Control of Renewable Energy Hybrid Micro Grid with Battery Energy Storage

A Project Report
Submitted in partial fulfilment of requirements
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In

Electrical Engineering

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Ashwini Chidambareshwar

CERTIFICATE

This is to certify that the project report entitled **“**Control of Renewable Energy Hybrid Micro Grid with Battery Energy Storage”, submitted by **Miss. Ashwini Chidambareshwar** to the **Indian Institute of Technology, Madras**, in partial fulfilment of the requirements for the award of the degree of **Bachelor of Technology** in **Electrical Engineering**, and is a bonafide record of work carried by her under my supervision.

Date: 4/5/2017

Place: Chennai

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ABSTRACT

Abstract—A micro-grid is a collection of loads and micro sources that operate as a single controllable system to provide both heat and power to a small area. A hybrid-grid consists of both AC and DC grid. AC power sources and loads are connected to the AC grid whereas DC power sources and loads are connected to the DC grid and both the grids are connected together by a bidirectional converter. In this, a hybrid micro-grid consisting a wind turbine and fuel cell stack is proposed to reduce the process of multiple AC-DC-AC and DC-AC-DC conversions which are commonly seen in an individual AC grid or DC grid. The proposed hybrid grid is operating in grid connected mode. The various control mechanisms are implemented for the power electronic converters for smooth power exchange between AC and DC grids and for stable operation of the proposed hybrid micro-grid under various resource conditions. A small hybrid grid is considered and simulated using the MATLAB/ SIMULINK environment.

Keywords—Hybrid grid; Fuel cell; Wind turbine generator; Grid connected mode; Bidirectional converter.

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CHAPTER 1
INTRODUCTION

For the past hundred years, the electrical power system is dominated mainly by the three phase AC power system due to various reasons such as efficient transformation of AC power at various voltage levels, for long distance transmission and for inherent characteristic from fossil fuel driven rotating machines for electric power generation. The basic structure of the present day power system is the integration of generation, transmission and distribution system. In conventional power plants, electricity is produced from fossil fuels such as coal, oil and natural gas and these generating stations will be located far away from the load centers due to safety concern and due to the availability of energy sources. Power generated from these stations are then transmitted over long distance at high voltage levels to the load centers and then delivered to the customer load points with the help of sub-transmission networks and distribution networks. This leads to the higher transmission losses and also the complexity of the system increases. Also, the environmental effects caused by these fossil fuels are high due to their high carbon emission. As a result, renewable energy resources such as wind, tidal, solar, small hydropower and biomass are becoming the best option for generating electric power due to their low environmental effects. The current power system is undergoing considerable amount of changes, because more renewable energy based power conversion systems are connected to the low voltage distribution systems as distributed generators due to their environment friendliness and reliability. On the other hand, dc loads such as LED lights, refrigerators and electric vehicles are increasing to save electric energy and to reduce emissions.

1.1 Present scenario

In the present system, these loads are supplied by means of AC power sources along with the help of power electronics converters. This further increases the cost of the system and appliances as it requires additional converters. When power can be supplied by renewable energy based distributed generators, there is no need for high voltage transmission and also transmission losses can be reduced. AC microgrids have been developed to enable the connection of renewable energy based power generating sources to the present AC system.

As stated earlier, due to increasing amount of DC loads in residential, industrial and commercial buildings the power system loads are becoming DC dominated. In many industries DC power is required for the speed control purpose. If these loads are supplied by means of AC grid, then it requires embedded AC/DC converters and DC/DC converters to supply different DC voltages. As a result, DC grids are resurging due to the various advantages of renewable energy sources and their inherent advantage of supplying DC loads .The multiple reverse conversions associated with an individual ac or dc grid leads to additional costs and losses and hence reduces the overall efficiency of the system.

1.2 Motivation

Microgrid became one of the key spot in research on distributed energy systems. Since the definition of the microgrid is paradigm of the first time, investigation in this area is growing continuously and there are numerous research projects in this moment all over the world. The increased infiltration of nonlinear loads and power electronic interfaced distribution generation system creates power quality issues in the distributed power system. In this paper, a comprehensive survey on microgrid to improve the power quality parameters is taken as the main objective. Furthermore, the detailed investigations are explored in this paper for the enhancement of power quality issues with the help of an optimization technique, filters, controllers, FACTS devices, compensators, and battery storag**e. Microgrid** may be defined as an agglomeration of distributed generation (DG) units usually linked through power electronic based devices (voltage source inverter) to the utility grid. DG units can be built with nonconventional energy sources such as fuel cells, wind turbines, hydroelectric power, and solar energy. Microgrid can function either tied to the grid or isolated from the grid. The impact of power quality hitches is concerning while linking microgrid to the main grid and it could become a foremost area to investigate. If unbalance in voltage is alarming, the solid state circuit breaker (CB), connected between the microgrid and utility grid, will open to isolate the microgrid. When voltage unbalance is not so intense, CB remains closed, resulting in sustained unbalance voltage at the point of common coupling (PCC). Generally power quality problems are not new in power system, but rectification methodology has increased in recent years

1.3 Conventional AC source and DC source

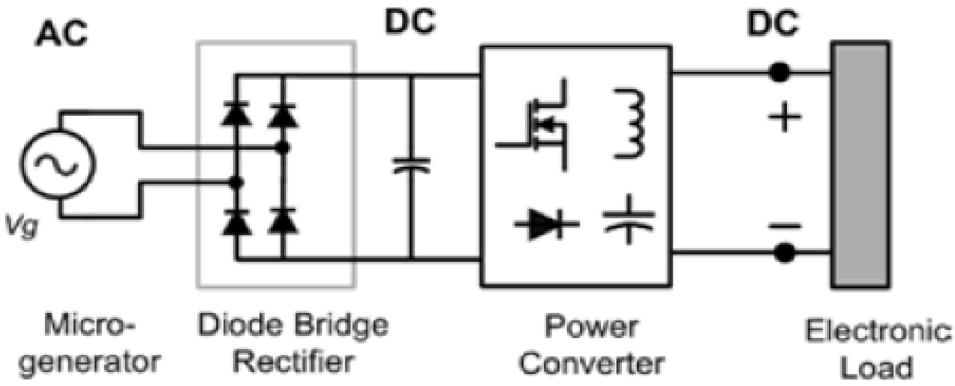


Figure 1.1 Conventional AC source

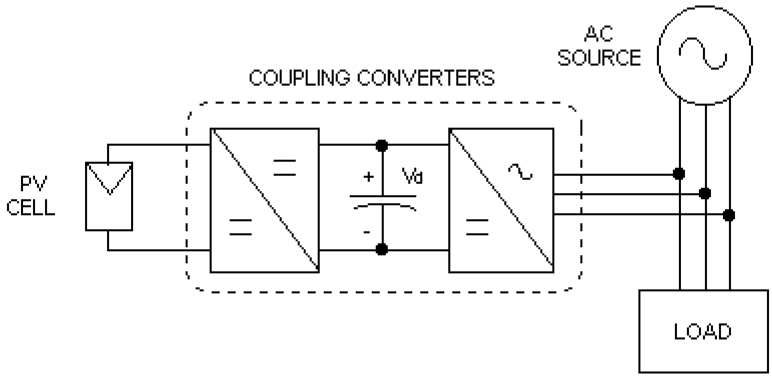


Figure 1.2 Conventional DC source

In conventional AC power systems AC voltage source is converted into DC power using an AC/DC inverter to supply DC loads. AC/DC/AC converters are also used in industrial drives to control motor speed. Because of the environmental issues associated with conventional power plant renewable resources are connected as distributed generators or ac microgrids. Also more and more DC loads like light emitting diode lights and electric vehicles are connected to AC power systems to save energy and reduce carbon dioxide (CO)emission. Long distance high voltage transmission is no longer necessary when power can be supplied by local renewable power sources. AC sources in a DC grid have to be converted into DC and AC loads connected into DC grid using DC/AC inverters. DC systems use power electronic based converters to convert AC sources to DC and distribute the power using DC lines. DC distribution becomes attractive for an industrial park with heavy motor controlled loads and sensitive electronic loads. The fast response capability of these power electronic converters help in providing highly reliable power supply and also facilitate effective filtering against disturbances. The employment of power electronic based converters help to suppress two main challenges associated with DC systems as reliable conversion from AC/DC/AC and interruption of DC current under normal as well as fault condition . Over a conventional AC grid system, DC grid has the advantage that power supply connected with the DC grid can be operated cooperatively because DC load voltage are controlled. The DC grid system operates in stand-alone mode in the case of the abnormal or fault situations of AC utility line, in which the generated power is supplied to the loads connected with the DC grid. Changes in the generated power and the load consumed power 8 can be compensated as a lump of power in the DC gird. The system cost and loss reduce because of the requirement of only one AC grid connected inverter .Therefore the efficiency is reduced due to multistage conversions in an AC or a DC grid.

