simply disconnected due to the occurrence of a fault. Without a strong grid and a firm system voltage, each microsource must now

regulate its own terminal voltage within an allowed range, determined by its internally generated reference. The microsource thus appears as a controlled voltage source, whose output should rightfully share the load demand with the other sources. The sharing should preferably be in proportion to their power ratings, so as not to overstress any individual entity.

18. [35-40] Integration of wind turbines and photovoltaic systems with grid leads to grid instability. One of the solutions to this problem can be achieved by the implementation of microgrid. Even though there are several advantages associated with microgrid operation, there are high transmission line losses. In a microgrid there are several units which can be utilized in a house or country. In a house renewable energy resources and storage devices are connected to DC bus with different converter topology from which DC loads can get power supply. Inverters are implemented for power transfer between AC and DC buses. Common and sensitive loads are connected to AC bus having different coupling points. During fault in the utility grid microgrid operates in islanded mode. If in any case renewable source can’t supply enough power and state of charge of storage devices are low microgrid disconnects common loads and supply power to the sensitive loads.

19. Distributed generation is gaining more popularity because of their advantages like environmental friendliness, expandability and availability without making any alternation to the existing transmission and distribution grid. Modern sources depend upon environmental and climatic conditions hence make them uncontrollable. Because of this problem microgrid concept comes into feature which cluster multiple distributed energy resources having different operating principles. In grid tied mode distributed green sources operates like controlled current source with surplus energy channelled by the mains to other distant loads. There is need of continuous tuning of source outputs which can be achieved with or without external communication links. In case of any malfunctions grid tied mode is proved less reliable as this leads to instability[41].

20. This paper discuss power quality for direct current (DC) electric power distribution systems, particularly DC microgrid. Four selected sample DC architectures are discussed to provide motivation for the consideration of power quality in DC systems. Secondly, a brief overview of power quality challenges in comparison to conventional alternating current (AC) distribution systems is given to establish the field of power quality.[42]

21. In this paper, the working of different energy storage is discussed such as battery, flywheel, superconductors. Battery as energy source is used in DC microgrid which is linked with different variable renewable sources. The control loop is discussed which is used to regulate the voltage and intermittency in grid.[42-46].

# CHAPTER 3

# DESIGN OF HIGH FREQUENCY TRANSFORMER FOR DUAL ACTIVE BRIDGE

## 3.1 GENERAL INTRODUCTION

With the advancement in power electronics the technology to interface various renewable energy as distributed generation have become feasible, but have increases the complexity in the existing power system. To wrestle out with this complexity, new technologies are introduced for reliable and efficient control of the system. Often these microgrid with DG's require power to be routed in both the directions, to curb the intermittency in power offered by the DG sources. To make it possible the configuration based on dual active bridge(DAB) with a high frequency transformer is used as a part of solid state transformer used providing isolation between DG's and the grid. The one side of SST is connected through power electronics converter to a DG or directly to a battery storage and other side of the SST with the grid. For bi-directional power flow , excess power is routed across the DAB for storing the energy into the battery storage system and in case of deficiency the same is fed through the back to the grid to curb the intermittency DAB. The power may be obtained from battery to maintain the DC grid voltage. The maintenance of dc grid facilitates the inverter output at constant voltage irrespective of loading condition.

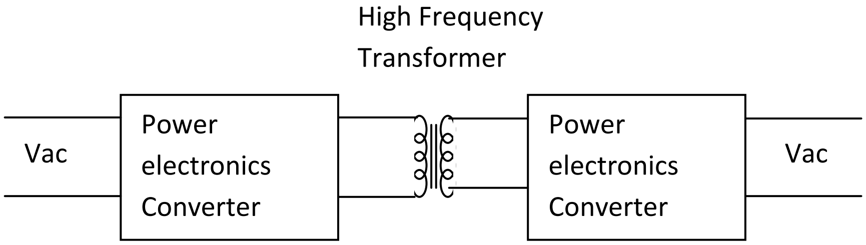
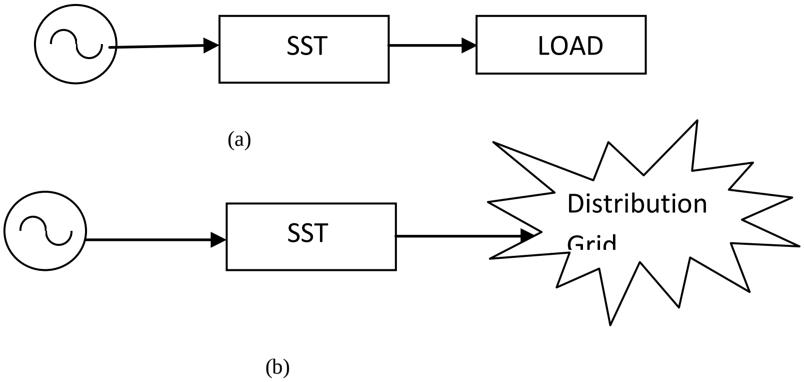


Fig.3.1 Block Diagram of Solid State Transformer

Conventionally Power transformer were used for isolation and for bi-directional power transfer requires bulky transformer. So to make system compact SST has resulted in a more efficient, reliable and compact. But although, power transformer being globally used has some disadvantages which are as follows:

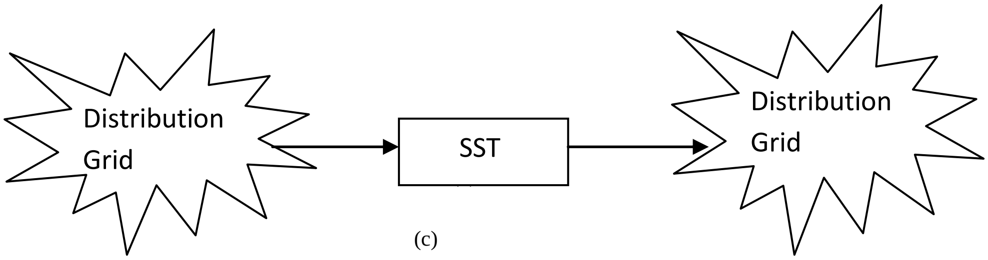
- Bulky size and heavy weight.
- Transformer oil can be harmful when exposed to the environment.
- Core saturation produces harmonics, which results in large inrush currents
- Unwanted characteristics on the input side, such as voltage dips, are represented in output waveform.
- Harmonics in the output current has an influence on the input. Depending on the transformer connection, the harmonics can propagate to the network or lead to an increase of primary winding losses.
- Relatively high losses at their average operation load. Transformers are usually designed with their maximum efficiency at near to full load, while transformers in a distribution environment have an average operation load of 30%.
- All LFTs suffer from non-perfect voltage regulation. The voltage regulation capability of a transformer is inversely proportional to its rating. At distribution level, the transformers are generally small and voltage regulation is not very good.

The conventional transformer with main function as the input- output voltage and current transformation. It is also prone to the disturbances. SST has been found to be a promising device to overcome this above said issues. The advantages of SST over conventional low frequency transformers are low volume and weight (due to its high-frequency operation compared with power transformer), fault isolation, voltage regulation, possibility of a DC input or output, immune to harmonics, easy integration of renewable energy resources and energy storage to it.



(a)

(b)



(c)

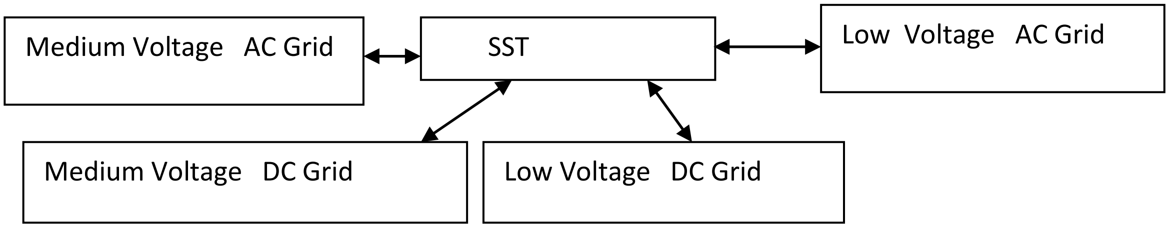


Figure 3.2: Schematic overview of the SST application

## 3.2 SCHEMATIC OVERVIEW

SST consists of one or more power electronics converters and an integrated high-frequency transformer. There are several SST architectures, but based on the topologies, they can be classified in four categories:-

1. Single-stage with no DC link (Figure 3.3.a)

2. Two-stage with a DC link on the secondary side (Figure 3.3.b)

3. Two-stage with a DC link on the primary side (Figure 3.3.c)

4. Three-stage with a DC link on both the primary and secondary side (Figure 3.3.d)

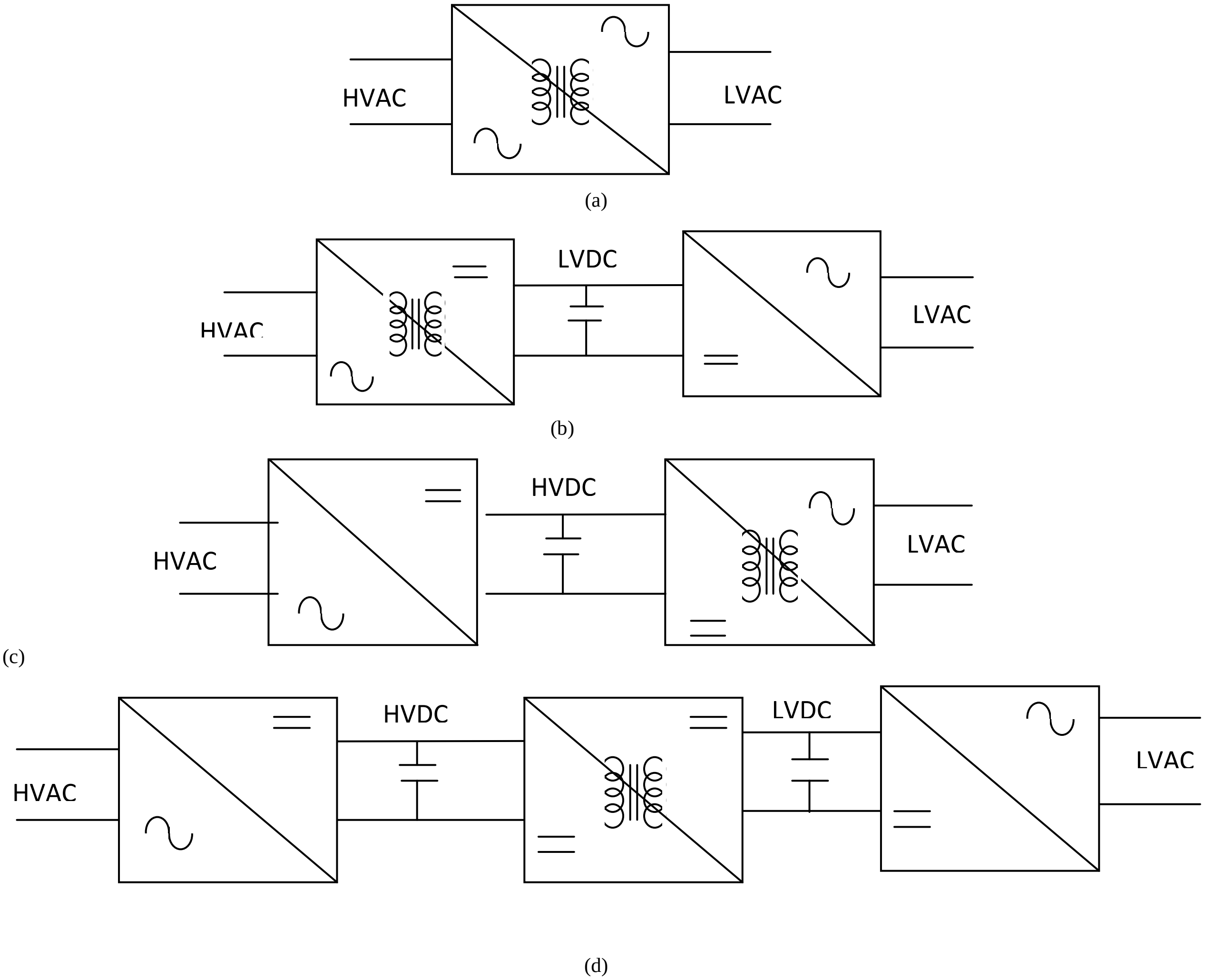


Fig. 3.3. SST configurations: a) single-stage, b) two-stage with LVDC link, c) two-stage with HVDC link, and d) three-stage.

Out of the four possible configurations, the three-stage architecture, with two DCs (Figure3.3.d), is most beneficial because of its high flexibility and controllability. The DC links areisolated with the HV- from the LV-side, facilating independent reactive or active power control and also to control the input voltage sag. It consists of an AC-DC conversion stage at the HV-side, a DC-DC conversion stage with high-frequency transformer for isolation and a DC-AC conversion stage at the LV-side.

SST also find application in a Cascaded H-Bridge multilevel converter with Phase Shift-Pulse Width (PS-PWM) modulation for the AC-DC stage.This combination provides a modular structure and is able to handle higher voltages.This topology is very compact, and when operating at a fixed voltage level with Phase Shift modulation, it has a high efficiency

## 3.3 BASIC TERMINOLOGIES IN HIGH FREQUENCY TRANSFORMER DESIGN

### 3.3.1 Area Product

The size of a power transformer is generally designated by a parameter called,
Area Product, $A_p$, as given by the following equation:
$A_p$ = area product = core cross section ($A_c$) x window area ($A_w$)
Using equation , the primary and secondary turns are given by
$N_1 = E_1 /4*K_f* A_c*B_m* f$
$N_2 = E_2 /4*K_f *A_c*B_m* f$
Current can be expressed in terms of current density as follows :

$I = J*a$ (wire) ….(3.1)

where,

J = current density

a(wire) = area of the conductor cross section through which current is flowing

As $N_1$ turns of primary has a cross section area of $a_1$ and $N_2$ turns of secondary has a cross section area of $a_2$, the total copper area that is to be made available for winding is

$N_1 *a_1 + N_2 *a_2$.

This theoretically should fit in the window area $A_w$. However, in practice the window area has to accommodate not only the bare wire, but the wire insulation, coil former, insulation paper used between windings, etc. If $K_w$ denotes this factor called window utilization factor, (whose value is less than unity) then
$K_w*A_w = N_1*a_1 + N_2*a_2$ ……(3.2)
Subtituting. Eq. (1) in Eq. (2) , we get
$K_w*A_w *J = N_1 * I_1 + N_2*I_2$ ……(3.3)

where

$I_1$ = Primary rms currents.

$I_2$ = Secondary rms currents.

Substituting for $N_1$and $N_2$ from equations, we obtain

$K_w*A_w*J$ =[$E_1$* $I_1$ + $E_2$* $I_2$ ]/(4*$K_f$ *$B_m$ *$A_c$*f) ……(3.4)

i.e. $A_p$ = $A_c$ *$A_w$ = [$E_1$ *$I_1$ + $E_2$ *$I_2$ ]/(4*$K_f$ *$K_w$ *$B_m$ *$A_c$*f *J) …….(3.5)

For a sine wave, the secondary VA, $P_{02}$, is given by-

$P_{02}$ = $E_2$*$I_2$ ....…(3.6)

where

$E_2$= secondary induced voltage(rms)

And the primary VA, $P_{01}$, is given by

eta * $P_{01}$ = $E_1$*$I_1$ = $P_{02}$ …….(3.7)

where,

$E_1$= Primary induced voltage(rms)

Eta = Efficiency of the transformer

where,

$P_{02}$ = Secondary VA

$K_f$ = form factor (1 for square wave, 1.11 for sine wave)

$B_m$ = allowed maximum flux density in tesla

J = current density in A/sq.m

$K_w$ = window utilization factor

f = frequency of operation in Hz

Using above equations the size of the transformer,is designed depending upon power level. The factor $K_w$(explained later may be taken as 0.4). The current density J is in the order of $3.5x10^6$ to $5x10^6$ Amp/$m^2$.

Generally, cores of different dimensions and standardized are available in the market. To choose the particular core size equation are used to calculate the required $A_p$and compare it with the value of standard cores and select one whose $A_p$is greater than the calculated $A_p$.

### 3.3.2 WINDOW UTILIZATION FACTOR ($K_w$)

There are several factors which decide the winding area that can be utilized, as against the window area that is available. The important factors are considered here.

**Coil former/Bobbin effect:** A bobbin or coil former that is used to house the winding has a certain thickness and this reduces the available window area. If the coil has multiple sections, then the factor further gets reduced.

**Space factor:** The second factor that causes a reduction in the winding space is the space factor $K_{w2}$. It can be defined as
= conductor area / (conductor area + insulation area)

This factor depends on the wire gauge. For example, for SWG 45 gauge having a nominal diameter, dno, of 0.071 mm, and a maximum diameter with insulation, dmax, of 0.086 mm If the wire gauge is thicker, like say SWG 14, the value of $K_{w2}$ comes out to Be 0.91. So, thinner the gauge, the lesser is the space factor.