1.4 Objective

The main objective of this thesis is the design of a hybrid microgrid which will reduce the losses and the process of multiple reverse conversions associated with individual AC and DC grid .The Hybrid Micro Grid consists of the following:

- AC and DC sub-grid
- Fuel Cell stack
- Wind turbine generator
- Bi-directional Converter

The above objectives will also result in

1. To maintain the constant voltage even when the load is applied
2. To use up the surplus power from the neighbourhood grid
3. To reduce the complexity and higher transmission losses

Scope of work:

The scope of the work narrows down to the PQ control scheme of the main converter, the output of the both AC and DC sources have been taken according to the required voltage, no detailed structure of modelling is calculated .The main focus is on the control scheme.

1.5 Technical challenges

Technical challenges in microgrid Protection system is one of the major challenges for microgrid which must react to both main grid and microgrid faults. The protection system should cut off the microgrid from the main grid as rapidly as necessary to protect the microgrid loads for the first case and for the second case the protection system should isolate the smallest part of the microgrid when clears the fault. A segmentation of microgrid, i.e. a design of multiple islands or sub-microgrids must be supported by microsource and load controllers. In these conditions problems related to selectivity (false, unnecessary tripping) and sensitivity (undetected faults or delayed tripping) of protection system may arise.

1.6 Problem Statement

To reduce the process of multiple DC/AC/DC or AC/DC/AC conversions in an individual AC or DC grid, hybrid microgrid Model is proposed, which also helps in reducing the energy loss due to multiple conversion with Renewable sources which has low environmental effects .

CHAPTER 2

HYBRID MICRO GRID

2.1 Introduction

A hybrid AC/DC microgrid helps to minimize these multiple reverse conversion problem which normally associated with individual AC grids or DC grids. In this hybrid system AC loads are connected to the AC grid and DC loads are connected to the DC grid and the AC and DC grids are connected through a bidirectional converter. The proposed architecture, operation and control of the hybrid microgrid are more complicated than those of individual DC grid or AC grid. The various control mechanisms for controlling the converters and to maintain the stable system operation in grid connected mode is explained in the following sections.

In order to analyse the operation of microgrid system both the modelling and controlling of the system are important issues. Hence the control and modelling are also the part of this thesis work. As a part of the thesis work the overall system is simulated using MATLAB environment. In simulation work the system is modelled using different state equations.

2.2 Block Diagram Of The Model

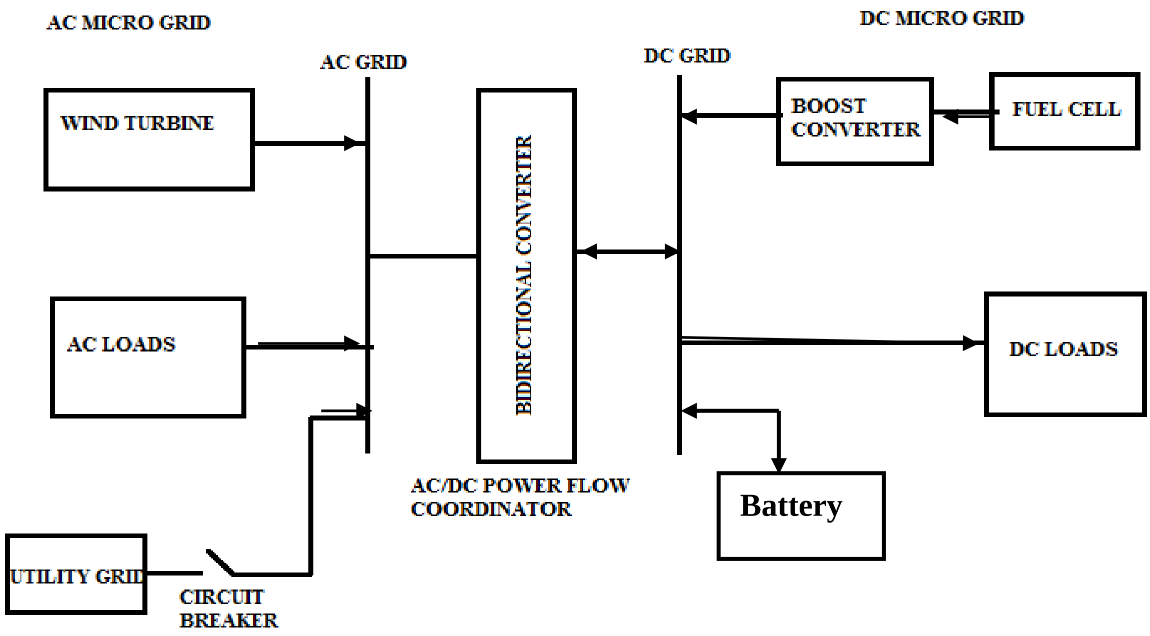


Figure 2.1 Hybrid AC/DC Micro Grid

2.3 Typical Hybrid AC/DC Micro Grid

Figure 2.1 shows the typical structure of a hybrid AC/DC microgrid. It consists of AC grid and DC grid and they are interconnected with the help of three phase bidirectional AC/DC converter (main converter) and a transformer. The three phase AC network of the hybrid grid is connected to the utility grid through a transformer and a circuit breaker. AC power sources such as tidal power plant, small diesel generator and wind turbine generator (WTG) are connected to the AC grid. AC energy storage devices such as flywheels are connected to the AC grid through converters. All types of AC loads can be connected to the AC network whereas DC power sources such as solar panels, fuel cell stacks are connected on the DC grid through DC/DC power converters. DC loads and energy storage devices such as batteries and super capacitors and electric vehicles can be connected to the DC grid through DC/DC converters.

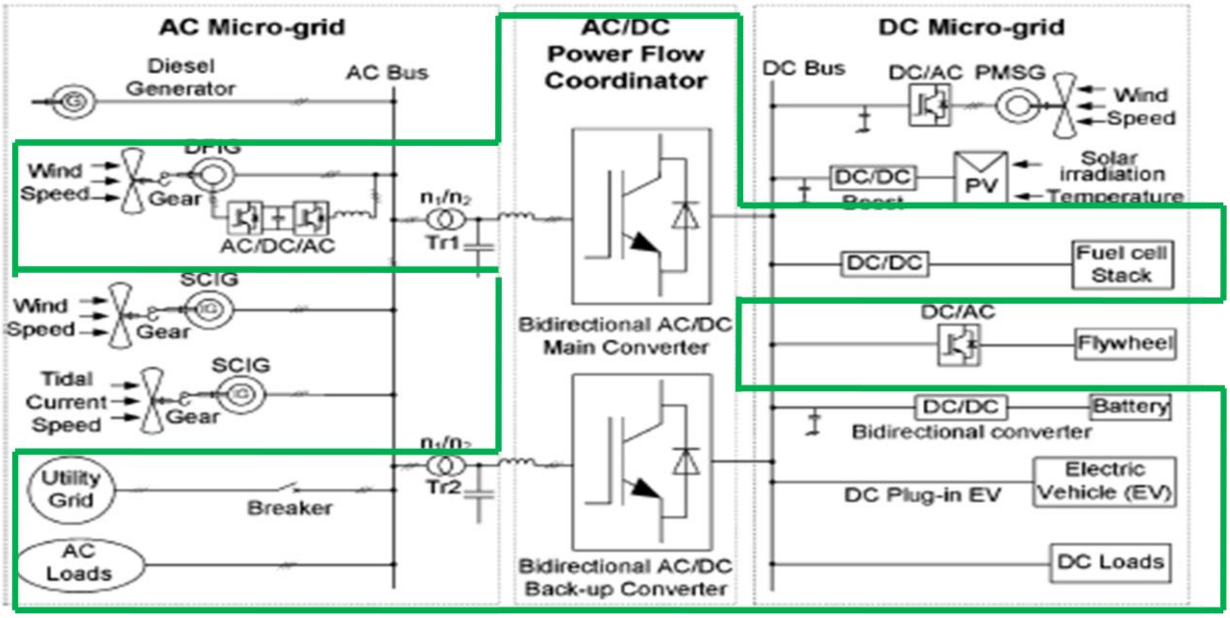


Figure 2.2 A typical Hybrid AC/DC Micro Grid

In an AC grid embedded AC/DC and DC/DC converters are required for various loads at different dc levels.AC/DC/AC converters are commonly used as drives, which is used in Doubly Fed Induction Generator (DFIG) for varying the magnitude and frequency.AC sources are converted to DC before connecting to DC grid and then AC/DC inverters are required for conventional AC loads if one has got only DC grid option.

2.4 Micro Grid

Micro grid is an integration of collection of loads and distributed micro sources to power a small area.

We are going to look upon the major 2 modes of operation in Micro grid

Two modes of Micro Grid

- Autonomous mode
- Grid Tied mode

2.4.1 Grid Tied Mode

Grid Tied mode function when the Hybrid Micro grid is connected to the grid.

In this mode the main converter is to provide stable DC bus voltage, and required reactive power to exchange power between AC and DC buses. Maximum power can be obtained by controlling the boost converter and wind turbine generators. When output power of DC sources is greater than DC loads the converter acts as inverter and in this situation power flows from DC to AC side. When generation of total power is less than the total load at DC side, the converter injects power from AC to DC side. The converter helps to inject power to the utility grid in case the total power generation is greater than the total load in the hybrid grid. Otherwise hybrid receives power from the utility grid. The role of battery converter is not important in system operation as power is balanced by utility grid.

2.4.2 Autonomous

It is the state when the grid is disconnected from the load and still the system functions.

The battery plays very important role for both power balance and voltage stability. DC bus voltage is maintained stable by battery converter or boost converter. The main converter is controlled to provide stable and high quality AC bus voltage.

2.4.3 System Configuration

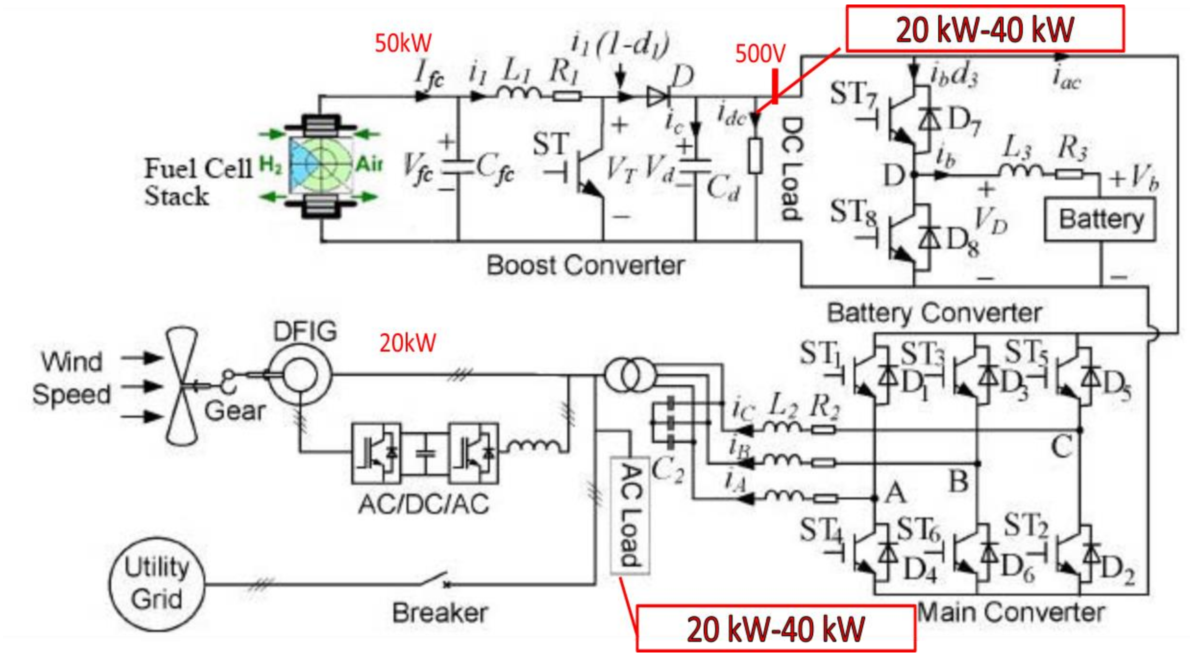


Figure 2.3 Compact Representation of the Model

The proposed system is modelled using Matlab/Simulink environment to simulate the system operation and control. In this system, 50 kW fuel cells stacks are used as a DC power source and it is connected to the DC grid through a DC/DC boost converter. The capacitor is used to reduce the ripples if the fuel cell output voltage. A 20 kW Doubly Fed Induction Generator (DFIG) WTG system is taken as AC power source and it is connected to the AC grid through a back to back AC/DC/AC converter. A battery is connected to the DC network as an energy storage device through a bidirectional DC/DC converter. AC loads and DC loads are connected correspondingly to AC and DC grids. In the following sections we are going to study upon each sources and components present in this Micro Grid.

2.4.4 Buck/Boost converter of the Main Battery Converter

In this section we going to explain the charging/discharging of the main battery converter.

Table 2.1 Charging of Battery

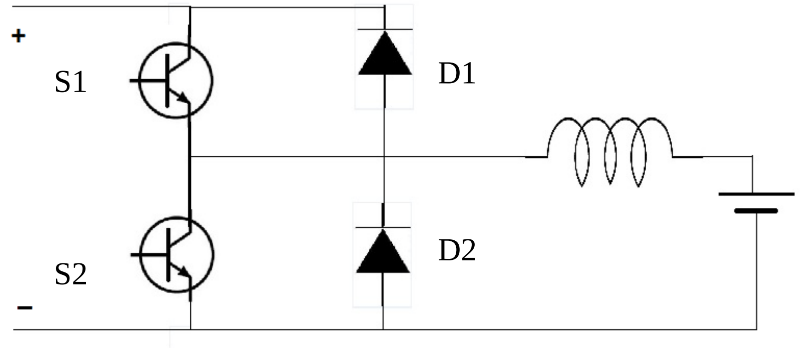
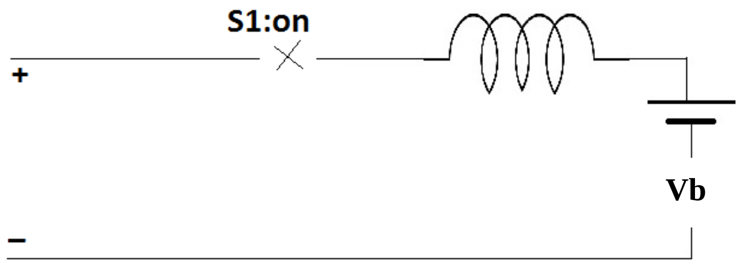
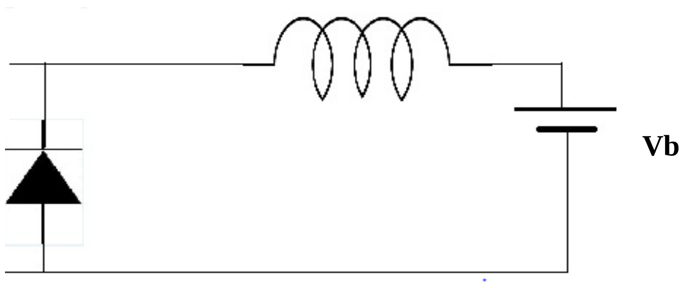
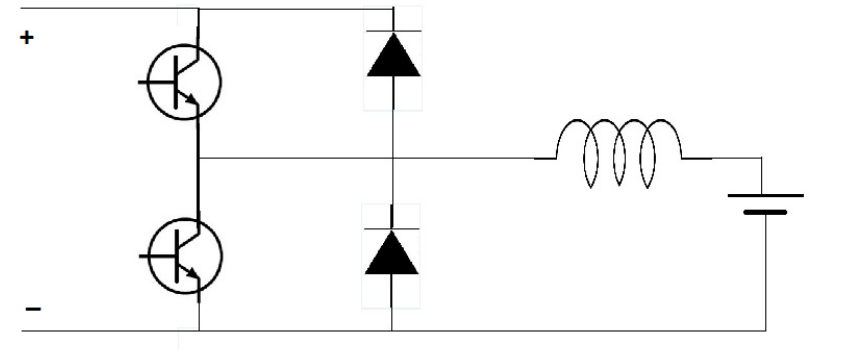
S1	S2	Diagram/charging	Formula
			