**Air gaps between conductors:** The third factor which reduces the available window area is the factor arising from the fact that the adjacent turns are not air tight. There is always a gap between the conductors (though very small). And generally wire which is circular in cross section, is wound on flat (square, rectangular) surface, thus, further deteriorating the utility factor. In practice, this factor $K_{w3}$ is found to be in the order of 0.6 to 0.9

**Insulation factor:** There is one more factor $K_{w4}$, called the insulation factor. Generally, while winding the transformer, there are several insulation layers that come into picture, like, a layer of insulation between say, the coil former and the primary winding, between the primary winding and secondary winding, etc. to meet the breakdown voltage requirements. If there are multiple secondaries, additional layers are to be used. This insulation requirement further reduces the area available for winding the wire.Thus, the actual area finally available is

Available area = $K_w$ x window area where,

$K_w = K_{w1} \times K_{w2} \times K_{w3} \times K_{w4}$ ……(3.8)

Typically, a value of $K_w = 0.3$ to 0.4 can be taken for design purposes. So, the effective window area available = $K_w * A_w$.

**Bobbin :-**

A bobbin is a spindle or cylinder, with or without flanges, on which wire, yarn, thread or film is wound. Bobbins are typically found in sewing machines, cameras, and within electronic equipment.In non-electrical applications the bobbin is used for tidy storage without tangles. In electrical applications a coil of wire carrying a current has important magnetic properties.

## 3.4 DESGN OF HIGH FREQUENCY TRANSFORMER

### 3.4.1 Step 1. Determination of input data

Power Rating = 4500VA

Switching Frequency = 20KHz

Minimum Input DC voltage = 420V

Output Voltage, $V_o = 4650V$

Maximum DC current = 10.7A

Rectifier Diode Voltage, $V_{diode} = 1V$

Maximum duty cycle,$d_{max} = 0.92$

Maximum ambient temperature, $T_{max} = 60^0$ C

Efficiency of transformer,$\eta_t = 97.9\%$

Maximum temperature rise = $51.5^0$ C

For steps mentioned below, design procedure is described as it is but final values for the designed transformer is inserted to show outcome.

### 3.4.2 Step 2.Estimate the total power loss in the transformer, $P_{total}$

$$P_{tot} = \left(\frac{Ptp}{\eta}\right) - P_{tp} = \left(\frac{4500}{0.979}\right) - 4500 = 96.527W \quad …..(3.9)$$

$P_{core} = 48.30W$

Copper loss, $P_{cu}$ = 15.22 W

### 3.4.3. Step 3. Determination of $\Delta B$

If the flux swing is core loss limited, the design is theoretically optimized by assigning the total losses equally between the copper and the core:

$P_{core} = P_{cu} = P_{tot} / 2$ Watts

$P_{core/kg} = P_{core} / wt$ : wt is weight of core ……(3.10)

The allowable ΔB can be determined from the switching frequency and the core loss per kilogram.

Using formula,

$P_{core/kg} = 6.5\ f^{1.51}\ Bac^{1.74}$ …….(3.11)

where, $B_{ac} = \Delta B /2$ Tesla

f is in KHz.

Putting values,

$P_{core/kg} = P_{core}/ \text{weight} = 48.30/2.9 = 16.64$W/kg

$P_{core/kg} = 6.6*(fsw)^{1.51}* (Bac)^{1.74}$

$16.642 = 6.5*(20000)^{1.51} *(Bac)^{1.74}$

Bac = 0.128T

$\Delta B = 2* B_{ac}= 0.255$T …….(3.12)

### 3.4.4 Step 4. Calculate the number of primary and secondary turns

Calculate the number of primary and secondary Turns

$N_{pmin} \geq \ Vcc(\text{min}) * \text{dmax} * 10000)/(\Delta\text{B} * \text{Acmin} * \text{fsw})$ ……(3.13)

And turn ratio (n) is calculated to calculate Ns.

*Turn ratio (n) = Np / Ns* …..(3.14)

Where n is calculated using,

n= [ Vcc (min) – Vtrans(sat) * d(max)] / ($V_o$ + $V_{diode}$) ….(3.15)

Using above two formulas, we calculate Ns

$N_{pmin}$= 67 turns

$$N_s = \frac{Np(Vo+Vdiode)}{(Vccmin-Vtrans,sat)*dmax} \quad \ldots.(3.16)$$

$N_s$ = 811

### 3.4.5 Step 5.Choose the required core size

Core AMCC-500 is selected from given total power loss, $P_{tot}$

| | |
|---|---|
| a = 2.5cm | $A_c$ = 11.3cm$^2$ |
| b = 4.0cm | weight = 2.9kg |
| c =8.5cm | $W_aA_c$= 384.2cm$^4$ |
| d = 5.5cm | SA = 854.5 cm$^2$ |
| e = 9.0cm | $l_c$= $l_m$ = 35.6cm |
| f = 13.5cm | |

$$SA = 2f(b+d) + 2(b+d)(b+e) + 2f(b+e) \quad \ldots..(3.17)$$

$$= 2x13.5(4+5.5) + 2x(4+5.5)x(4+9) + 2X13.5(4+9)$$

$$= 854.5\ cm^2$$

### 3.4.6 Step 5: Calculate the primary and secondary current densities

For best utilization of the window area, all windings should be operated with the same current densities J. otherwise, a field gradient will exist, causing a higher current density in one part of the window area, this will cause localized hot spots in the windings.

A initial current densities chosen is 300 A/cm$^2$ which with many iterations comes out to be 243.68 (244 A/cm$^2$) with further iterations.

In order to maintain safety requirements and insulation between windings, a window utilization factor Kw = 0.4 is normally achievable.

For primary conductor area we have:

*Ap = 0.5 Wa*Kw* ....for singe ended primary and single ended secondary transformer.

Primary and secondary winding cross sections are based on the core's window area:-

$W_a = \frac{\text{WaAc}}{\text{Ac}} = \frac{384.2\ \text{cm4}}{11.3\ \ \text{cm2}} = 34\ \text{cm}^2$ ……(3.18)

With $W_a$= 34 $\text{cm}^2$, we got $A_p$=4.82 $\text{mm}^2$

$A_p = \frac{\text{Iprms}}{\text{J}}\ \text{cm}^2 = \frac{14.47}{3} = 4.82\text{mm}$ …..(3.19)

Cross section for one primary conductor is, $A_p$(1 conductor) = 0.1015$\text{mm}^2$
From APPENDIX B, SWG 12 is selected

$A_s = \frac{\text{Isrms}}{\text{J}} = \frac{0.93}{3} = 0.31\text{mm}^2$ …….(3.20)

Cross section for one secondary conductor is, $A_s$(1 conductor) = $1.911\text{x}10^{-4}\ \text{mm}^2$

From APPENDIX B, SWG 22 is selected

Now, $I_{srms} = (P_{tp}/Vo) * (dmax)^{0.5}$ …...(3.21)
$I_{prms}$ = 14.47A
$I_{srms}$ = 0.93A
J = 1.421A/$\text{mm}^2$

### 3.4.7 Step 7: Select suitable conductors and estimate total copper losses

Resistivity of copper,

$\rho$ at $50^0$C = ($\rho$ at $20^0$C)[1+0.0042(T at $50^0$C – T at $20^0$C)] ….(3.22)
= $1.7424\text{x}10^{-8}$[1+0.0042(30)]
= $1.95\text{x}10^{-8}$ohm-cm

Estimation of total copper loss and winding resistances

MTL = 2(a+2b+d) …..(3.23)
= 2x(2.5+8+5.5)
= 32cm

Winding resistance of primary side $\Omega_p = \frac{\text{MTL x Np x }\rho}{\text{Ap (1 conductor)}}$ ……(3.24)
= 41.24m$\Omega$

Winding resistance of secondary side $\Omega_s = \dfrac{\text{MTL x Ns x } \rho}{\text{As (1 conductor)}} = 7743.167\ \text{m}\Omega$

Copper loss of primary, $P_{prim\ cu} = (Iprms)^2\ \Omega_p$ ….(3.25)
= 8.55W

Copper loss of secondary, $P_{sec\ cu} = (Isrms)^2\ \Omega s$ ..….(3.26)
= 6.67W

Total loss, $P_{cu} = P_{prim\ cu} + P_{sec\ cu}$ …..(3.27)
= 15.22W

### 3.5 Determination Of Design Parameters

Hypothetically an ideal transformer would work with direct-current excitation, with the core flux increasing linearly with time. In practice, the flux rises to the point where magnetic saturation of the core occurs, causing a large increase in the magnetizing current and overheating the transformer. All practical transformers must therefore operate with alternating (or pulsed direct) current.

Operation of a transformer at its designed voltage but at a higher frequency than intended will lead to reduced magnetizing current. At lower frequency, the magnetizing current will increase. Operation of a transformer at other than its design frequency may require assessment of voltages, losses, and cooling to establish if safe operation is practical. For example, transformers may need to be equipped with 'volts per hertz' over-excitation relays to protect the transformer from overvoltage at higher than rated frequency.

#### 3.5.1 Resistance models

The resistance models depict the core loss resistance($R_c$)and the primary($R_1$) and secondary($R_2$) winding resistances.

**a) Core Loss Resistance**

The losses in the core consisits of two major components, the hysteresis loss and the eddy current loss.The hysteresis loss can be calculated using

$P_h = k_h f B^x$ ..…..(3.28)

where

$k_h$ = a constant (material dependent)

x = Steinmetz factor

This calculation requires an estimate of the magnetic flux density which can be obtained from the "transformation equation" as

$$B = \frac{V1}{4.44N1fAc} \qquad \text{…..(3.29)}$$

where

$V_1$ = primary voltage $c_1^2\, l_c^2\, N_1^2$

The value of B can be checked againstan optimal value for the core material.

The eddy current loss is expressed as

$$P_{cc} = \frac{c1^2 lc\; e1{}^\wedge 2}{12f\rho cN1{}^\wedge 2Ac} \qquad \text{…..(3.30)}$$

The Steinmetz factor has a value between 1.8 to 2.5

where

$c_l$ = lamination thickness

$\rho_c$ = operating resistivity of the core

$A_c$ = cross-sectional area of the core

$E_1$ = induced primary voltage

The variation of the resistivitywith temperature of all materials should be ac-counted for, since the transformer will be heated up under operation. The operating resistivity at temperature $T^0$ C is

$$\rho = \frac{(1+\Delta\rho T)\rho 20\text{C}}{(1+20\Delta\rho)} \qquad \text{…..(3.31)}$$

where,

$\Delta\rho$ = thermal resistivity coefficient

$\rho_{20}{}^{o}{}_{C}$ = material resistivity at $20^{o}$C

The hysteresis and eddy current losses can be expressed in terms of the induced voltage $e_1$ as

$P_h = \frac{e1^2}{Rh}$ ……(3.32)

$P_{ec} = \frac{e1^2}{Rec}$ ……(3.33)

where

$R_h$ = hysteresis loss equivalent resistance

$R_{ec}$ = eddy current loss equivalent resistance

Thus $R_h$ and $R_{ec}$ can be included in the model as core loss resistance $R_c$.$R_c$ is expressed as

$R_c = \frac{\mathrm{Rh.Rec}}{Rh + \mathrm{Rec}}$ …..(3.34)

**(b) Primary winding Resistance**

The primary winding resistance is

$R_1 = \frac{\rho 1\ l1}{A1}$ ….(3.35)

Where

$\rho_1$ = resistivity of the primary winding wire

$l_1$ = effective length of the wire

$A_1$ = cross sectional are of the wire

The effective length of the wire is estimated by calculating the length of the wire on each layer of the winding and then summing over all layers, taking into account the increasing diameter of each layer wound around the previous one.

**(c)Secondary winding Resistance**

The secondary winding Resistance is

$R_2 = \frac{\rho 2\ l2}{A2}$ …..(3.36)

where

$\rho_2$ = resistivity of the secondary winding wire

$l_2$ = effective length of the wire

$A_2$ = cross sectional are of the wire

As for the primary winding, the effective length of the secondary winding wire is calculated by approximating the length of the wire on each layer of secondary winding and then summing over all layers.

### 3.5.2 Inductive Reactance Models

The inductive reactance models contain the magnetising reactance ($X_m$) and the primary ($X_1$) and secondary ($X_2$) leakage reactances.

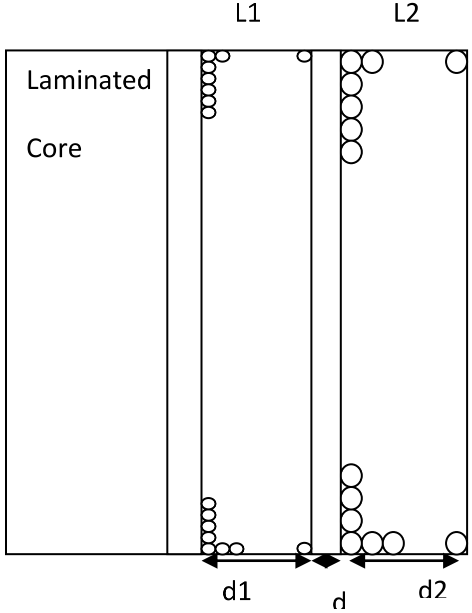


Fig3.4Axial view of the transformer showingcomponent dimensions and material properties

a)**MagnetisingReactances**

The Magnetising Reactance is

$$X_{m} = \frac{\omega x \mathrm{Np2 \ x \ \mu o \ x \ \mu rc \ x \ Ac}}{\mathrm{lc}} \quad \text{……(3.37)}$$

where$\mu rc$ = permeability of free space = 1025(from graph)
and $\mu_o$ = permeability of core$4\pi \times 10^{-7} Hm^{-1}$
$\omega = 2\pi f$

$$= \frac{2 \ x\pi x \ 20000x \ 68 \ x68 \ x \ 4\pi \ \mathrm{x} \ 10-7 \ \mathrm{x} \ 11.3}{35.6}$$

= 23063210.42ohm

$L_m = \frac{Xm}{2\,\pi f}$ …..(3.38)

$= 183.531$ H

At primary side, SWG 12 is selected with diameter of wire is = 2.756mm = 0.2756cm

In one layer number of turns will be = $\frac{8.5}{0.2756}$ = 30 turns

Number of layers = $\frac{67}{30}$ = 2.172 = 3turns

$d_1$ = number of layer x SWG of 12 …..(3.39)

= 3 x 2.756 = 8.2682mm = 0.8268cm

At secondary side, SWG 22 is selected with diameter of wire is = 0.77mm = 0.077cm

In one layer number of turns will be = $\frac{8.5}{0.077}$ = 110.389 turns

Number of layers = $\frac{811}{110.389}$= 8 turns

$d_2$ = number of layer x SWG of 12 ……(3.40)

= 8 x 0.77 = 6.16mm = 0.616cm

Δd = Diameter of insulation provided between primary and secondary layers and is generally taken 1.1mm thick.

**(b) Primary and secondary Leakage Reactances**

The primary and secondary leakage reactances are assumed to be the same and are each half of the total leakage reactance

Now,

$X_1 = X_2{}' = \left(\frac{\omega x \mathrm{Np2\ x\ }\zeta \mathrm{12\ x\ }\zeta}{\mathrm{lc}}\right) \mathrm{x}\ \frac{1}{2}$ ……(3.41) where,

$\zeta_{12}$ = winding thickness factor

$= D_1 + D_2 + \Delta d = 0.015528\text{m}$

$$\delta' = \frac{D1+D2}{3} + \Delta d = 5.909\text{x}10^{-3}\ \text{m}$$

$$X_1 = X_2' = \left(\frac{2\ x\pi x\ 20000\ x\ 67\ x\ 67\ \text{x}\ 4\ \text{x}\ 5.909\ \text{x}10-3\ \text{x}\ 0.015528\ \text{x}\ 4\ \text{x}\ \pi\ \text{x}\ 10-7}{35.6\ \text{x}\ 10-2}\right) \text{x}\ \frac{1}{2}$$

$= 0.3654086\Omega$

$$L_1 = L_2 = \frac{X1}{2\,\pi f} = 2.9078\ \text{x}10^{-6}\ \text{H}$$

The above calculation is done, is now verified by MATLAB simulink

### 3.6 Simulation and verified result of High Frequency Transformer

The designing of high frequency transformer is done which is verified by the simulation. The input voltage at transformer is 420V which deliver the current of 100A. At secondary side the voltage is 4650V which produces the current of 10A. The pulse generated implies the delta angle shift which result it that whether it deliver total power at load side or some angle shift in it to deliver some power.