ON D	OFF		$\frac{Ldi}{dt} = \frac{Vs-Vb}{L}$
OFF (1-D)	OFF		$\frac{di(dis)}{dt}=\frac{Vb}{L}$
Combining Both we get;		$(\frac{Vs-Vb}{L})DTs-\frac{Vb}{L}$(L-D)Ts=0 Vb=DVs	During charging the converter operates as Buck converter

Table 2.2 Discharging of Battery

<table>
<tr><th>S1</th><th>S2</th><th>Diagram/Discharging</th><th>Formula</th></tr>
<tr><td></td><td></td><td>
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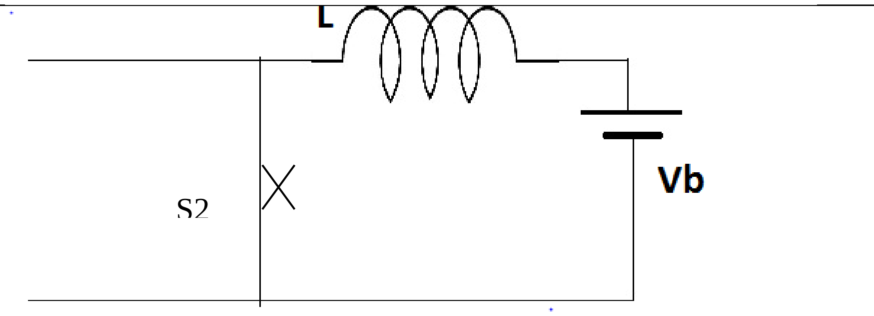
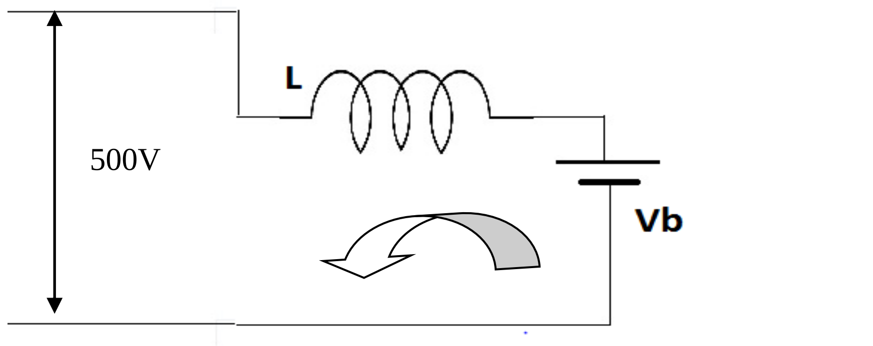
<tr><td>OFF</td><td>ON</td><td>
</td><td>$\frac{di(dis)}{dt}=\frac{Vb}{L}$</td></tr>
<tr><td>OFF</td><td>OFF</td><td>
</td><td>$\frac{Vb-Vs}{L}=\frac{di}{dt}$</td></tr>
<tr><td></td><td></td><td>Vb=$\frac{Vs}{1-D}$ where D<1</td><td>During discharging mode acts as Boost converter</td></tr>
</table>

2.5 Summary

Chapter 2 describes about the outline of the Hybrid Model with overall block diagram with the considered sources and the different modes of Micro Grid operation ,also the charging and discharging characteristics of the Main Battery converter where Buck performs charging and Boost performs discharging .

Chapter 3

FUEL CELL

In this Chapter we are going to discuss about the modelling of the fuel cell stack which is the DC source in the DC Micro grid and to obtain the voltage and Power of the fuel cell.

3.1 The Fuel cell system

A fuel cell is an electrochemical device that converts the chemical energy of the fuel (hydrogen) into electrical energy. It is centered on a chemical reaction between the fuel and the oxidant (generally oxygen) to produce electricity where water and heat are by products. This conversion of the fuel into energy takes place without combustion. Generally, efficiency of the fuel cells ranges from 40-60% and can be improved to 80-90% in cogeneration applications. The waste heat produced by the lower temperature cells is undesirable since it cannot be used for any application and thus limits the efficiency of the system. The higher temperature fuel cells have higher efficiency since the heat produced can be used for heating purposes.

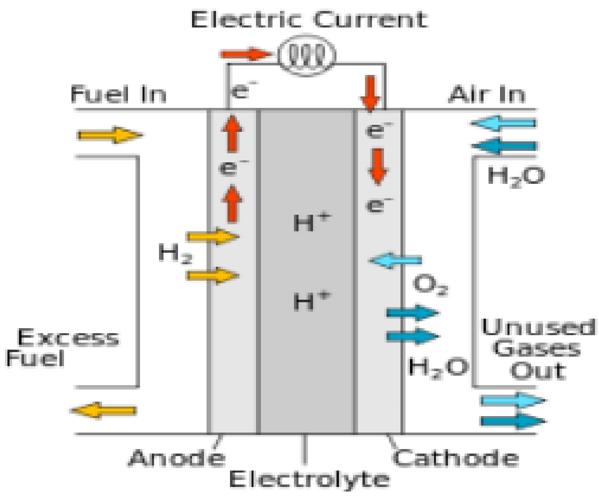


Figure 3.1 Schematic of an individual fuel cell

3.1.1 Operating Principle.

The structure and the functioning of a fuel cell is similar to that of a battery except that the fuel can be continuously fed into the cell. The cell consists of two electrodes, anode (negative electrode) and cathode (positive electrode) separated by an electrolyte. Fuel is fed into the anode where electrochemical oxidation takes place and the oxidant is fed into the cathode where electrochemical reduction takes place to produce electric current and water is the primary product of the cell reaction. Figure 3.1 shows the flows of reactants in a simplified fuel cell. Fig 3.1 Schematic of an individual fuel cell. The hydrogen which enters the anode side is broken into hydrogen ions and electrons with the help of the catalyst. In case of lower temperature cells like the PEMFC and the PAFC, the hydrogen ions move through the electrolyte and the electrons flow through the external circuit. The oxygen which enters through the cathode side combines with these hydrogen ions and electrons to form water as shown in the above figure. As this water is removed, more ions are passed through the electrolyte to continue the reaction which results in further power production. In the SOFC, it is not the hydrogen ions which move through the electrolyte, but the oxygen radicals. In case of MCFC, carbon dioxide combines with the oxygen and electrons to form carbonate ions, which are transmitted through the electrolyte. Fuel cells are classified based on the type of electrolyte used. A solid polymer membrane electrolyte is fitted between two platinum catalyzed porous electrodes for PEM fuel cells. MCFCs have a liquid lithium-potassium or lithium-sodium based electrolyte while SOFCs employ a solid yittra-stablized zirconia ceramic electrolyte. The catalyst used for SOFC and MCFC are perovsikites and nickel, respectively, the cost of which is comparatively lower than that used for PEMFC. The typical anode and cathode reactions for a hydrogen fuel cell are given by Equations (1) and (2) respectively. The number of cells depends on the desired power

output.

$$H_2 \longrightarrow 2\,H^+ + 2e^- \quad (1)$$

$$\frac{1}{2}O_2 + 2H^+ + 2e^- \quad (2)$$

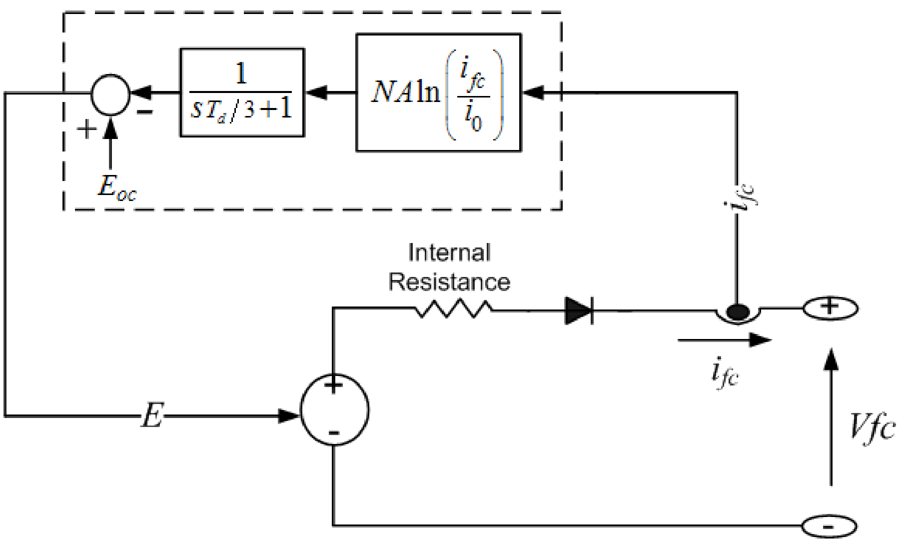


Figure 3.2 Fuel cell stack Model

To calculate Vfc and Pfc voltage and power of the fuel cell stack we need to calculate the losses of fuel cell based on the polarisation curve,in next section we are going to look upon the simplified model of fuel cell stack to calculate the fuel cell losses.

3.2 Simplified fuel cell model

The simplified model represents a particular fuel cell stack operating at nominal conditions of temperature and pressure. The parameters of the equivalent circuit can be modified based on the polarization curve obtained from the manufacturer datasheet. We need input in the mask the value of the voltage at 0 and 1 A, the nominal and the maximum operating points, for the parameters to be calculated. A diode is used to prevent the flow of negative current into the stack.

A typical polarization curve consists of three regions:

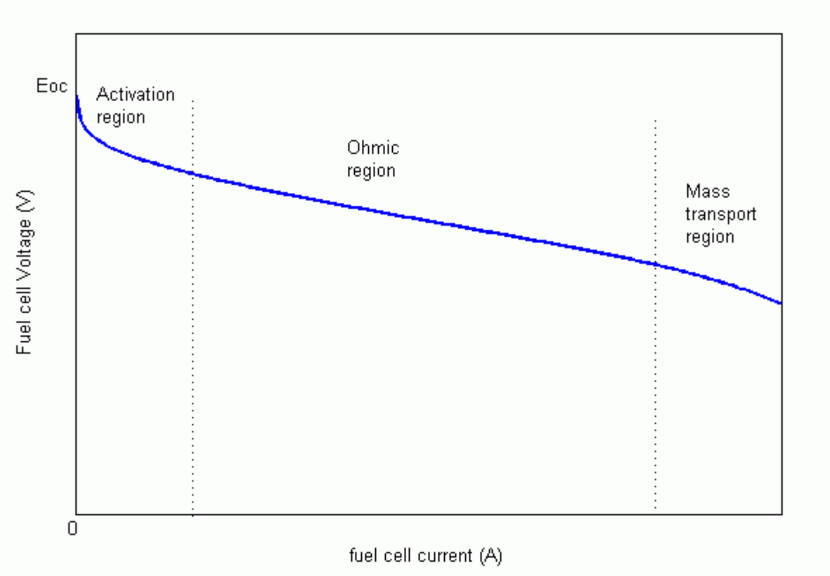


Figure 3.3 three regions of losses

.

The first region represents the activation voltage drop due to the slowness of the chemical reactions taking place at electrode surfaces. Depending on the temperature and operating pressure, type of electrode, and catalyst used, this region is more or less wide. The second region represents the resistive losses due the internal resistance of the fuel cell stack. Finally, the third region represents the mass transport losses resulting from the change in concentration of reactants as the fuel is used.

3.3 Parameters of fuel cell

To plot the VI characteristics of fuel cell stack from the following Parameters

Table 3.1 Parameters of fuel cell

Voltage at 0A and 1A[V_0(v),V_1(v)	260	64	
Nominal operating point Inom(A)	100		
Nominal operating point Vnom(V)	48		
Maximum operating point Iend(A),Vend(V)	102	46	
Number of cells	68		
Nominal stack efficiency(%)	56		
Operating Temperature (Celsius)	65		
Nominal Air flow rate(lpm)	300		
Nominal supply pressure[fuel(bar),Air(bar)]	6	1	
Nominal Composition (%) [H2 O2 H2O (Air)]	99.95	21	1

Table 3.2 Fuel cell Nominal parameters

Fuel Cell Nominal Parameters	Value
Stack power	4800W
Maximal	4692W
Fuel Cell Resistance	1.2267 ohms
Nerst Voltage of one cell	1.155 V
Nominal Utilization	
H2	99.42%
O2	46.54%
Full Flow Rate[Fuel Fr]At Nominal Hydrogen Utilization	
Nominal	9.836lpm
Maximum	10.03lpm
Airflow Rate [Airfr]At Nominal Oxidant Utilisation.	
Nominal	300lpm
Maximum	306lpm
Fuel Supply pressure [Pfuel]	6 bar
Air Supply pressure [Pair]	1 bar
System Temperature	338K

Where *Vfc* and *Efc* are the fuel cell output voltage and internal voltage.

Vact,fc, *Vohm,fc* and *Vconc,fc* are activation, ohmic and concentration voltage drops inside the fuel cell .

The total power generated by the fuel cell stack is represented as:

$$V_{fc} = E_{fc} - V_{actfc} - V_{ohmfc} - V_{concfc} \quad (1)$$

$$P_{fc} = N_o V_{fc} I_{fc} \quad (2)$$

Where *Pfc* is the total power generated by the fuel cell stack. *N0* is the number of cells in the stack series, *Ifc* is the stack current

.

Characteristic curve of fuel cell VI plot

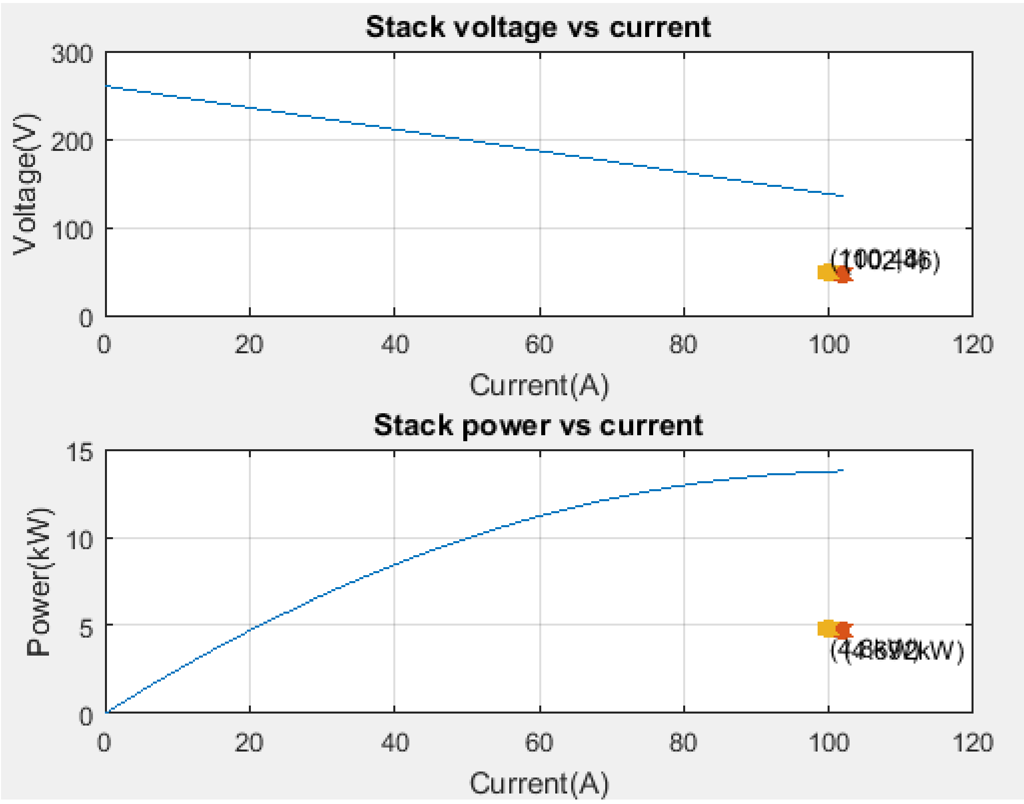


Figure 3.4 Plot V I characteristics

3.4 Summary

Chapter 3 describes the Output Power and Output Voltage of Fuel cell is determined and VI characteristic and Power current (PI) is been plotted in Matlab Simulink where the nominal and maximum value of VI is analysed at (100,48),(102,46) and PI at (4.8KW,4.692KW).