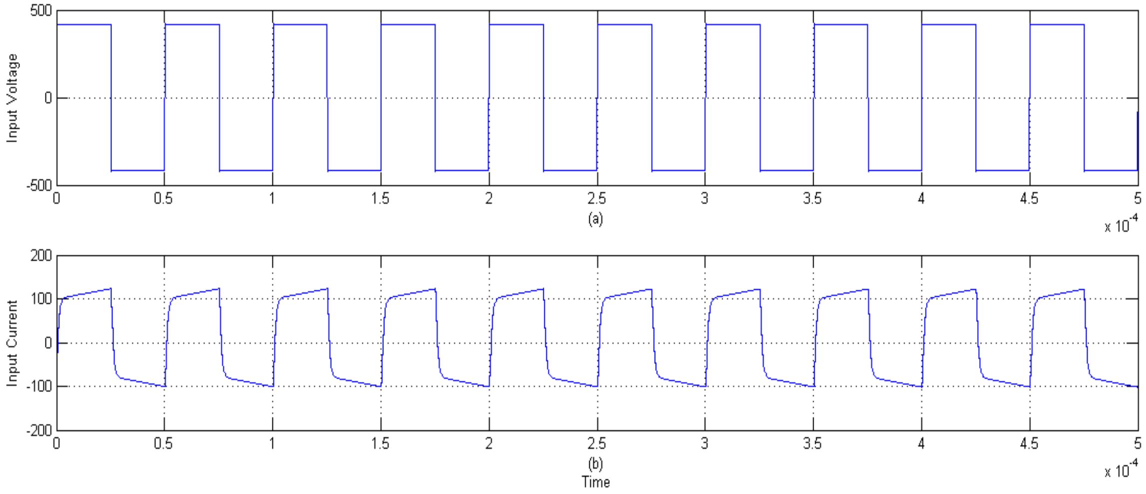


Fig3.5 Waveform(a) Input Voltage (b) Input Current of HFT

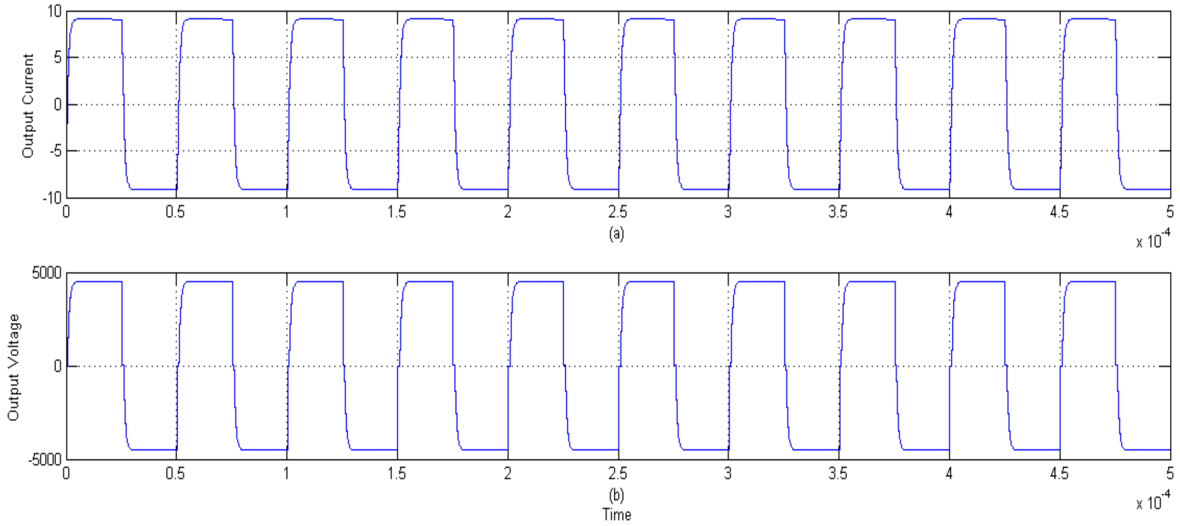


Fig.3.6 Waveform (a) Output Current (b) Output Voltage of HFT

The above fig3.5(a)-(b) and 3.6(a)-(b) shows the input and output voltage and current respectively of high frequency transformer.

## 3.7Application of Solid State Transformer

- Offshore energy generation
- Locomotives and other traction systems
- Smart Grids

## 3.8Applications of the SST in the grid

- Application between generation source and load or distribution grid
- Application between two distribution grids
- Connection between the MV- and LV-grid
- Connection between MV-grid and loads
- Application as interface for distributed generation and smart grids

# CHAPTER 4

# MODELLING, ANALYSIS, SIMULATION AND CONTROL OF DUAL ACTIVE BRIDGE FOR BI-DIRECTIONAL POWER TRANSFER

With the increasing demand of power the quality and reliability of power supply without interruption, has become a necessity.To maintainuninterrupted power supply, even when one of the generation unit or system fail in islanded operation of the micro grid the storage system have become indispensible. Often the interconnection of low voltage high current battery storage system demands a bidirectional converts for supply of power during deficient conditions and during surplus condition on the connected sources, absorb the power to offer load matching. Bi-directional DC converter(BDC) therefore has gained huge importance due to the increase in need of systems with the capability of bidirectional energy transfer between two different dc buses. Traditional BDC finds application in dc motor drives and now it is used to interface various renewable energy systems, fuel cell energy systems, hybrid electric vehicles (HEV), battery storage etc. BDC also finds application in UPS where one terminal is connected to the grid and other terminal is used to charge battery in normal operation mode but in back up mode, reverse the supply from the battery, i.e.it feeds the loads via inverter.

Renewable energy resources like wind, solar being intermittent in nature, hence is often not suitable to solely depend on the source for feeding the loads. The problem of intermittency may be curbed by usingsame energy storage device in conjunction with renewable energy resource to compensate fluctuations and to maintain a smooth and continuous power flow to the load. The most common and economical energy storage devices in medium-power range are batteries which may be used to exchange power between storage device and the rest of system via dc-dc converter. Such converters are desirable to have bidirectional power flow capability with flexible control in all operating modes.

### 4.2 Types of Bidirectional DC converter

Bidirectional DC converter are of two types non isolated Bidirectional DC converter (NBDC) and isolated Bidirectional DC converter (IBDC).

#### 4.2.1 Non Isolated Bi-directional DC Converter(NBDC)-

Generally, Buck type of dc-dc converters were used for power flow but being Unidirectional, it’s not possible to maintain the continuous supply of power. Buck and boost converter (fig4.1 & fig.4.2) which block the reverse flow of current. So by removing the diode from it, can be transformed into bidirectional converters.

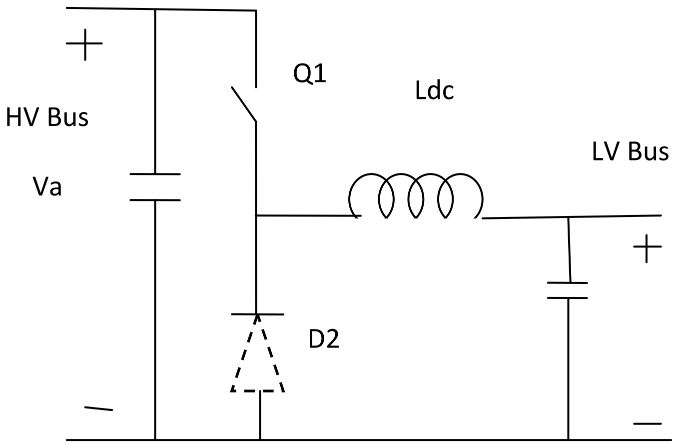


Fig.4.1 Unidirectional Buck Converter

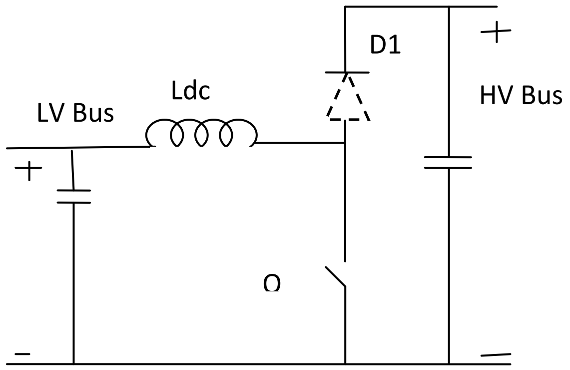


Fig.4.2 Unidrectional Boost Converter

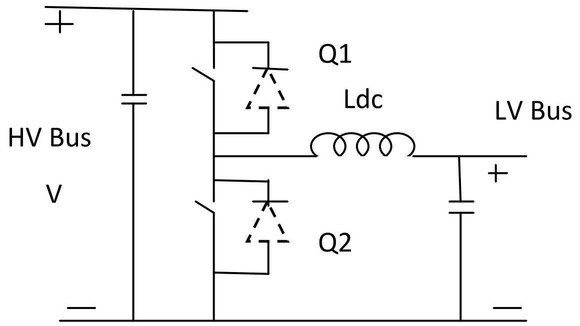


Fig.4.3 Transformation to bidirectional converter by substituting diodes with a controllable switch

From fig.4.3, it is seen that in buck mode, i.e. when the power is transferred from high voltage (HV) to the low voltage (LV) side, Q1 is the active switch while Q2 is kept off and in boost mode, when the power is transferred from LV to HV side, Q2 acts as a controlled switch and Q1 is kept off. The inductor which is present in the LV side results in lower ripple current which is advantageous in some applications. For example, it is usually preferred to charge/discharge batteries with low ripple current to achieve higher efficiency and longer life time. Some of the major limitations associated with the NBDC shown in Fig. 4.3 are:

- It can only operate in buck mode in one direction and boost in the other. Technically, it means that the voltage ratio d, which is defined as d= $V_b/V_a$, is either smaller or greater than unity in one direction.

- When the voltage ratio becomes large, this structure becomes impractical.

- They lack in galvanic isolation between two sides.

To overcome this limitation, improved structures have been proposed. When the magnitude of two dc bus voltages is close to each other and the voltage ratio is smaller or greater than unity is required, the buck-boost or Cuk converters are the appropriate choice. Fig. 4.4.a shows the basic configurations of a NBDC based on buck-boost converter. The polarity of dc buses is reverse with respect to a common ground which is a burden in many applications.

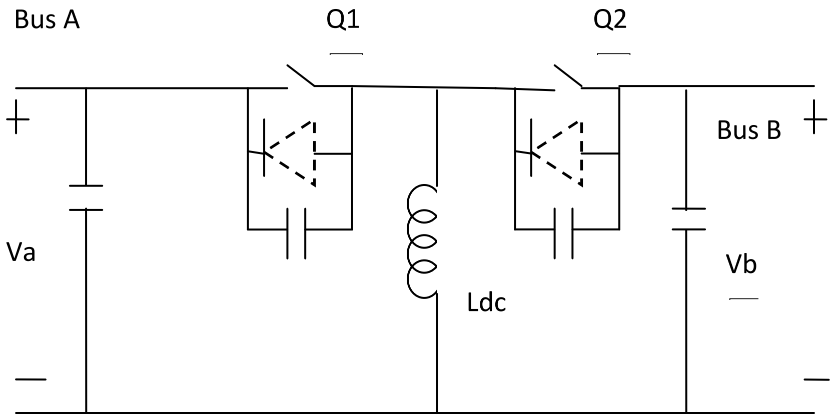


Fig.4.4.a Bidirectional buck-boost

This problem can be resolved by adding more switches to this configuration as shown in Fig. 4.4.b.

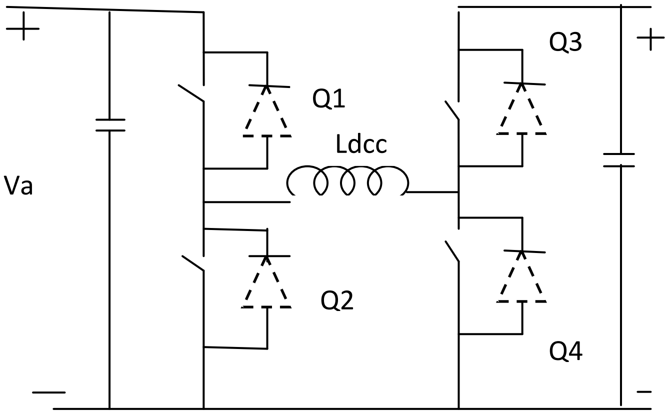


Fig.4.4b Two back-to-back connected NBDC

The operation of the NBDC of Fig. 4.4.a.: the inductor is the main energy transfer element in this converter. In each switching cycle it is charged through source side active switch for the duration of Ton = DT, where $T=1/f_{sw}$ is the switching period and D is the duty cycle. This energy is then discharged to load during $T_{off} = (1-D)T$.

In fig.4.4(b) it's the four-switch buck-boost converter the principle of operation is the same as above. In the left to right power transfer mode, Q1 and Q4 act as active switches, while in the right to left power transfer the opposite switches (Q2 and Q3) are controlled. Synchronous rectification technique can be employed in this configuration in order to add more features and improve efficiency.

### 4.2.2 Isolated Bidirectional DC converter (IBDC)

IBDC structure consists of two high-frequency switching dc-ac converters and a high-frequency transformer which is primarily used to maintain galvanic isolation between two sources and voltage matching between two low and high voltage buses. The transformer is used for ac quantities at its terminals and thus a dc-ac converter is employed on one side and ac-dc converter on other side. As energy is transfer in either direction which is required for the system, with dc-ac and ac-dc converter having bidirectional energy transfer capabilities. The dc buses in this structure must also be able to either generate or absorb energy. These buses are connected to a dc source or an active load like battery, ultra-capacitor or dc-link capacitor.

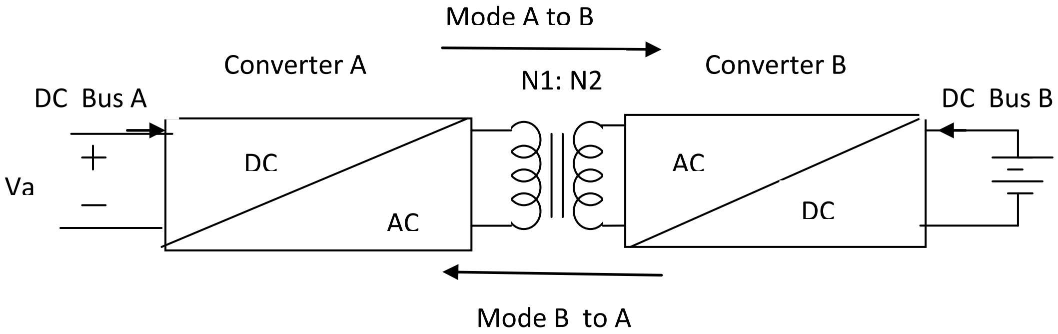


Fig.4.5 Basic structure of an IBDC

### 4.3 Type of converter

Considering Fig.4.5, an important characteristic of IBDC which is shown is that it has converter at each side. Basically, two types of switching converters are identified.

- Current-type (or current-fed) structure : It has an inductor with stiff current characteristic at its terminals which acts like a current source, like conventional boost converter at its input terminals.
- Voltage type (or voltage-fed) structure : It has a capacitor with stiff voltage characteristic at its terminals which acts like a voltage source, like conventional buck converter at its input terminals. The operation, switching strategy and other operational aspects of these converters are different.

With researches, different configuration had been proposed through researches. One of the configuration of IBDC is Dual Active Bridge which will be discussed in this thesis. Bidirectional isolated dc-dc DAB converters were used for high power density and high power dc-dc converters. The DAB topology is used because it has zero-voltage switching (ZVS), bidirectional power flow, and lower component stresses.

## 4.4 Circuit Configuration

The converter was introduced by De Doncker, 1991 and Kheraluwala , in 1992. It consists of two full-bridge circuits, which are connected to high frequency transformer. Each switching bridge is made up of four high-frequency active controllable switching devices (MOSFETs or IGBTs) in DAB connection. Such connection is similar to the one used in full-bridge dc-dc converters, instead of using uncontrollable switching devices selection of IGBT is done to control and maintain dc voltage at grid rather than only converting it into DC source. As this converters use two active bridges formed by active controllable devices, that’s why it is known as “Dual Active Bridge”. The full bridge on the left side is connected to battery, and the full bridge on the right side is attached to the the DC-bus. A high-frequency transformer is used along with high-frequency switching devices because it reduces the weight and volume of the devices. Beside galvanic isolation, the high-frequency transformer also has some leakage inductance in its primary and secondary windings, which together act as an energy storage component. The leakage inductance also helps achieve soft switching. During switching transients, transformer current resonates with the capacitors in parallel with switching devices, limiting the dv/dt and di/dt across the switches.

SST are introduced with several topologies  which has been introduced. Six representative SST topologies have been selected for detailed analysis and comparison:

a) Modular single-stage comprising AC-AC Full-bridge converters, b) modular single stage comprising AC-AC Flyback converters, c) modular two stage comprising AC-DC isolated Boost converters and a PWM dual-phase inverter, d) modular two-stage comprising AC-DC Dual Active Bridges (DAB) and a PWM dual-phase inverter, e) modular three-stage comprising a cascaded full bridges based multilevel rectifier, DCDC DAB modules and a PWM dual-phase inverter, and finally, f) modular three stage comprising a diode-clamped multilevel rectifier, DC-DC Full-bridge converters and a PWM dual-phase inverter.