Chapter 4

MODELLING OF BATTERY CONVERTER

4.1 Battery

In our modern society the role of batteries is important as energy carriers, because of its presence in devices for everyday use. At the end of the 20th century the demand for batteries rapidly increased due to the large interest in wireless devices. Today, the battery industry comes under the category of large-scale industry which produces several million batteries per month. Improving the energy capacity is one major development issue, however, for consumer products, safety is probably considered equally important today. With the introduction of hybrid electric vehicles into the market there is technological development in the battery field which leads to reduction of fuel consumption and gas emissions. Battery development is a major task for both industry and academic research.

4.2 Modeling of battery

The battery is modelled as a nonlinear voltage source whose output voltage depends not only on the current but also on the battery state of charge (SOC), which is a non-linear function of the current and time . Fig 4.1 represents a basic model of battery.

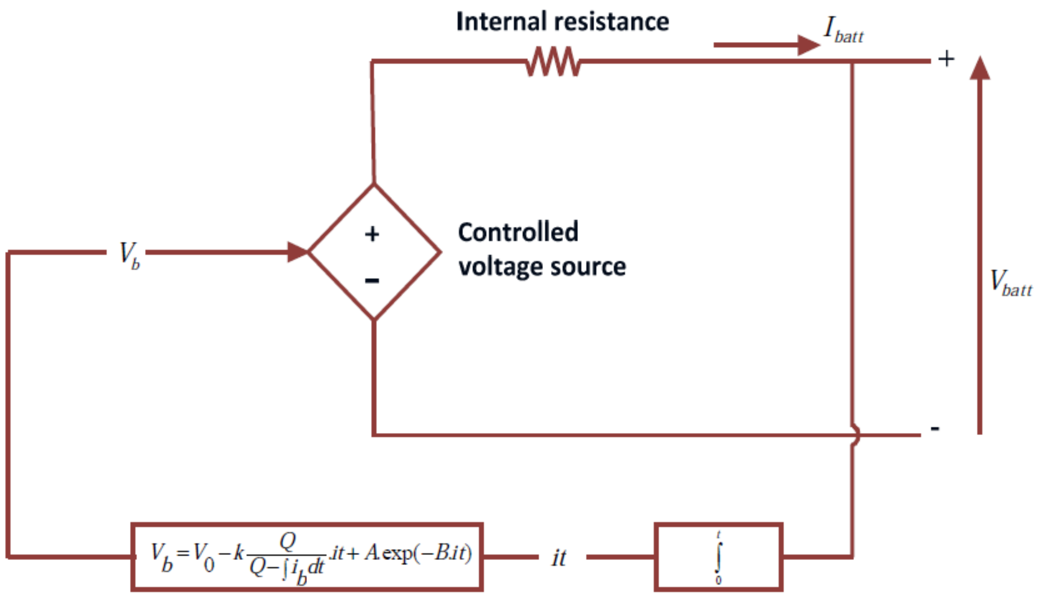


Figure 4.1 :Model of battery

Two parameters to represent state of a battery i.e. terminal voltage and state of charge canbe written as:

$$V_b = V_0 + R_b i_b - K\frac{Q}{Q-\int i_b dt} + A * \exp(B \int i_b\, dt)$$

$$SOC = 100(1 + \frac{\int i_b dt}{Q})$$

The original shepherd model has a non-linear term equal to $K\frac{Q}{Q-\int i_b dt}$. this Term represents a non-linear voltage that changes with the amplitude of the current and the actual charge of the battery. So when there is complete discharge of battery and no flow of current, the voltage of the battery will be nearly zero. As soon as a current circulates again, the voltage falls abruptly. This model yields accurate results and also represents the behaviour of the battery.

To Plot the nominal current discharge characteristics we need to calculate the following terms,

E_0 = Constant voltage (V)

K = Polarization constant (Ah^{-1}) or Polarization resistance (Ohms)

A = Exponential voltage (V)

B = Exponential capacity $(Ah)^{-1}$

To calculate the above 4 terms we need to know these following parameters,

E_{Batt} = Nonlinear voltage (V)

Exp(s) = Exponential zone dynamics (V)

Sel(s) = Represents the battery mode. Sel(s) = 0 during battery discharge, Sel(s) = 1 during battery charging.

i* = Low frequency current dynamics (A)

ib = Battery charging current (A)

it = Extracted capacity (Ah)

Q = Maximum battery capacity (Ah)

Rb=Internal resistance of the battery

V_o=open circuit voltage of the battery

Equations:

To calculate the efficiency of the battery

$\eta = 1 - \frac{Inom.R.Inom}{Vnom.Inom}$

$I_{nom} = Q_{nom}.0.2/_{1hr}$

$$\eta = 1 - \frac{(Q_{nom}.R.0.2)}{V_{nom}}$$

A= voltage drop during the exponential zone (V)

$A = E_{full} - E_{exp}$

$E_0 = E_{full} + K + Ri - A$

$K = \frac{(Efull - ENom + A(exp(-B.QNom) - 1)).(Q - QNom)}{QNom}$

Table 4.1 Battery Parameters

Lead Acid Battery	Values
Nominal Voltage	300
Rated Capacity(Ah)	1
Initial State Of Charge %	90%
Battery response time(s)	30

Table 1.2 - Discharge of battery

Discharge of battery	
Maximum capacity(Ah)	1.0417
Cut off voltage(V)	225
Fully charged voltage (V)	326.6447
Nominal discharge current (A)	0.2
Capacity (Ah) at nominal voltage(Q_{nom})	0.31028
Exponential zone[voltage(v),capacity(Ah)	305.4276 ,0.00333
Discharge current(A)	6.5 ,13,32.5
Internal Resistance(Ω)	3

4.3 Theoretical Calculation

η= 0.31028*0.2=0.06205

1`- $\frac{0.062056*3}{300}$

Efficiency η=99.93%

Voltage drop during the exponential zone(V)

A=326.6447V-305.4276V

A=21.2171(V)

Charge at the end of exponential zone

B= (3/(1/300))=**900(Ah)$^{-1}$**

Polarisation voltage (k)=

$$\frac{((326.6447-300)+21.2171\left(e^{(-900*0.31028)}-1\right).(1.0417-0.31028))}{0.31028}$$

K =12.79

Voltage constant (V)