### 4.5 Working of DAB

The two bridge of DAB are controlled in coherent manner one  bridge switching is controlled by providing a high frequency square wave command with 50% duty ratio and other bridge. Controlled pulse is generated by Phase shiftingthe bridge one square wave depending on the power demand. The two bridges square waves can be suitably phase shifted with respect to each other to control the power flow from one DC bus to another depending on the availability of power. The power flow of a DAB converter may be controlled by varying the phase shift between the two bridges. Such phase shift changes the voltage across the transformer leakage inductance and depending upon the gradient of voltage magnitude. In the direction of power flow and the amount of power transferred are controlled. Power transfer is done from the leading bridge to the lagging bridge. The shift in delta(phase) anglewith respect to another bridge either lagging or leading is decided by comparing the other bridges dc link voltage with respect to the reference voltage and the error is fed to PI controller to decide the delta or phase angle with repect to first bridge.

DAB converters are also identified as the core circuit in the power electronic converter system between an ac power system and a renewable power source.

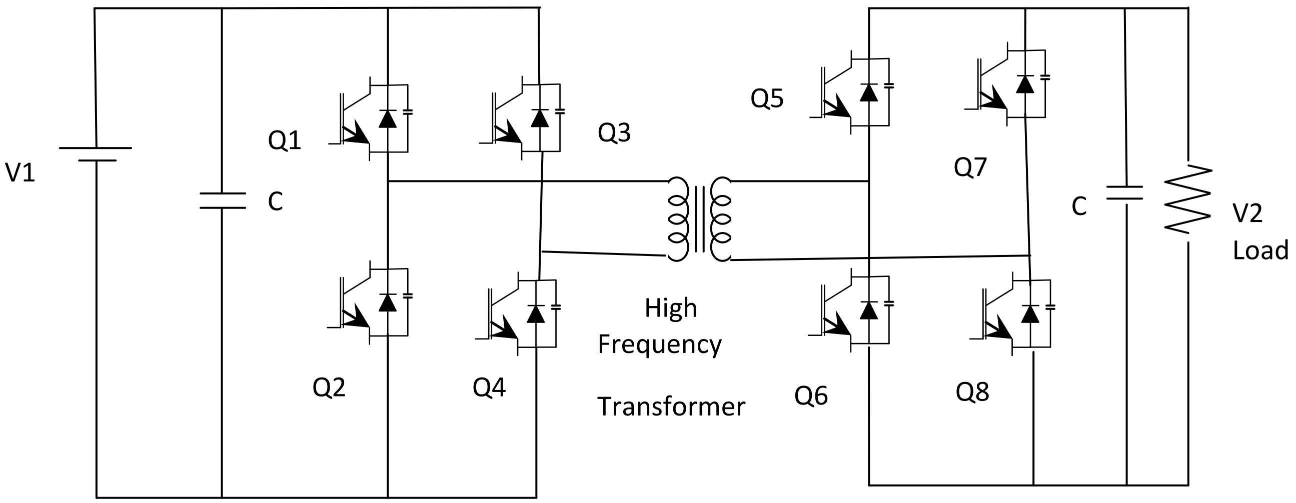


Fig4.6 Circuit diagram of Dual Active Bridge

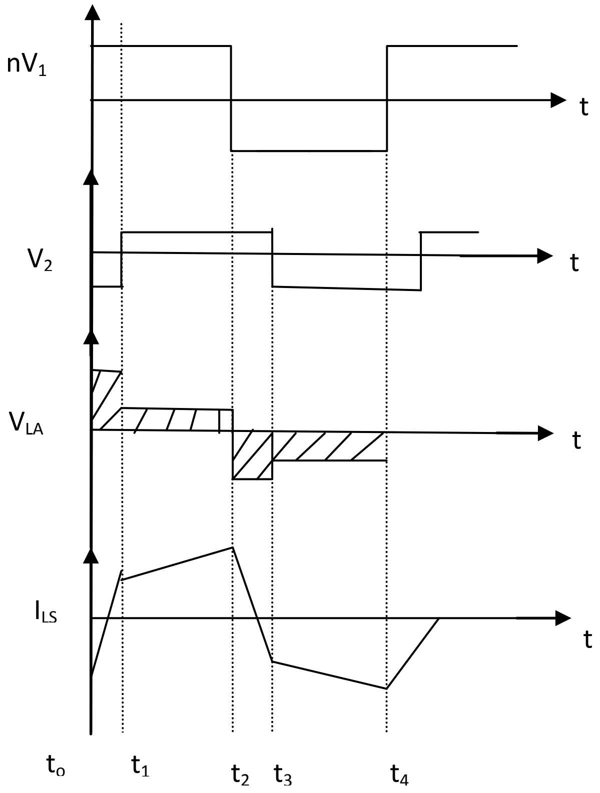


Fig4.7 Waveform for heavy load condition

### 4.5.1 Steady State Operation

For different operating mode of DAB, phase shift angle, load condition and output voltage is considered distinguished. Considering the turn-ratio of transformer as *n*, primary and secondary voltage $V_1$ bad $V_2$ with switching frequency as $f_s$. The half switching period $T_s$ is given by equation

$$T_s = \frac{1}{2fs} \qquad \text{.......(4.1)}$$

The duty cycle or say phase shift is given by equation based on half switching period which is

$$D = \frac{ton}{Ts} \qquad \text{.......(4.2)}$$

So $DT_s$ is the phase shift between two bridges and $I_{Ls}$ is the current through leakage inductance of secondary winding.

## 4.6 Various operating mode based on output current

Different operating mode based on the output current having different loading condition is delineated in fig.4.7

### 4.6.1 Heavy load condition

The inductor current $I_{Ls}$ increases from the negative value $i(t) < 0$ in beginning of switching cycle and reaches to positive value $i(t_o)$ at end of half switching cycle. There are six different segments which come forth in switching cycle as show in fig.4.7 assuming $V_2$ to be larger than $nV_1$.

Mode 0[$t_0$ , $t_1$]: In this $Q_1$ and $Q_4$ are turned on therefore $V_1$ and $nV_1$ are positive of primary side. At same time $Q_6$ and $Q_7$ are turned on of secondary side but due to negative current in inductor flywheel $D_6$ and $D_7$ and $Q_6$ and $Q_7$ would notcurrent. So the voltage across it is given by equation $V_{LS} = nV_1 + V_2$. The inductor current increases linearly from negative value and become zero at $t_1$.

Mode 1[$t_1$, $t_2$]: $Q_1$ and $Q_4$ of primary and $Q_6$ and $Q_7$ of secondary bridges are still on. Current continued to be in increasing but it had become positive therefore $Q_6$ and $Q_7$ would now conduct current. Therefore total current increases during [$t_0$, $t_2$] is given by equation-

$$\Delta I_{Ls}=\frac{DTs}{Ls}(V_2 + nV_1) \qquad \text{......(4.3)}$$

Therefore

$$i(t_2) = i(t_0) + \frac{DTs}{Ls}(V_2 + nV_1) \qquad \text{.......(4.4)}$$

Mode 2 [$t_{2,}$ $t_3$] : In this mode, $Q_1$ and $Q_4$ continued to be turned on but $Q_6$ and $Q_7$ are turned off, meanwhile $Q_5$ and $Q_8$ are turned on. The voltage produce is $V_{LS} = nV_1 - V_2 < 0$

The leakage inductor current increment during interval [$t_2$, $t_3$] is:

$$\Delta I_{Ls}=\frac{(1-D)Ts}{Ls}(nV_1-V_2) \qquad \text{......(4.5)}$$

$$i(t_3) = i(t_2) + \frac{(1-D)Ts}{Ls}(nV_1 - V_2) \qquad \text{.......(4.6)}$$

Mode 3[$t_{3,}$ $t_4$]: In this mode, $Q_2$ and $Q_3$ switches continued to be turned on and $Q_5$ and $Q_8$ are turned on. Hence the primary and secondary voltage reverses and the current decreases from $i(t_3)$ to zero.

Mode 4[$t_{4,}$ $t_5$]: Switches $Q_2$ and $Q_3$ of primary and $Q_5$ and $Q_8$ of secondary continued to be turned on. The current decreases linearly to negative to its maximum, meanwhile $Q_5$ and $Q_8$ switches conduct current. Therefore the current increased in inductor $L_s$ in mode 3 and 4 is given by equation:

$$\Delta I_{Ls}=-\frac{DTs}{Ls}(nV_1 + V_2) \qquad \text{..... (4.7)}$$

Mode 5[$t_{5,}$ $t_6$]: In this mode, switches $Q_5$ and $Q_8$ are turned off and diode $D_6$ and $D_8$ begin to freewheel. The current incremented in inductor $L_s$ is given by:

$$\Delta I_{Ls}=\frac{(1-D)Ts}{Ls}(V_2 - nV_1) \qquad \text{......(4.8)}$$

From the symmetry of inductance current, $i(t_0) = -i(t_3)$. From equation 45 to 48, the current in inductor $L_s$ obtained is given by equation:

$$i(t_o) = \frac{1}{4fsLs}[(1-2D)V_2 - nV_1] \qquad ......(4.9)$$

Maximum current is given by equation:

$$I_{max} = i(t_2) = \frac{1}{4fsLs}[\ -(1-2D)\ nV1 + V_2\ ] \qquad ......(4.10)$$

The above analysis of different operating modes is based on condition that $i(t_o) < 0$, or

$(1-2D)V_2 < nV_1$.

### 4.6.2 Light Load Condition

When the condition $(1-2D)V_2 > nV_1$ or $i(t_o) > 0$, then it represents light load condition. From fig.4.8, current increased from starting and became negative t the end of half switching cycle.

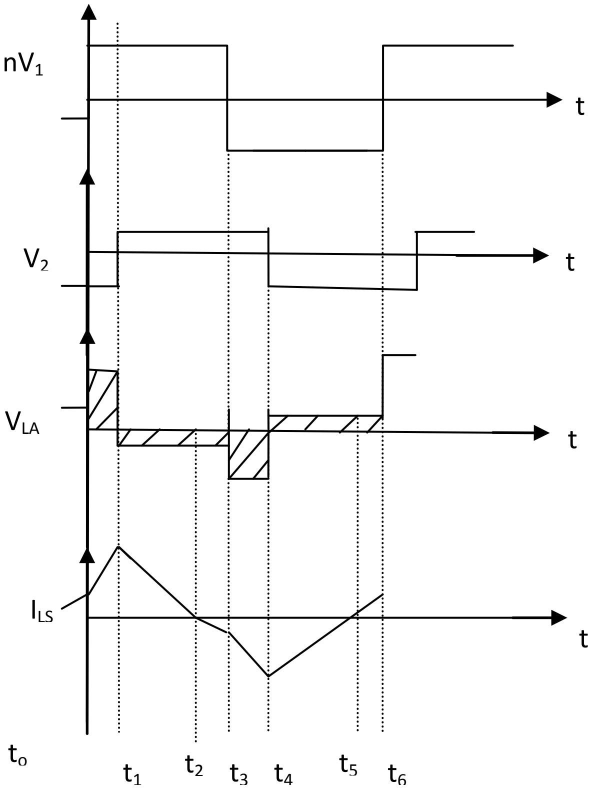


Fig4.8 Waveform for Light load condition

The above equation analysis shows the boundary condition. The average current of the leakage inductor in one half cycle switching is given below equation which is derived from fig4.7

$I_{avg}= \frac{1}{2Ts}(I_{max} + i(t_o)DT_s + (I_{max} – i(t_o))(1-D)T_s]$

$= \frac{1}{2fsLs}D(1- D)V_2$ ......(4.11)

Power supplied is

$P = nV_1I_{avg}= \frac{nV1V2}{2fsLs}D(1- D)V_2$ ......(4.12)

Assuming load having fixed resistance, output power is given by

$P_o = \frac{V2\char`^2}{Rl}$ .....(4.13)

Where $R_l$is load resistance

In transformer neglecting the switching losses, the power supplied will be equal to output power i.e.,

$P = P_o$

So, $V_2 = \frac{nV1}{2fsLs}D(1- D)V_2R_l$ .....(4.14)

Equation 4.14 shows that, for a given switching frequency, leakage inductance and input voltage, the output voltage derived is directly proportional to the load resistance and duty ratio or we can say phase shift angle.

### 4.7 Performance Evaluation through Simulation Results

The DAB performance is evaluated for unidirectional and bi-directional power flow at various duty cycle through simulation work in MATLAB.

#### 4.7.1 Unidirectional Power flow of DAB with various duty cycle

There are two modes of operation of DAB i.e. on-grid and off-grid mode of operation. In on-grid mode of operation terminal voltage is controlled by grid, which is supposed to be stiff and thus even if there is a variation of wind speed (renewable energy source) there is no appreciable change / fluctuation of voltage at the load terminals. The change in wind speed (renewable source power) causes intermittency in power through load. This power intermittency is eliminated / reduced to a greater extent by using such topology. The topology / load / system is optimised for rated wind speed and with decrease in wind speed (power of renewable source) the excess power demand of load is supplied by battery system which in now in discharging mode of operation via DAB and power intermittency is reduced greatly.

In isolated mode of operation of there is a great dependency on wind speed (renewable energy power) and with the variation of input power output voltage at load terminals fluctuates and this is a major problem concerned with major renewable energy sources mainly wind energy systems. With the fall of wind speed terminal voltage of wind generators also falls and the present topology of battery system is responsible for maintaining the voltage at the load terminals. In this mode also the battery system is in discharging mode of operation.

It is observed that in case of both on-grid and off-grid modes of operation the present configuration / topology utilises the excess power stored in the battery system (via discharging the battery) to regulate power and voltage intermittency respectively. The following simulink model shows the present configuration of unidirectional power flow.

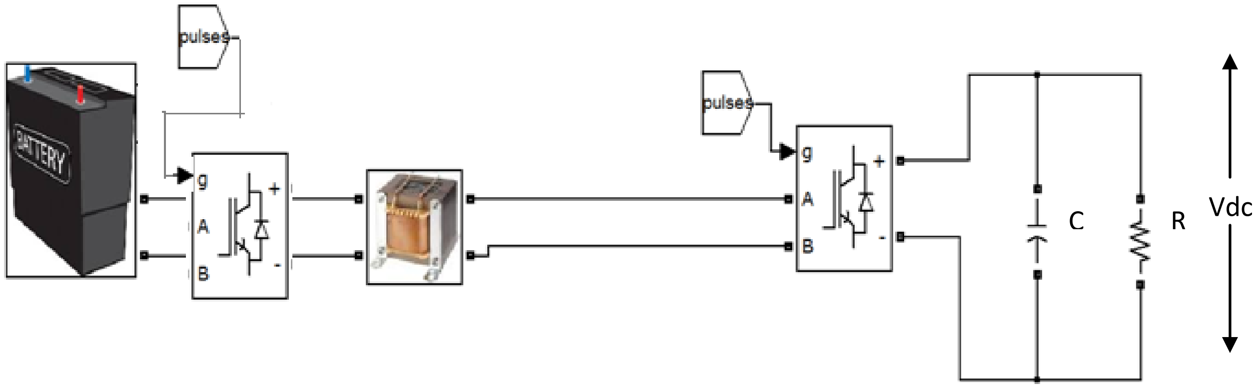


Fig4.9 System configuration for unidirectional power flow

**4.7.1.1 Simulation-** Gate pulse is shifted with a duty cycle of

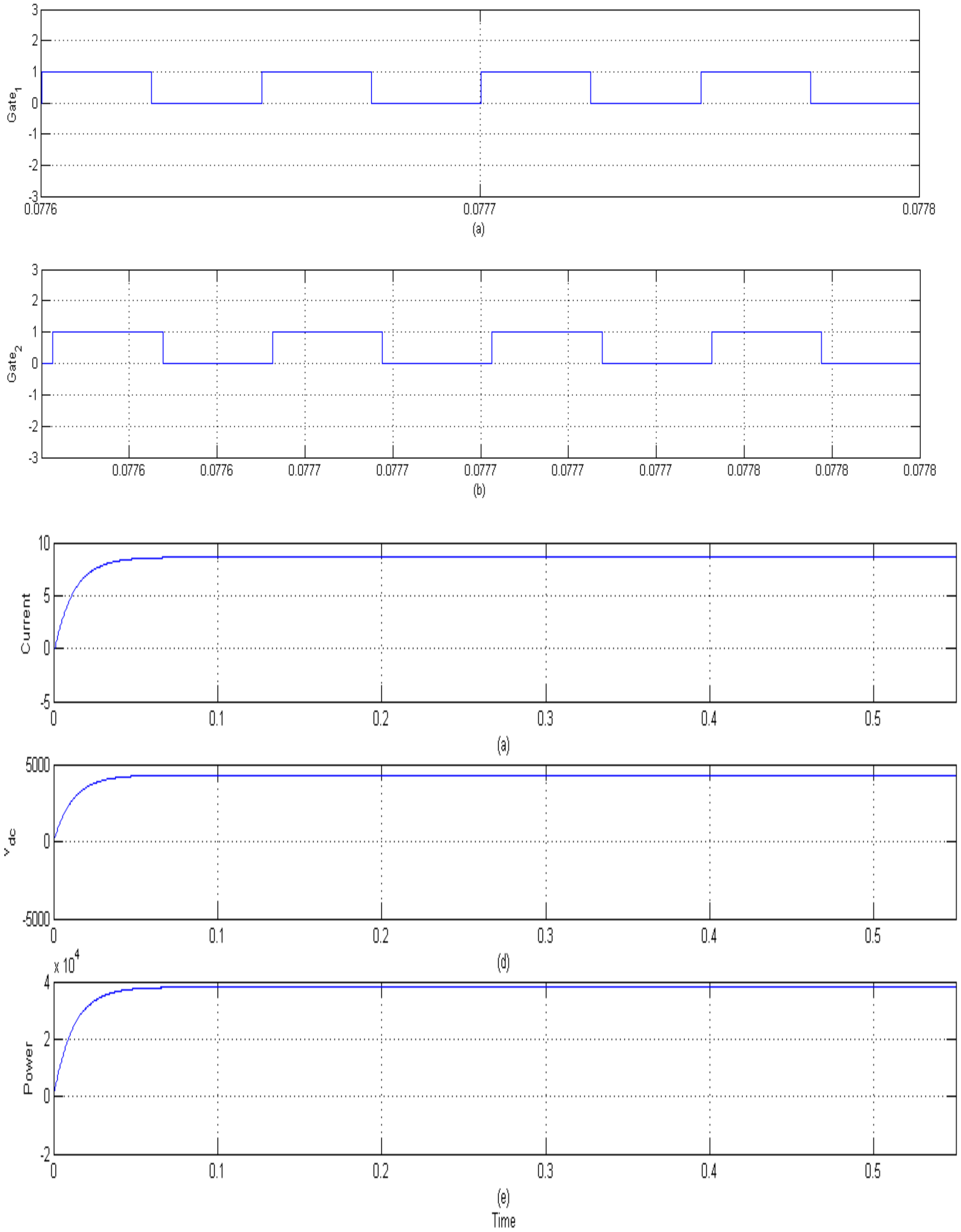


Fig4.10 Performanceof(a) Gate$_1$ (b) Gate$_2$ (c) Current (d) DC Voltage (e) Power for unidirectional power flow of DAB

#### 4.7.1.2 Analysis of unidirectional power flow of DAB

Fig 4.10 shows the MATLAB simulink model of the unidirectional power flow in a battery which act as supplier in on or off grid mode to regulate voltage and reduce power intermittency. Fig4.8(a)-(e) shows the wafeform f gating pulse given to IGBT, load current, dc output voltage, output power respectively. The simulation result shows that before t = 0.05sec the shifting in gating pulse applied on IGBT's the voltage and power are increasing which shows that they are trying to maintain the maintain the voltage at load side and curb the intermittency. After t = 0.05sec, voltage and power settled down to its steady state i.e. to the desired value of the grid at load side.

**TABLE-4.1**

| | |
|---|---|
| **Current** | 8.622A |
| **$V_{dc}$** | 4310V |
| **Power** | $3.806 \times 10^4$W |

### 4.7.2 Bidirectional mode of operation of DAB with various duty cycle

With the demand of rise and extinction of conventional sources, renewable energy sources for are now use to produce electricity. The renewable sources being variable in nature like wind whose speed is not constant may produce constant voltage or power through dual active bridge using bi-directional power flow concept is proposed in which power converters play vital role for the effective utilization of the energy generated by alternate energy sources. Various alternate sources are linked to each other at common DC bus. Moreover the DAB is also being connected at same DC bus.

Fig.4.11 shows the designing of a bidirectional power converter module which support a range of loads or sources which are flexible in nature .

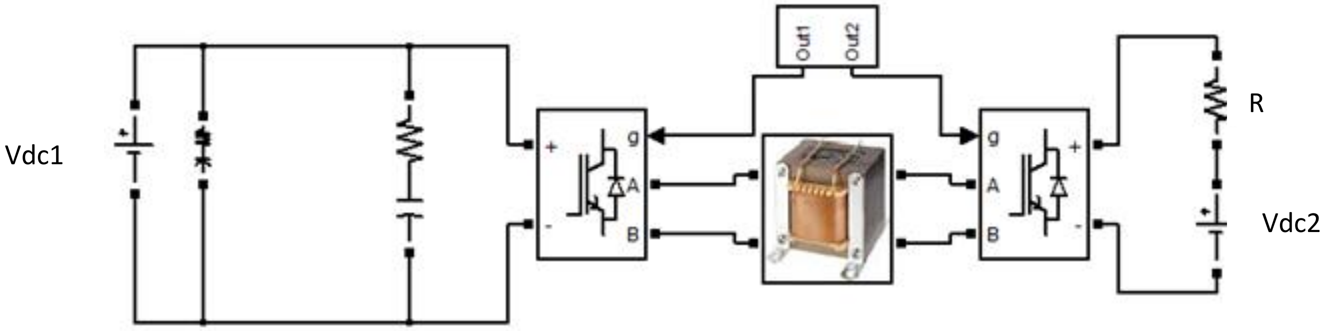
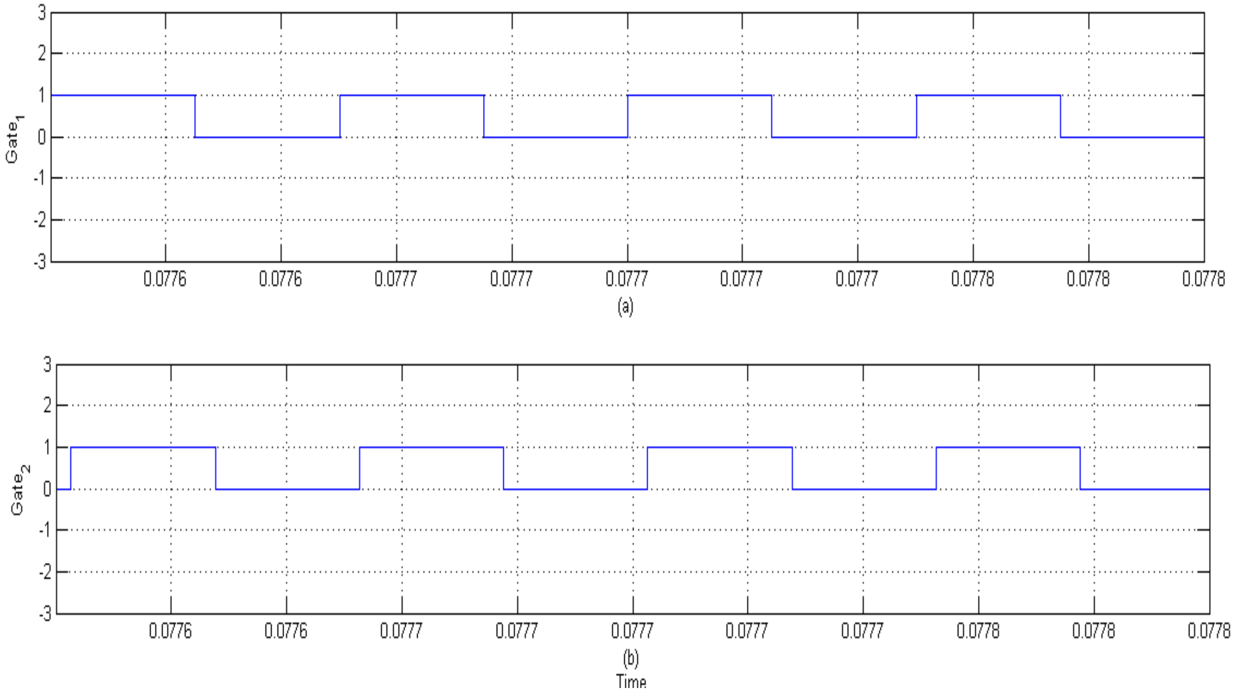


Fig.4.11 System Configuration of Bi-Directional Power Flow

### 4.7.2.1 Simulation for Bi-directional power flow of DAB

As DAB can work in both discharging and charging condition to always balance the supply at load without being intermittent

**For Discharging**



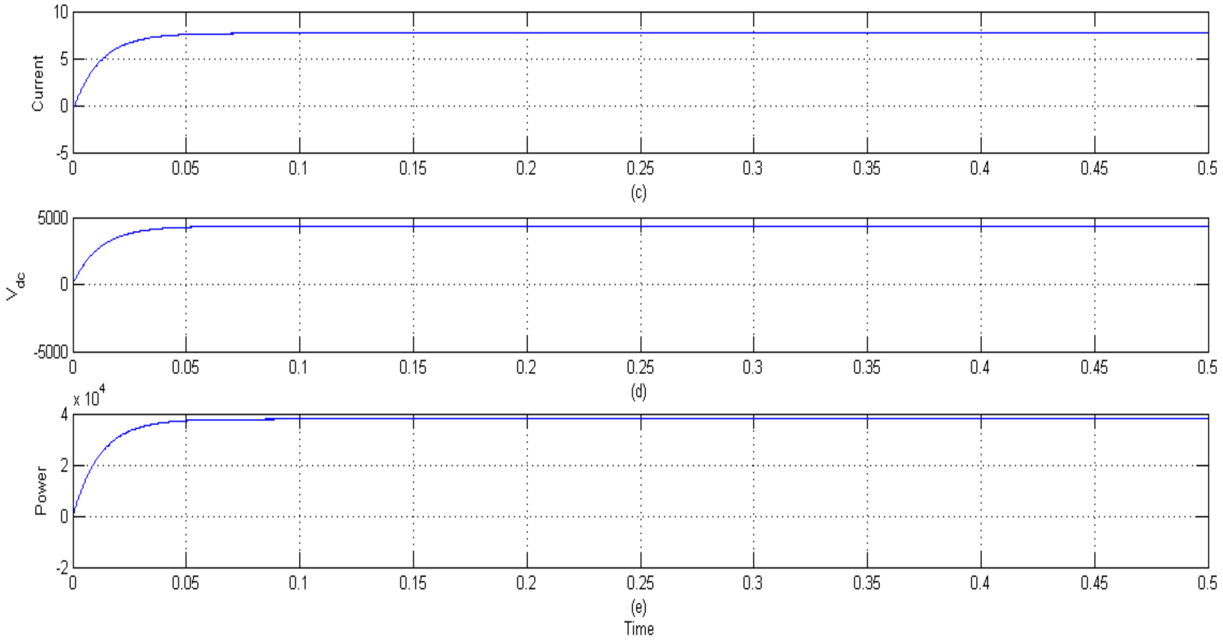


Fig.4.12 Performance of(a) $Gate_1$ (b) $Gate_2$ (c) Current (d) DC Voltage (e) Power for discharging condition

### 4.7.2.2 For Charging Condition

The gate pulse Gate1 lag the Gate2 pulses which means that the battery will charge. The simulation result is shown in Fig.4.13

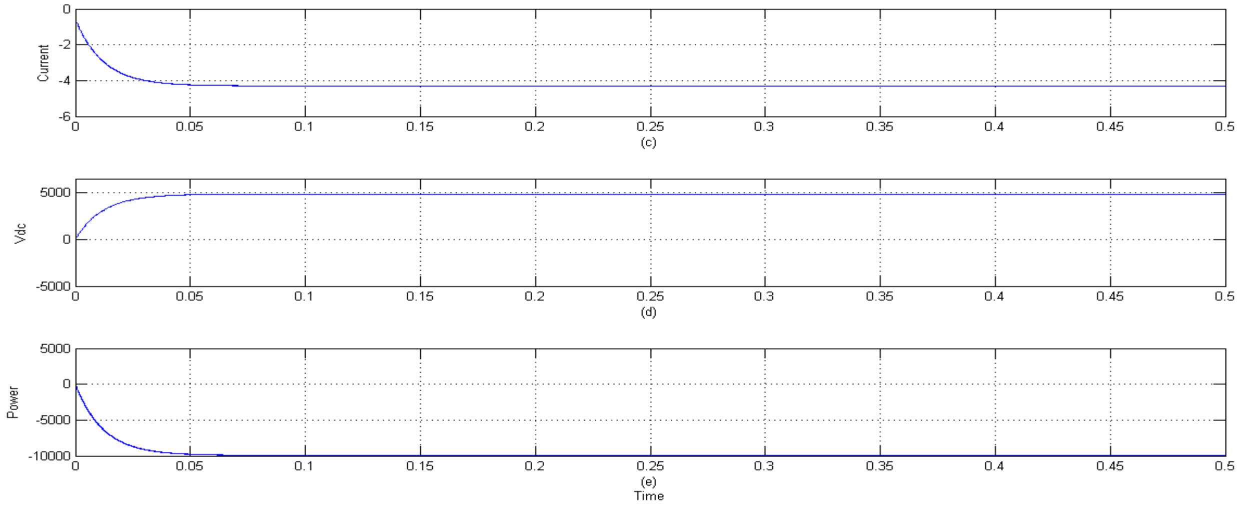


Fig.4.13 Performance of(a) $Gate_1$ (b) $Gate_2$ (c) Current (d) DC Voltage (e) Power in charging condition

#### 4.7.2.3 Analysis of discharging and charging condition

The MATLAB simulation in Fig.4.12(a)-(e) and Fig.4.13(a)-(e) shows the discharging and charging mode of battery. When equivalent current is positive, it shows that some energy is moved to the dc side to regulate the voltage and curb the intermittency. In this converter operates in rectifier mode. Contrary to this, when the equivalent current is negative, excess energy is removed from dc side and it is used to charge the battery, thus the converter operates in inverter mode.

**TABLE-4.2**

| **DISCHARGING** | |
|---|---|
| Current | 7.671A |
| $V_{dc}$ | 4335V |
| Power | $3.789\text{x}10^4$W |
| **CHARGING** | |
| Current | -4.377A |
| $V_{dc}$ | 4851V |
| Power | -9923W |

### 4.8 Conclusion-

In this chapter the modelling and simulation of dual active bridge for bi-directional power flow is discussed for transfer of power from battery stack to the terminals of a DC microgrid. The control algorithm developed bi-directional power flow has been tested and evaluated for controlled power flow across the DAB. Such control has been demonstrated to have made the power system stable and has effectively regulated the power flow since when there is excess of supply due to renewable sources for charging the battery and when the renewable sources are not able to maintain grid voltage, battery has supplied the power to regulate the voltage at the terminals to which RES are connected.

.

# CHAPTER 5

# CASCADED INTEGRATION OF RENEWABLE ENERGY SOURCE WITH BATTERY SUPPORT

## 5.1 Overview

The Distributed generation with renewable energy sources(RES) interface such as wind and PV are being utilized broadly nowadays because of various advantages including their free availability, etc. However, the power management for RESs is still challenging due production offluctuating power due to their dependence on weather which it posses great challenge for grid integration for stable and reliable system operation particularly for voltage regulation. Advancement in power electronics and faster control hasopened the opportunities for effective mitigation of problems faced due to such intermittency in generation by the Renewable Energy Sources(RESs). Similarly, for off-grid applications of RESs especially with a rapidly growing DC system challenges in power management are also due for investigations.

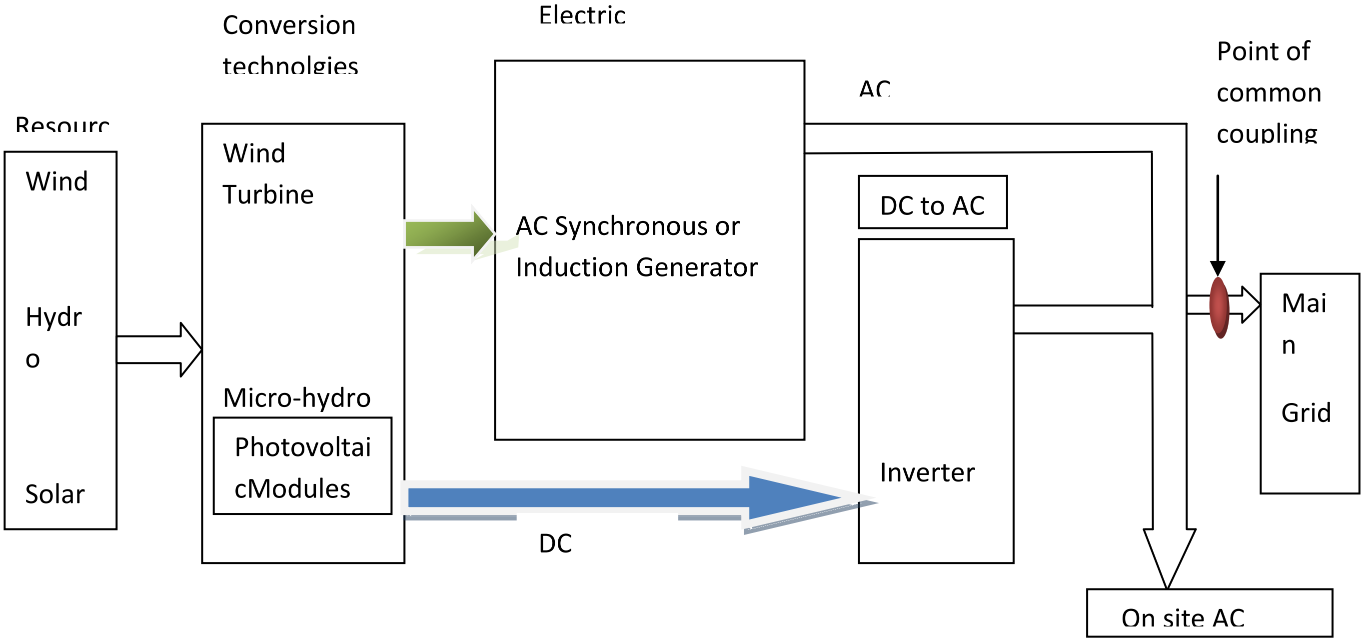


Fig.5.1 Energy pathways in a renewable power micro-grid connected with the utility grid

Among RESs, the wind energy source along with its power electronic based interfacing unit termed as Wind Power System (WPS) plays a dominant role in the overall power generation. Although large wind farms are still being constructed all over the world, in last few years records show sudden increasein focus on small scale wind turbines due to their lower impact on landscapes, lower noise levels, and their capability to operate separately from the grid in islanded communities. Research is due for development of power electronics interfaces with the capability of stabilizing the normalcy in the system and effectively mitigating the ill effect of the intermittent nature of wind energy so that tight voltage regulation on the grid can be met. The suitable example for the advancement for such type of system is Variable Speed Wind Turbines (VSWT) equipped with permanent magnet synchronous generators (PMSG) and full-scale power electronics based converters.