E_0= 326.6447+12.834+(3*0.2)+ 21.2171

E_0=313.13 V

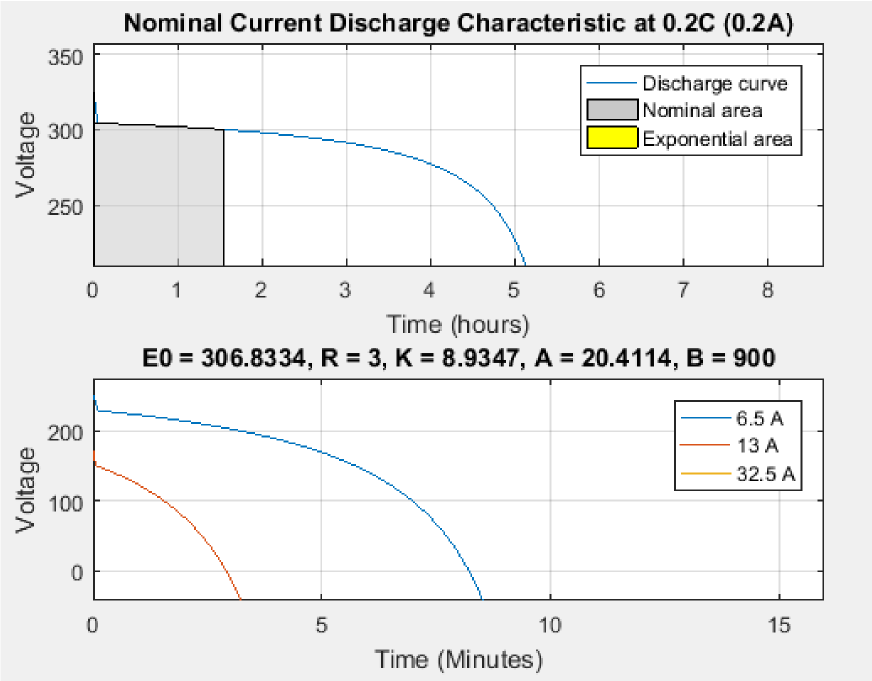


Figure 4.2 Discharge characteristic

4.4 Summary

Chapter 4 describes about the Modelling of battery ,the terminal voltage of the battery and the state of charge is determined by the equation by calculating the voltage drop ,exponential zone ,polarisation voltage theoretically with the nominal parameters and comparing with the simulated value .Discharge characteristic is been plotted with Matlab Simulink.

Chapter 5

PARK TRANSFORMATION

Rotating Frame

This is used for the control system used in this paper when the DC source and Battery is less than the DC load ,then Power from AC is given to the DC load for this smooth exchange of power we need this ABC to DQ Rotating frame is necessary so that constant DC voltage can be maintained.

5.1 ABC to DQ and DQ to ABC

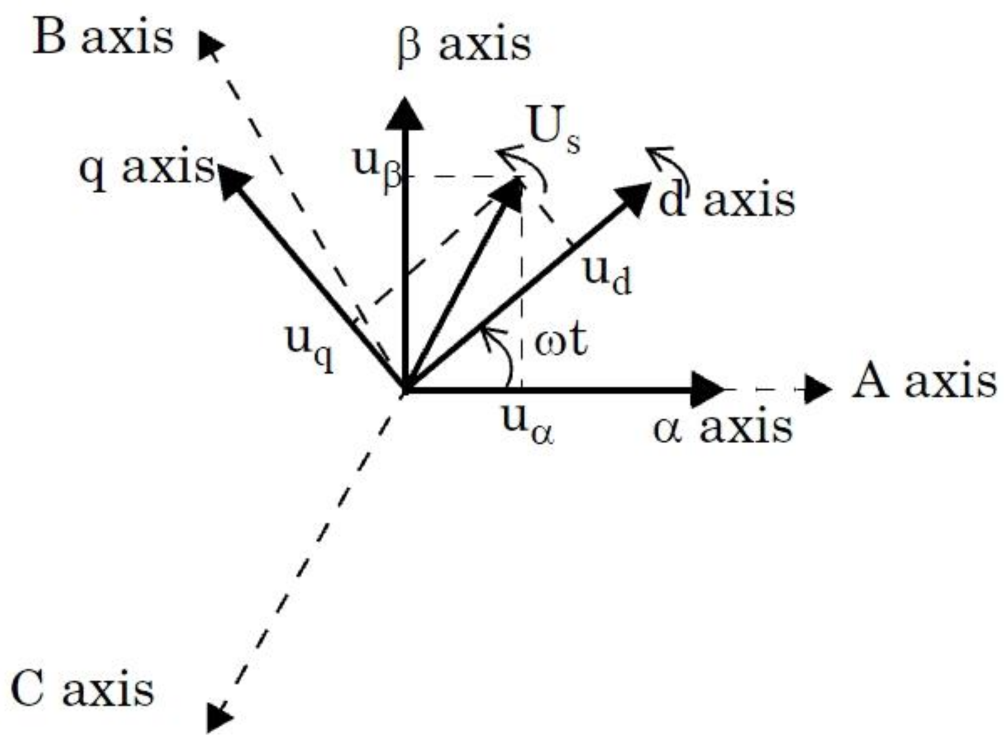


Figure 5.1 Rotating frame dq

The abc to dq0 block performs a Park transformation in a rotating reference frame.
The dq0 to abc block performs an inverse Park transformation.
Rotating frame aligned with A axis at t = 0. This type of Park transformation is also known as the cosinus-based Park transformation.
Rotating frame aligned 90 degrees behind A axis. This type of Park transformation is also known as the sinus-based Park transformation. We are deducing the dq0 components from abc signals by performing an abc to αβ0 Clarke transformation in a fixed reference frame. Then we perform an αβ0 to dq0 transformation in a rotating reference frame, that is, −(ω.t) rotation on the space vector $Us = u\alpha + j\cdot u\beta$.

The abc-to-dq0 transformation depends on the dq frame alignment at t = 0. The position of the rotating frame is given by ω.t (where ω represents the dq frame rotation speed).
When the rotating frame is aligned with A axis, the following relations are obtained.

5.1.1 Equation of rotating frames

$$V_s = V_d + \mathrm{j}\cdot V_q = \left(V_\alpha + j\cdot V_\beta\right)\cdot e^{-j\omega t} = \frac{2}{3}\cdot\left(V_a + V_b\cdot e^{\frac{j2\pi}{3}} + V_c\cdot e^{\frac{j2\pi}{3}}\right)\cdot e^{-j\omega t}$$

$$V_0 = \frac{1}{3}(V_a + V_b + V_c)$$

$$\begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos(\omega t) & \cos\left(\omega t - \frac{2\pi}{3}\right) & \cos\left(\omega t + \frac{2\pi}{3}\right) \\ -\sin(\omega t) & -\sin\left(\omega t - \frac{2\pi}{3}\right) & -\sin\left(\omega t + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

Inverse transformation is given by

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} \cos(\omega t) & -\sin(\omega t) & 1 \\ \cos\left(\omega t - \frac{2\pi}{3}\right) & -\sin\left(\omega t - \frac{2\pi}{3}\right) & 1 \\ \cos\left(\omega t + \frac{2\pi}{3}\right) & -\sin\left(\omega t + \frac{2\pi}{3}\right) & 1 \end{bmatrix}\begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix}$$

When the rotating frame is aligned 90 degrees behind A axis, the following relations are obtained:

$$V_s = V_d + \mathrm{j}\cdot V_q = \left(V_\alpha + j\cdot V_\beta\right)\cdot e^{-\mathrm{j}\left(\omega t - \frac{\pi}{2}\right)}$$

$$\begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} = \begin{bmatrix} \sin(\omega t) & -\cos(\omega t) & 0 \\ \cos(\omega t) & \sin(\omega t) & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

Inverse transformation is given by

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} \sin(\omega t) & \cos(\omega t) & 1 \\ \sin\left(\omega t - \frac{2\pi}{3}\right) & \cos\left(\omega t - \frac{2\pi}{3}\right) & 1 \\ \sin\left(\omega t + \frac{2\pi}{3}\right) & \cos\left(\omega t + \frac{2\pi}{3}\right) & 1 \end{bmatrix}\begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix}$$