## 5.2 DifferentMode of connection

There are different way through which renewable sources may be connected to produce electricity and to reduce the intermittency. Basically there are two ways for interfacing:-

i) Parallel mode
ii) Cascaded Mode

In parallel operation of renewable energy sources, there is need of high boosting transformer to meet the requirement at load side which may increase the cost of the system. So to avoid such bulky and costly system, the better way to connect the system is in cascaded mode. The cascaded connection offer clear cut advantages for maintaining the regulation of voltage with balancing the intermittency in power in the microgrid to which these are connected.

### 5.3 Mode of operation:

There are two modes of operation in which microgrid can be connected to regulate the voltage and to reduce the power intermittent nature. These are

i) Islanded mode

ii) Grid connected mode

#### 5.3.1 Islanded (Off-grid) Mode

In an islanded (off-grid) mode, WPS can be operated in a hybrid system or in a microgrid. However, the indeterminate behaviour of wind and fluctuation in loads make the operation of WPS more challenging than in a grid connected application. The variation in wind speed leads to a fluctuation in torque and output power of the wind turbine. As a result, there is a variation in the voltage profile from desired values. The integration of energy storage with the standalone operation of WPS improves the voltage responses in the presence of fluctuating wind speed and varying load demand. Energy storage is capable of supplying voltage during abnormal conditions such as wind gusts and sudden load variations. Thus, we can say battery storage is one of the best suited storage technologies for wind power applications, due to its high energy density levels. The off-grid WPS demands a cost effective and smaller footprint system with high level of power quality and reliability.

In an autonomous mode, the conventional current controlled strategy may not be suitable, as there is no stiff source to maintain the voltage at the PCC. Hence when grid is disconnected, the interface controller with a battery source should be switched to a voltage control mode and the voltage regulation is done which is maintained to rated load voltage

In islanded mode, it’s always necessary to maintain the constant voltage. As in this mode different RES are connected with a battery storage. The load matching is always necessary in this modefor stable supply of electricity. Wind energy source with variability in its outputmay be connected with the battery so that even the input voltage is changing, it act as storage and follow charging and discharging conditions. So that when the wind speed is high and power generation is more than demanded, it doesnot led to increase in load voltage but instead charge the battery storage. Similarly when speed is not upto level to maintain load voltage, battery storage will discharge, to supply deficit power to maintain load voltage atrated value. So in islanded mode of operation, for uninterruptable power supplymatching of the load will be required for regulationof the voltage.

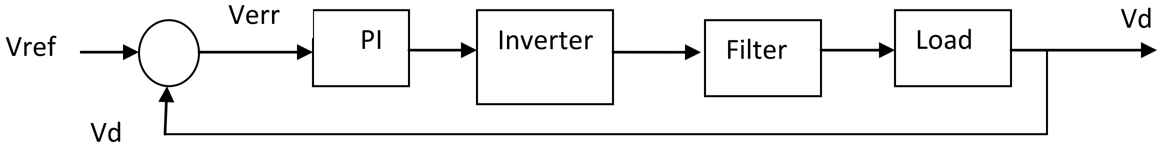


Fig5.2 Block Diagram for Islanding Mode

### 5.3.2 Grid Connected mode-

In a grid connected mode, the voltage across the grid remains constant. In this mode of operation, as there is change in load(depending on demand may be more or less demand of power) the power across it changes. As the voltage remain constant, the current changes according to the situation on the grid. If the demand is more downside towards the load end, the grid will supply the deficit power to the load and if demand is less power will be injected into the grid. The gradual changes in the voltage are tolerable by the grid, but frequent and sudden changes in the power due to intermittency may cause the problem in voltage regulation at point of common coupling (PCC). In this way in grid connected mode, current play the vital role by maintaining the DC bus voltage of the inverter constant.

Thus in grid connected mode of operation, the inverter conveniently operates in current-controlled mode when it is connected to the utility, and regulates the current injected into the micro grid at PCC. The utility is assumed to be relatively stiff and maintains the power intermittency across the load when the load is changing .

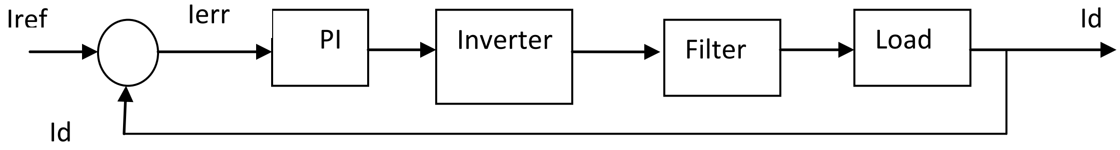


Fig5.3 Block Diagram for Grid Connected Mode

In grid connected mode, different renewable sources are connected with grid which is required to mitigate the intermittency of power. When renewable sources are intermittent it will affect the PCC voltage typically at the point which is distant from the distribution transformer, and if the PCC voltage fluctuates the current control would become difficult.The voltage does not affect much till the time the situation is reached where reverse current flows towards the grid side.

## 5.4 MODELIN MATLAB/SIMULINK

Simulation for islanded mode is done using simpower system toolbox in MATLAB/SIMULINK. Voltage generation at different voltage level for different wind speed are implemented using variable voltage source and this is cascaded with battery energy storage system as shown in Fig.5.4.

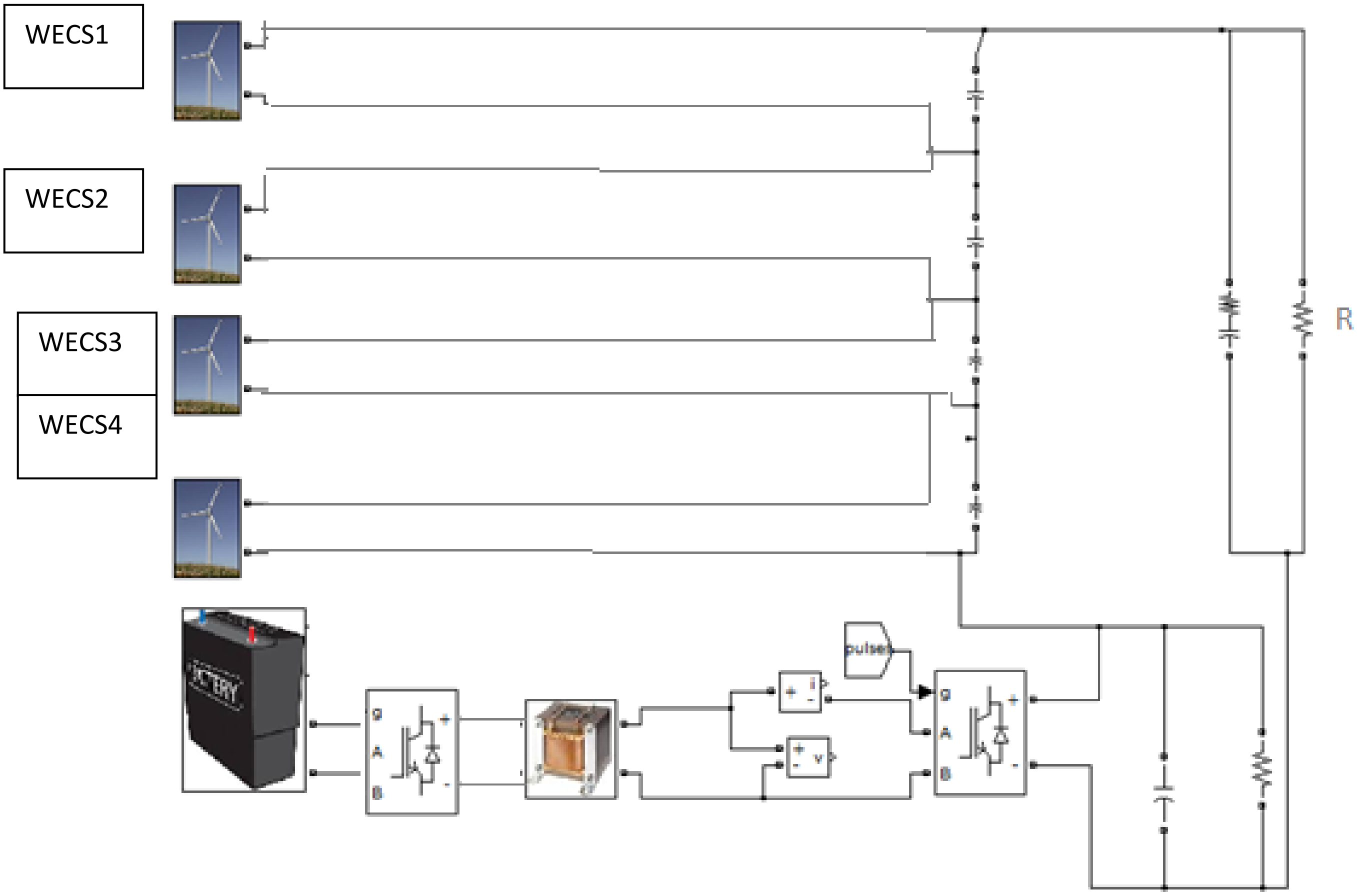


Fig5.4 ModellingSimulation of Islanded Mode

Different wind sources after achieving rectification at dc links, various wind powers are cascaded in conjunction with battery as storage energy is used for the voltage regulation at the DC bus. Since battery work as storage i.e. when the wind speed is sufficient to maintain the grid voltage the battery will get charge at that moment whereas when there will be dip in voltage due to wind sources battery supplies power to regulate voltage and to curb the intermittency of power.

In Simulink model, variable wind sources are connected to battery which is to maintain the continuous supply of power. Fig.5.5(a)-(g) shows the current, voltage and power of wind sources, battery, and DC output cross load.

### 5.4.1 Wind Energy Conversion System(WECS) Feeding to Isolated Perturbing to DC load with Intermittent Source Conditions

The performance of the proposed cascaded WECS with battery support is evaluated amidst intermittency in sources and perturbing loading conditions for isolated system feeding DC loads.

#### 5.4.1.1 Under Load Perturbation

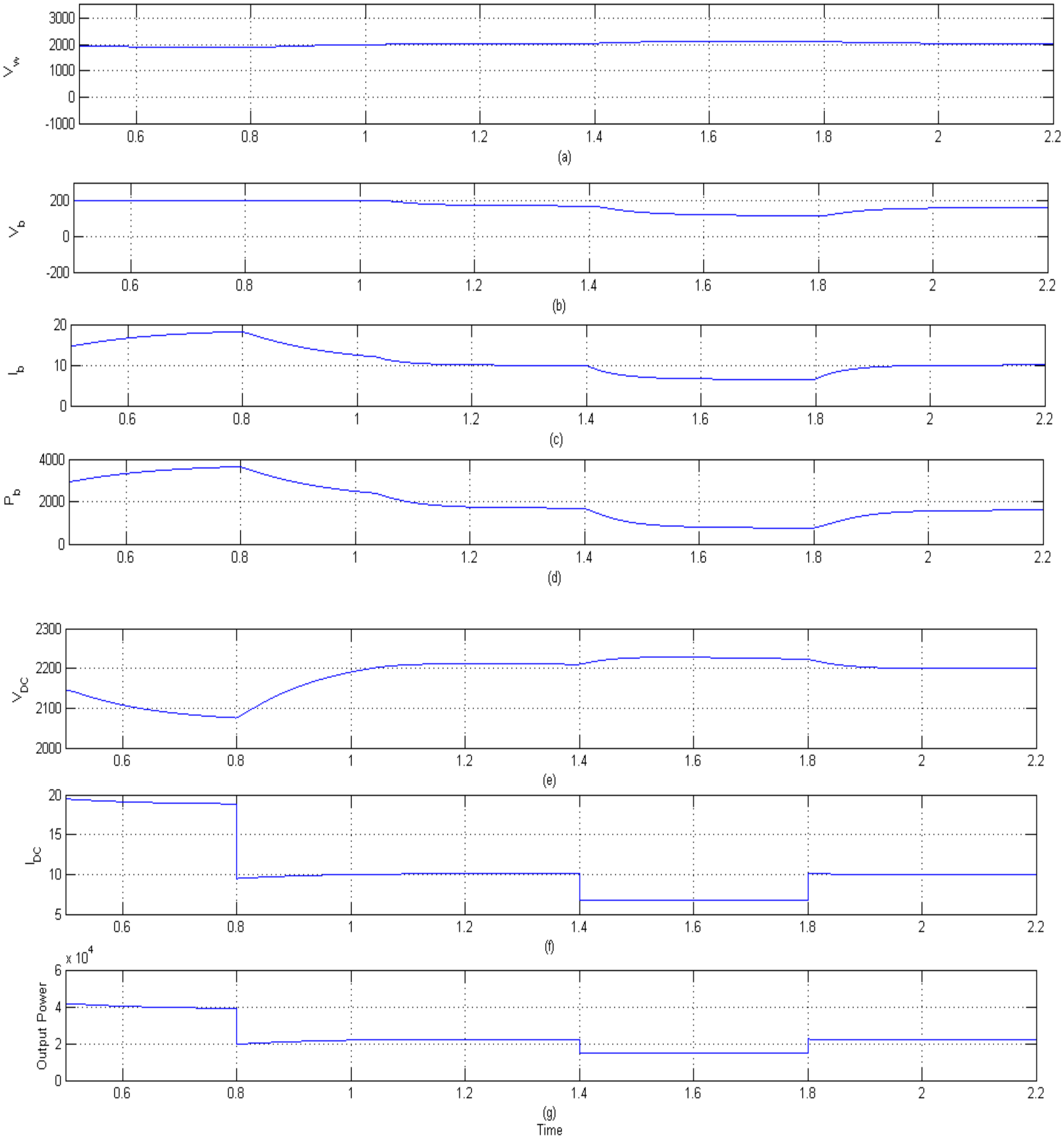


Fig 5.5Performance of WECS feeding to Isolated perturbed DC Load (a) Wind Voltage (b) Battery Volatge (c) Battery Current (d) Battery Power (e) DC Output Voltage (f) Load Current (g) Power Across load at different time range

In Fig 5.5 considering the droop characteristic, the wind voltage is kept constant and load is changed across it. Earlier from t =0sec to t=0.5sec it is at its rated load condition. From t=0.5sec to t= 0.8 sec WECS is heavily loaded so we can see from Fig5.5(f), the value of current is high. From t = 0.8sec to t = 1.4 sec WCES is at its rated condition i.e.the value of current is at its committed value. From t=1.4sec to t = 1.8sec, WECS is lightly loaded so the value of current falls and again form t=1.8sec to t=2.2sec it is at its rated condition. Even though there is perturbance in load condition, the voltage across load is balanced to 2.2kV with slight transient in it which settles very fast to its rated DC output voltage. Meanwhile the performance of battery is also checked i.e. when the load is heavily loaded and wind sources are not able to maintain voltage across load battery is getting discharged to regulate the voltage across DC bus. From Fig.5.5(b),its seen that, from t=1.4sec to t=1.8sec, when there is light load condition and wind sources are sufficient to regulate voltage, voltage across battery gets drop from 200V to 170V.

#### 5.4.1.2 With Intermittency in Source

In this case the load is kept constant and variation in WECS sources is done. The switching time is done at different time to show the intermittency in sources. From Fig5.6(a), t= 0.5sec to t=1sec, wind voltage as source is 2000V, rest of the voltage i.e.200V is maintained by battery as energy source which helps in regulating the voltage across DC bus. From t=1sec to t=1.5sec the source voltage drop down to 1980V, so the battery voltage increases in that period of time by 240V. Even though there is intermittency in sources voltage is still maintained to 2.2kV across DC bus. From Fig5.6(e)-(g),it can be concluded that when there is intermittency in source DC side voltage is swell and tries to obtain the steady state condition.

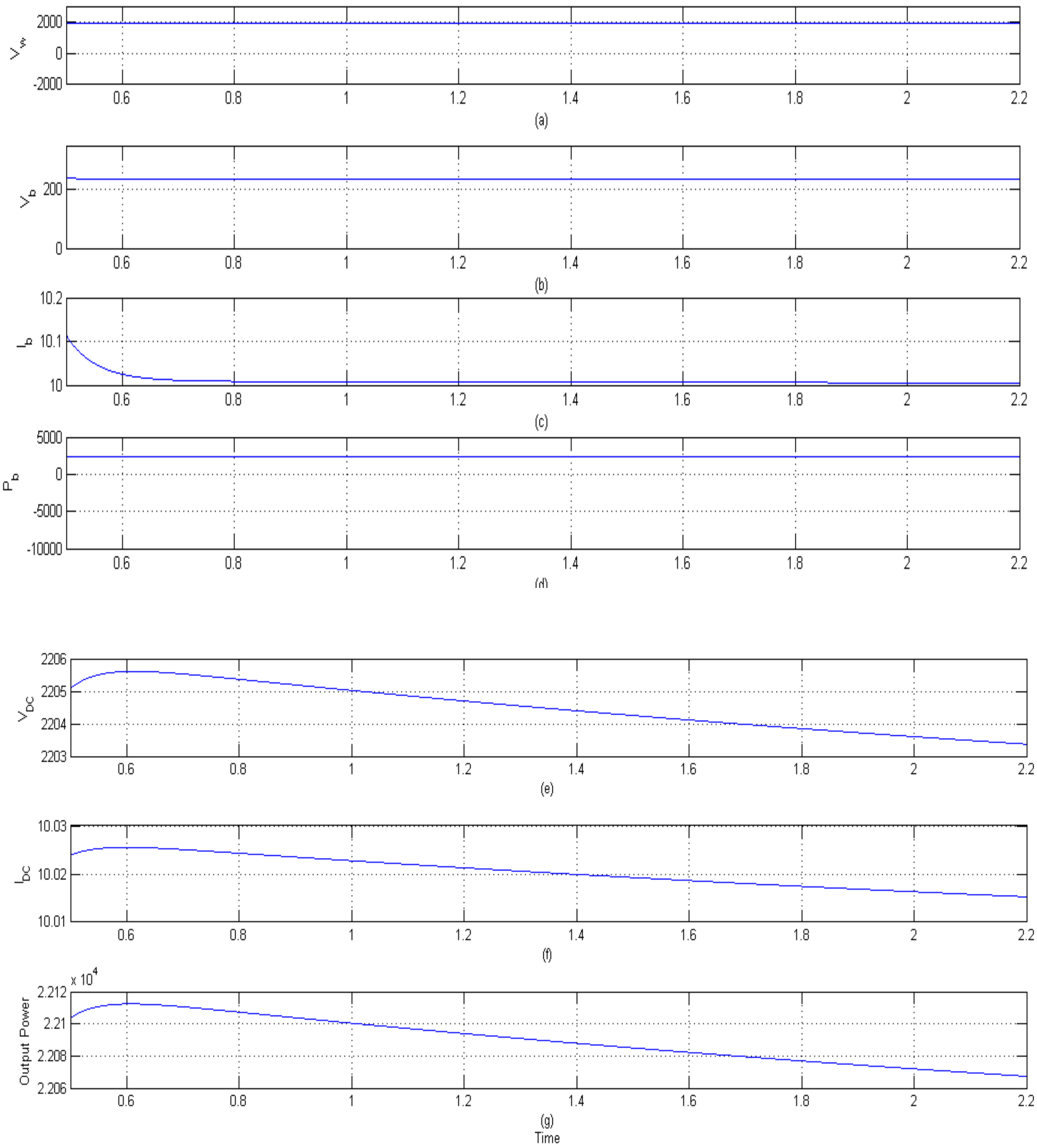


Fig 5.6Performance of WECS feeding to Isolated mode while intermittency in wind source (a) Wind Voltage (b) Battery Volatge (c) Battery Current (d) Battery Power (e) DC Output Voltage (f) Load Current (g) Power Across load at different time range

## 5.5 CONNECTION OF PROPOSED WECS WITH AC MICROGRID-

WECS integrated with battery energy source which is regulating the voltage across DC bus by 2.2kV is now connected to AC microgrid system to connect this regulated voltage to AC system so that it can be used widely.

.

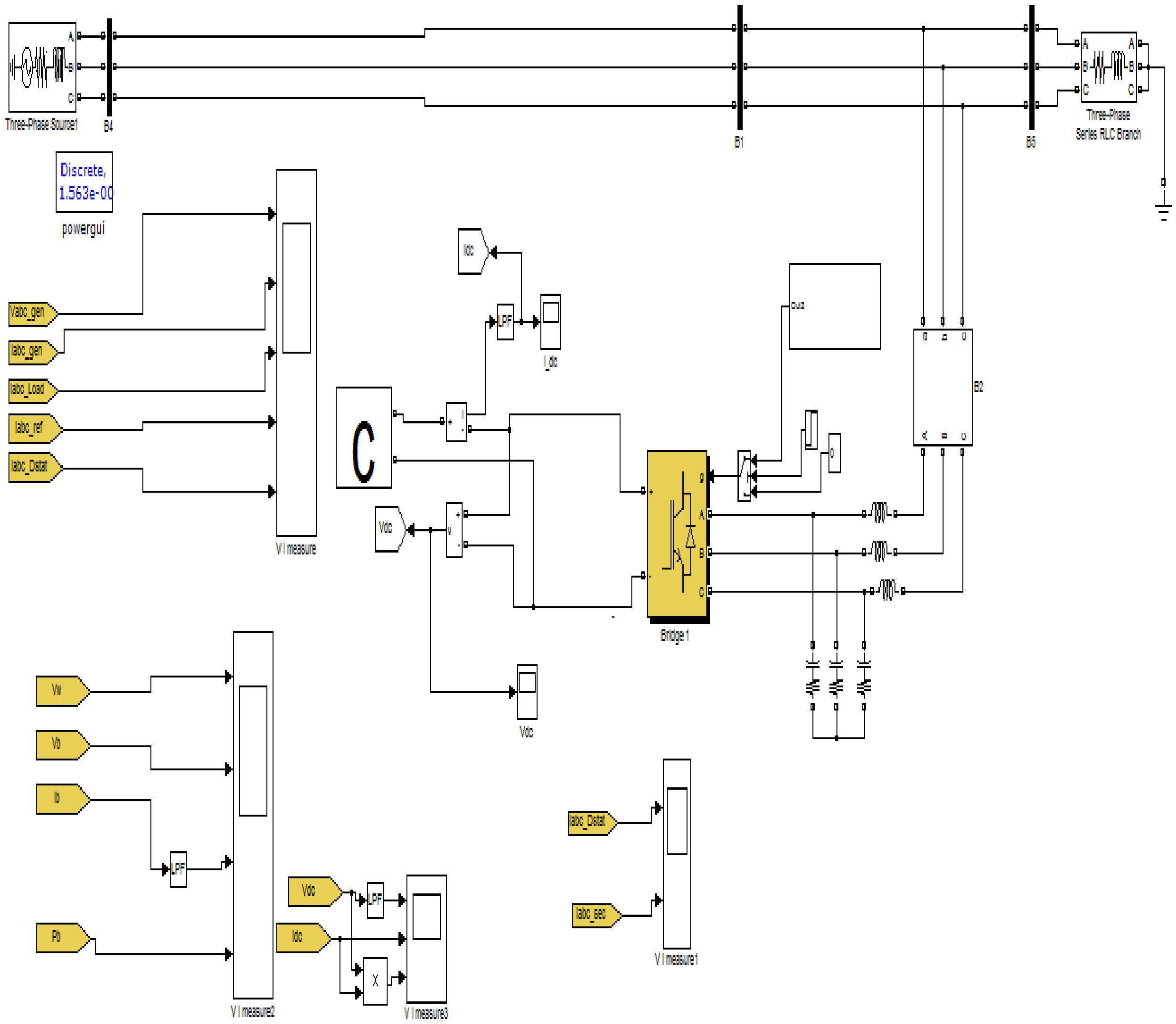


Fig.5.7 SIMULINK model of AC Microgrid

### 5.5.1 WithIntermittencyIn the Sources

While connecting AC microgrid to DC bus side, the intermittency in sources is produced to evaluate the performance across inverter and DC bus side.

From Fig.5.8(a), the intermittency in sources at different time is produced. From t=0sec to t=2sec, total voltage produced by wind energy sources is 2150V, voltage across battery tries to maintain the differential voltage at DC bus. From t =2se to t =4sec, voltage drop by 2120V, battery voltage will not suddenly increase to that point so it rises slowly and to maintain voltage at DC side. The slow rise in battery voltage will not create any transient in power system in such short duration of time.From t=4sec to t=6sec, the voltage produced by wind sources is 2090V, so the voltage across the battery rises by 110V to curb the intermittency at DC bus side.

As the effect of intermittency can be seen on DC bus voltage in Fig5.8(e), as different timings from t=0sec to t=6sec, DC voltage is changing and trying to achieve its regulated voltage of 2.2kV. As droop characteristics condition is followed so ±50V can be tolerated across the load side. The effect of intermittency can be seen on current and power across battery as well as DC bus side from Fig5.8(c)-(d) and Fig(f)-(g) respectively.

In Fig.5.9(a)-(e), the performance at AC side is evaluated, generated voltage at AC side is always constant even though the wind sources are intermittent in nature, the value across generating side is 1200V. The current across generated side($I_{abcgen}$), load side(IabcLoad) is same i.e.10A. The current at reference and STATCOM side is found to be same as of 5A.

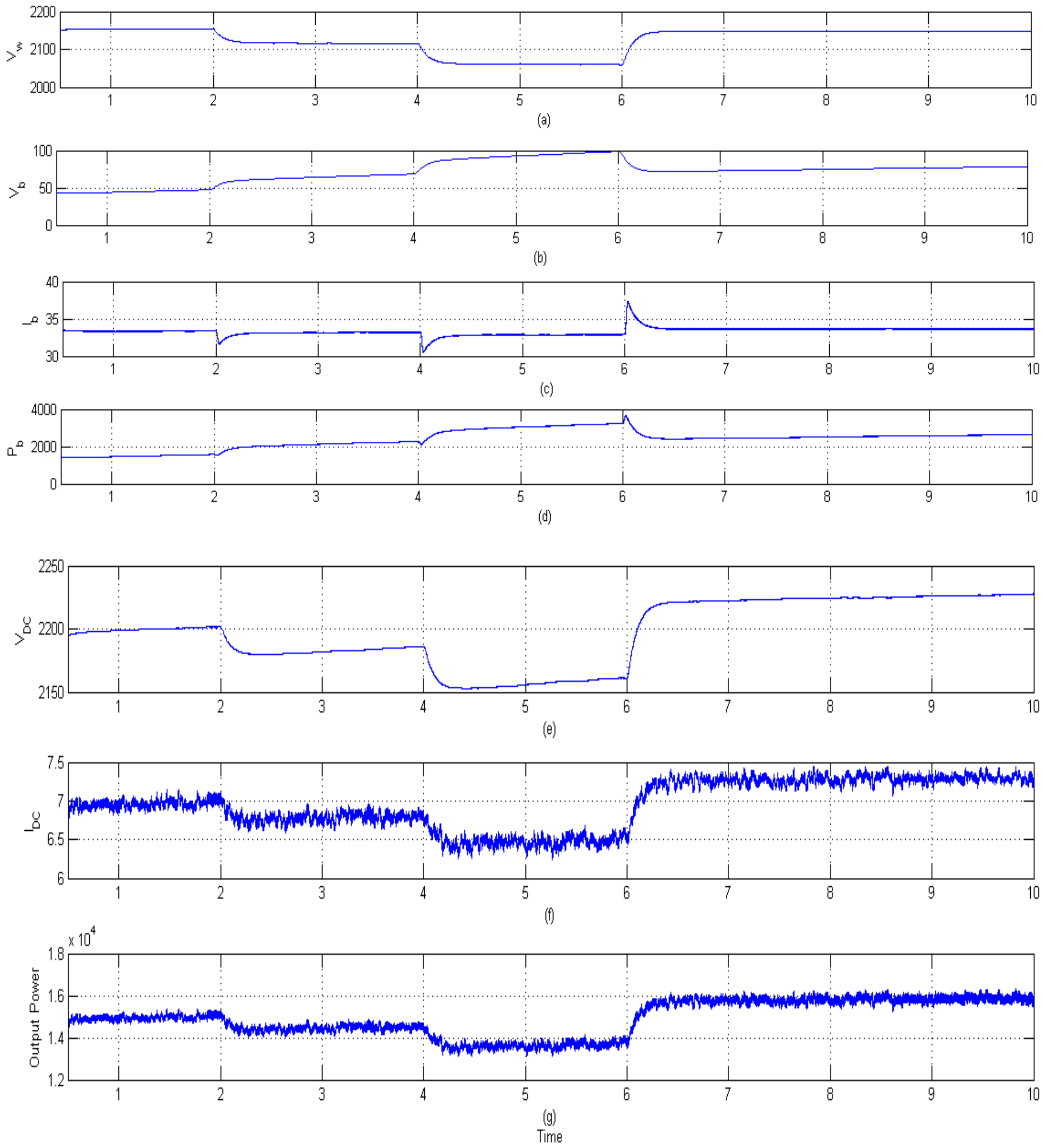


Fig 5.8Performance of WECS feeding to Isolated perturbed DC Load (a) Wind Voltage (b) Battery Volatge (c) Battery Current (d) Battery Power (e) DC Output Voltage (f) Load Current (g) Power Across load at different time range

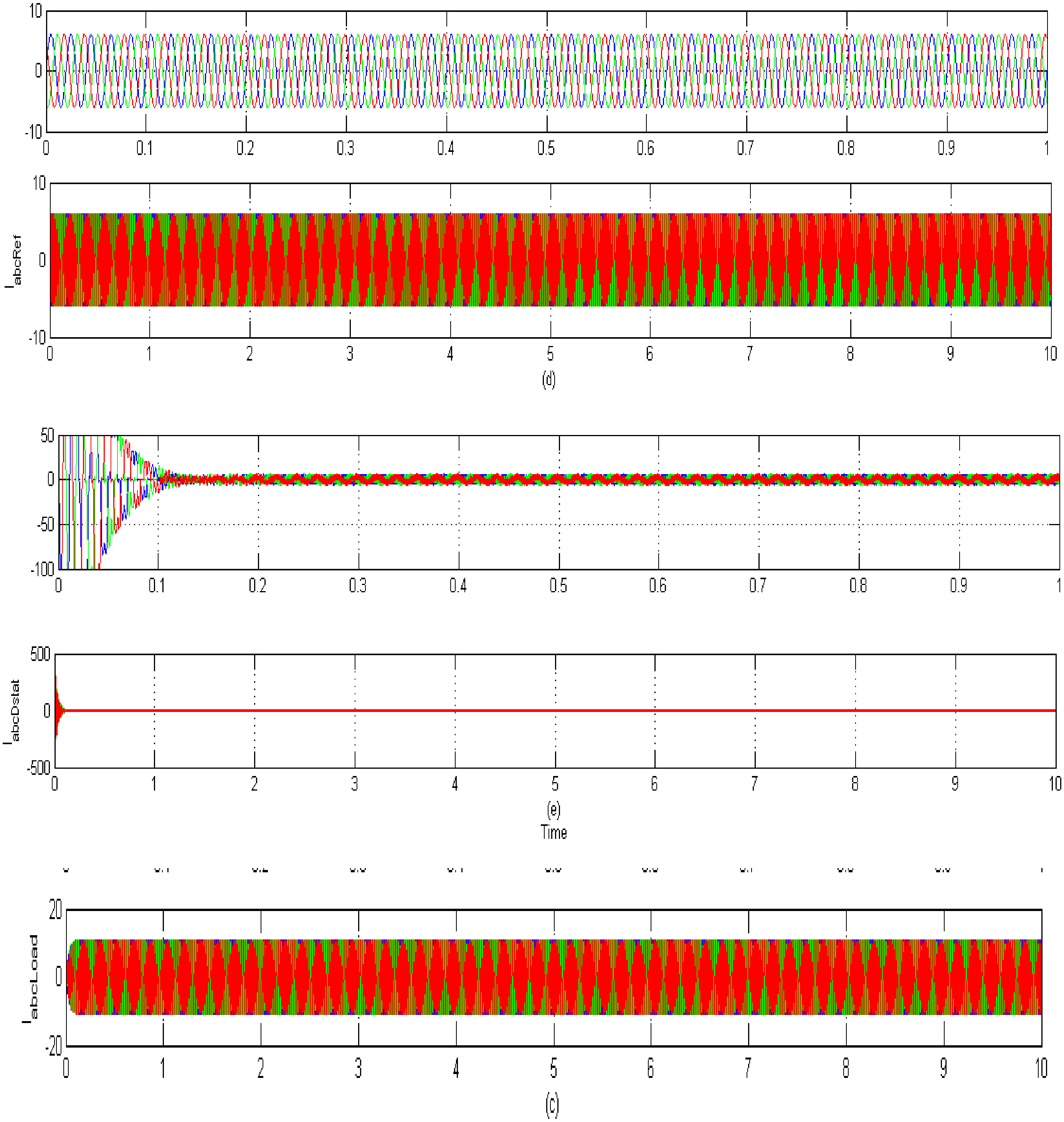


Fig.5.9 Performance of AC microgrid when source at DC side is intermittent (a)$V_{abcGen}$ (b) $I_{abcGen}$(c) $I_{abcLoad}$ (d) $I_{abcref}$ (e) $I_{abcDstat}$

### 5.5.2 Load Perturbation

In Fig 5.10 considering the droop characteristic, the wind voltage is kept constant and load is perturbed at different time. From t =0sec to t=1sec it is at its light load condition. From t=1sec to t= 2sec WECS is heavily loaded so we can see from Fig5.10.(f), . From t = 2sec to t = 10 sec WCES is at its rated condition.. Even though there is perturbance in load condition, the voltage across load is balanced to 2250kV(±50V in droop condition can be considered) with slight transient in it which settles very fast to its rated DC output voltage. Meanwhile the performance of battery is also checked i.e. when the load is heavily loaded and wind sources are not able to maintain voltage across load, battery is getting discharged to regulate the voltage across DC bus. From Fig.5.5(b),its seen that, from t=0sec to t=1sec, when there is light load condition and wind sources are sufficient to regulate voltage, voltage across battery is very less approximately 15V. After t=2sec it is continuously supplying 25V voltage.

The effect of load perturbance can be seen on voltage, current and power at DC bus side. When its heavily loaded at t=1sec to t=2sec, the committed current rises from 10a to 15A to maintain the voltage across the load side. At light and rated condition the current is at its committed value.

When DC bus is connected to AC microgrid, the effect of it can be seen on reference current and STATCOM current. As the committed current value rises from 10A to 15A, it means that at light and rated condition, power produced from DC side is transferred as such to inverter of AC system but in heavy load condition the voltage will decrease so more demand of cuurebt is needed which is given by the inverter side of AC system to DC bus so as to maintain voltage to 2.2kV. The simulated analysis is shown in Fig.5.11.

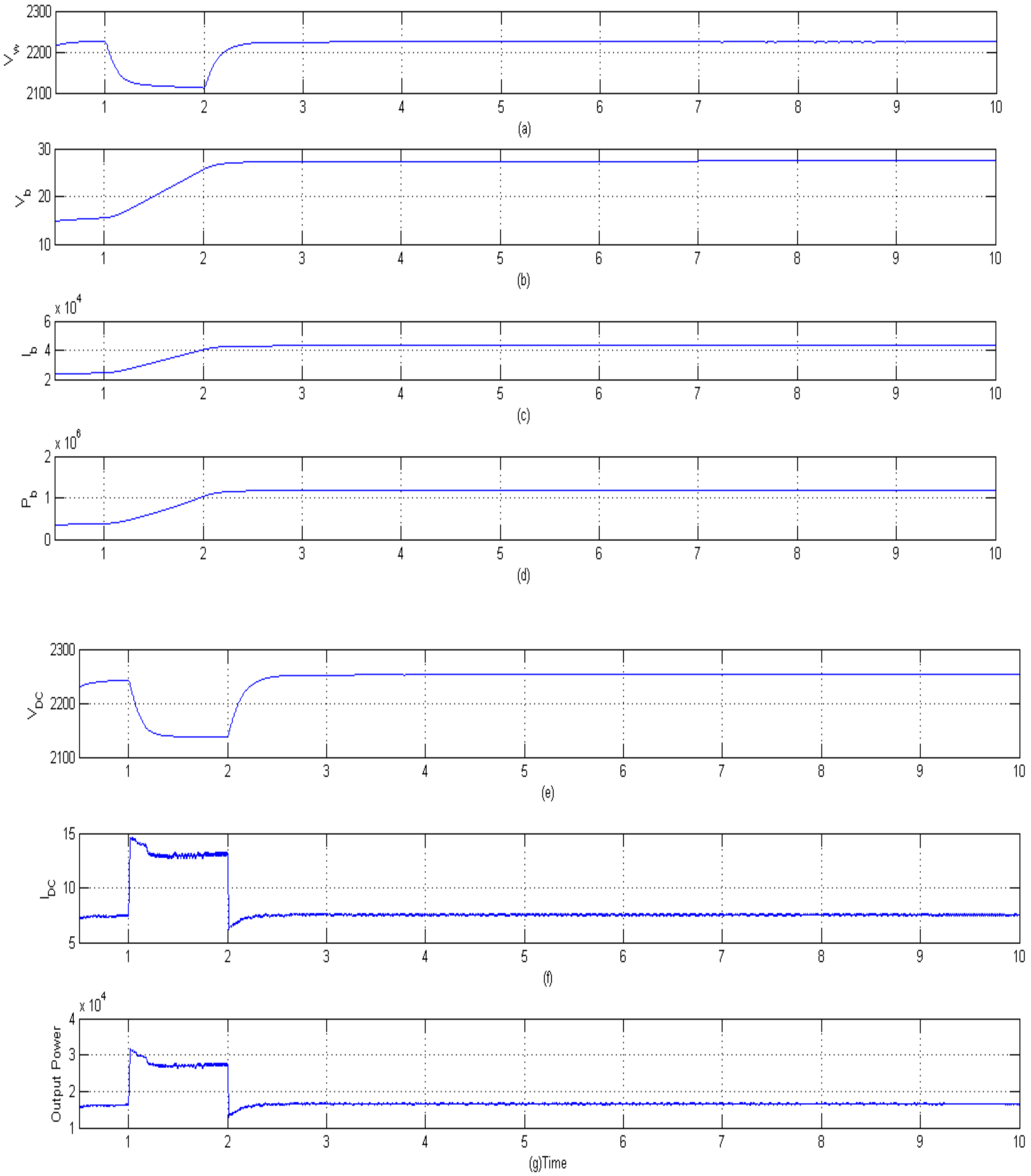


Fig 5.10Performance of WECS feeding to Isolated perturbed DC Load (a) Wind Voltage (b) Battery Volatge (c) Battery Current (d) Battery Power (e) DC Output Voltage (f) Load Current (g) Power Across load at different time range

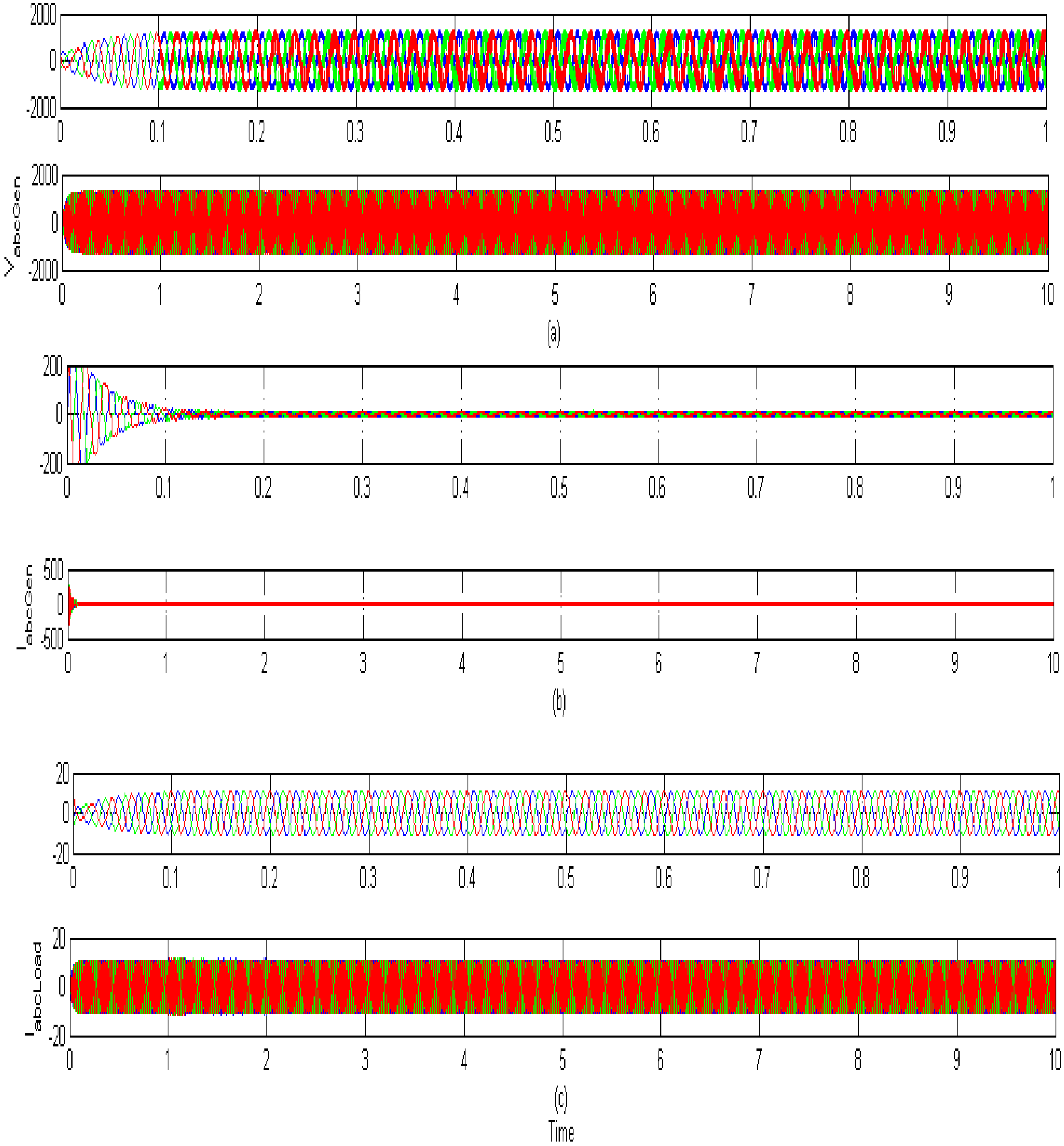


Fig.5.11 Performance of AC microgrid when load at DC side is iperturbed(a)$V_{abcGen}$ (b) $I_{abcGen}$(c) $I_{abcLoad}$

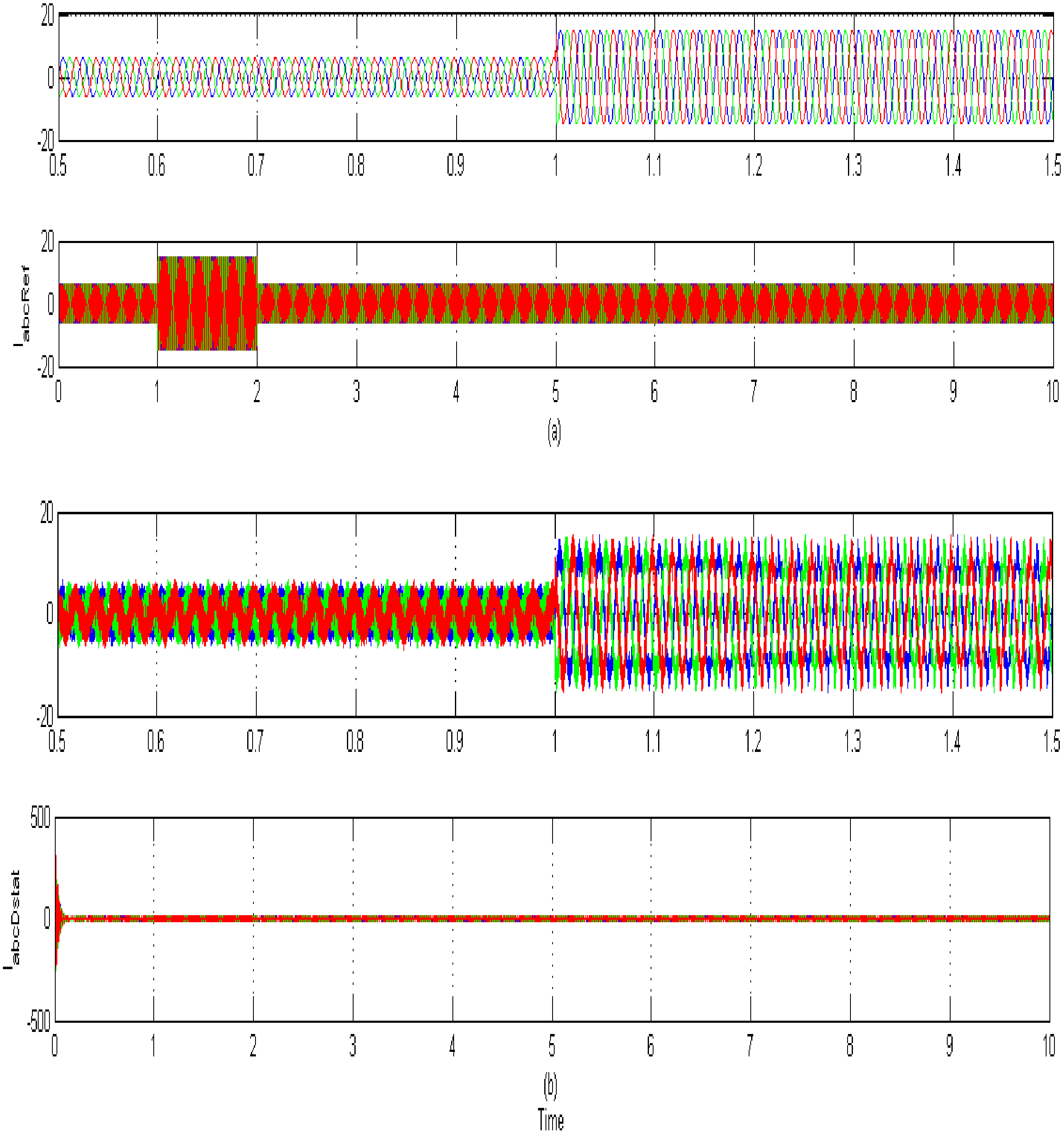


Fig.5.12 Performance of AC microgrid when load at DC side is iperturbed( (d) $I_{abcref}$ (e) $I_{abcDstat}$

### 5.6 Conclusion

A cascaded configuration of intermittent renewable sources with bidirectional battery storage system on a common DC bus has been successfully investigated. The developed control scheme operates both the DAB and the grid tied inverter successfully for power balanced operation. The presented results have successfully demonstrated that intermittency in sources and perturbance of power supplied to the load either on common DC bus or through the grid tied inverter to the microgrid is effectively mitigated through battery support. The control scheme is single butb effective and carry for digital implementation on a digital controller. The merit of the configuration is evident from the result since the voltage regulation is carried out by the differential voltage caused due to intermittent sources, and the power flow is also controlled by the grid tied inverter.

# CHAPTER 6

# CONCLUSION AND FUTURE SCOPE WORK

In amicrogridoperation and the integration of RES plays a vital role. The already week such microgrid is subjected to a great threat on the account of voltage regulation amidst intermittent RES. Often such cases are dealt curatively through either by a costly BESS or incorporation of DC microgrid interface with storage support. The intermittency is quite common with small or micro wind turbine, which has option for connectivity only with low voltage and low capacity microgrids, making it more and more vulnerable in terms of voltage regulation due to intermittency in power. Often such systems are encouraged for their connection to high capacity microgrids, where the effect of voltage regulation could be minimally felt. Thus, a converter with high voltage gain becomes essential before its integration to the grid.

The thesis has presented a new topology of cascaded connection of small/micro wind energy conversion system to enable its connectivity to a higher voltage level, and utilizing the small voltage stacked battery system to mitigate the intermittency in power. For the uninterruptable and regulated power supply, the presented topology works very effectively in conjunction with small capacity battery storage which works with differential voltage.

The amorphous core high frequency transformer has been designed and the design has been validated by its comprehensive testing through simulation by matching its performance corresponding to power output versus duty cycle, vis-a-vis the values obtained analytically. The modelling of microgrid, DAB, grid tied inverter, etcare done in MATLAB/SIMULINK environment. The models are developed for converters to maintain stable system under various loading conditions. The coordinated control facilitates the power exchange between DC and AC gridor DC-DC grid. For DC-DC power exchange between battery and DC grid DAB configuration has been used for working at high frequency, thus enabling higher efficiencies with smaller size. The performance of the proposed system is evaluated through simulation results. The results have clearly demonstrated that an effective control of power over bi-directional power flow has been obtained using proposed scheme.

The proposed system has been evaluated for dynamic response amidst intermittency in the sources and perturbations in the connected load, and/or injection of power into the microgrid. The simulation result shows the voltage is regulated even for all the cases of power intermittency and mismatch to provide continuous power flow with regulated voltage on the DC bus.

## FUTURE WORK

1. To develop the hardware prototype of the proposed system and testing it as per the standards.
2. The develop faster and intelligent algorithm for DC bus control both through the DAB and inverter side.
3. To develop hardware prototype evaluate the (i) Wind and (ii) PV-Wind hybrid systems in an isolated and grid connected modes, to solve the issues such as control and grid integration for the microgrid and energy storage schemes.
4. Power supply and load demand matching is an essentialcondition for the operation of power system, especially in microgrid.
5. Low Voltage Ride through capability, power quality and stability can be considered for future work. Hence inclusion of these parameters provides gray areas to be looked into for further research.