5.1.2 Coupling dq equations:

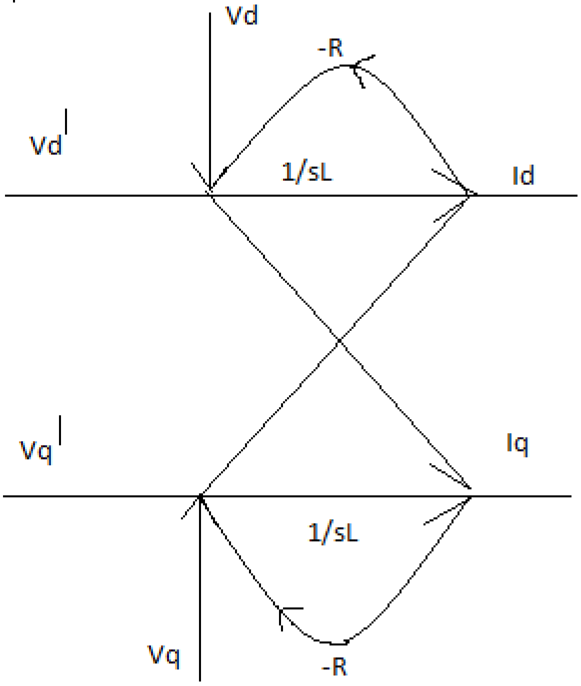


Figure 5.2 Coupling of dq equations

This coupling effect is then eliminated using PI controller to maintain fixed DC Voltage

$$\frac{di_d}{dt} = \frac{-R}{L} i_d + \omega i_q + \frac{1}{L}[V_d' - V_d]$$

$$\frac{di_q}{dt} = \frac{-R}{L} i_q - \omega i_d + \frac{1}{L}[V_q' - V_q]$$

$$V_d' = L\frac{di_d}{dt} + Ri_d - \omega L i_q + V_d$$

$$V_q' = L\frac{di_q}{dt} + Ri_q + \omega L i_d + V_q$$

5.2 Doubly Fed Induction Generator

5.2.1 Output Power of Wind turbines

With the use of power of the wind, wind turbines produce electricity to drive an electrical generator. Usually wind passes over the blades, generating lift and exerting a turning force. Inside the nacelle the rotating blades turn a shaft then goes into a gearbox. The gearbox helps in increasing the rotational speed for the operation of the generator and utilizes magnetic fields to convert the rotational energy into electrical energy. Then the output electrical power goes to a transformer, which converts the electricity to the appropriate voltage for the power collection system. A wind turbine extracts kinetic energy from the swept area of the blades.

The power contained in the wind is given by the kinetic energy of the flowing air massper unit time. The equation for the power contained in the wind can then be written as

$$P_{air} = \frac{1}{2}(air\ mass\ per\ unit\ time)(V_w)^2$$

$$=\frac{1}{2}(\rho A V_w)(V_w)^2$$

$$= \frac{1}{2}\ \rho A {V_w}^3 \qquad (5.1)$$

Although Eq. (5.1) describes the availability of power in the wind, power transferred tothe wind turbine rotor is reduced by the power coefficient C_p.

$$C_p = \frac{P_{wind\ turbine}}{P_{air}}$$

A maximum value of C_p.is defined by the Betz limit, which states that a turbine can neverextract more than 59.3% of the power from an air stream. In reality, wind turbine rotors have maximum C_p.values in the range 25-45%.

$$P_{wind\ turbine} = C_p * P_{air}$$

It is also conventional to define a tip speed ratio λ as

$$\lambda = \frac{\omega R}{V_w}$$

5.2 DFIG system

The doubly fed induction machine is the most widely machine in these days. The induction machine can be used as a generator or motor. Though demand in the direction of motor is less because of its mechanical wear at the slip rings but they have gained their prominence for generator application in wind and water power plant because of its obvious adoptability capacity and nature of tractability. This section describes the detail analysis of overall DFIG system.

5.2.1 Mathematical Model of DFIG

DFIG is a wound rotor type induction machine, its stator consists of stator frame, stator core, poly phase (3-phase) distributed winding, two end covers, bearing etc. The stator core is stack of cylindrical steel laminations which are slotted along their inner periphery for housing the 3-phase winding. Its rotor consists of slots in the outer periphery to house the windings like stator. The machine works on the principle of Electromagnetic Induction and the energy transfer takes place by means of transfer action. So the machine can represent as a transformer which is rotatory in action not stationary. This section explains the basic mathematical modelling of DFIG. In this section the machine modelling is explained by taking two phase parameters into consideration.

a) Modelling of DFIG in synchronously rotating frame

Fig 5.3 and 5.4 demonstrates the equivalent circuit diagram of an induction machine. The machine is signified as a two phase machine in this figure.

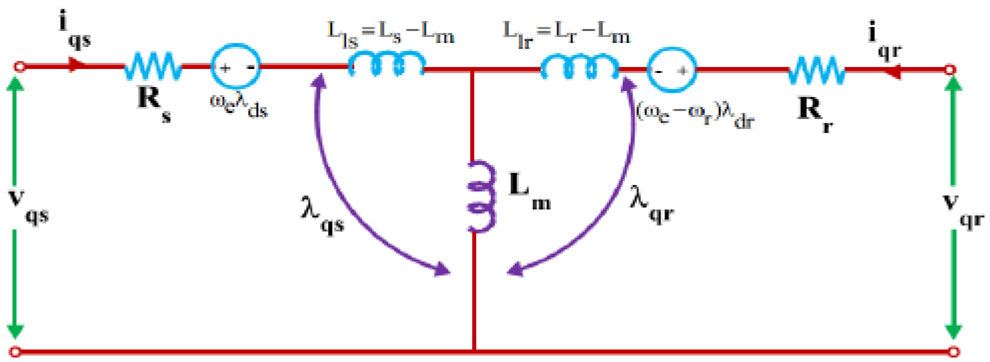


Figure 5.3 Dynamic d-q equivalent circuit of DFIG (q-axis circuit)

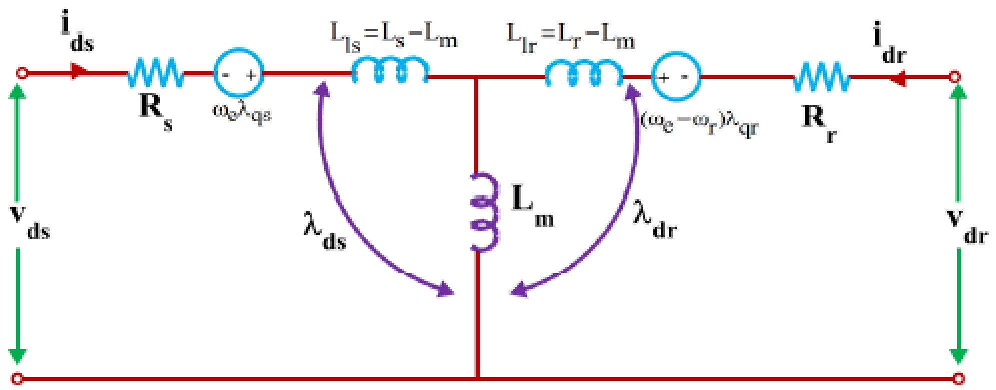


Figure 5.4 Dynamic d-q equivalent circuit of DFIG (d-axis circuit)

Equations for the stator circuit can be written as

$$V_{qs}^{s} = R_s i_{qs}^{s} + \frac{d}{dt}\lambda_{qs}^{s} \qquad (5.2)$$

$$V_{ds}^{s} = R_s i_{ds}^{s} + \frac{d}{dt}\lambda_{ds}^{s} \qquad (5.3)$$

In d-q frame Eq (5.2) and (5.3) can be written as

$$V_{qs} = R_s i_{qs} + \frac{d}{dt}\lambda_{qs} + (\omega_e \lambda_{ds})$$

$$V_{ds} = R_s i_{ds} + \frac{d}{dt}\lambda_{ds} - (\omega_e \lambda_{qs})$$

Where all the variables are in synchronously rotating frame. The bracketed terms indicate the back emf or speed emf or counter emf due to the rotation of axes as in the case of DC machines. When the angular speed ω_e is zero, the speed e.m.f due to d and q axis is zero and the equations changes to stationary form. If the rotor is blocked or not moving, i.e. $\omega_r = 0$, the machine equations can be written as

$$V_{qr} = R_r i_{qr} + \frac{d}{dt}\lambda_{qr} + (\omega_e \lambda_{dr})$$

$$V_{dr} = R_r i_{dr} + \frac{d}{dt}\lambda_{dr} + (\omega_e \lambda_{qr})$$

Let the rotor rotates at an angular speed ω_r, then the d-q axes fixed on the rotor fictitiously will move at a relative speed $(\omega_e - \omega_r)$ to the synchronously rotating frame. By replacing $(\omega_e - \omega_r)$ in place of ω_e the d-q frame rotor equations can be written as

$$V_{qr} = R_r i_{qr} + \frac{d}{dt}\lambda_{qr} + (\omega_e - \omega_r)\lambda_{dr}$$
$$V_{dr} = R_r i_{dr} + \frac{d}{dt}\lambda_{dr} - (\omega_e - \omega_r)\lambda_{qr}$$

The flux linkage expressions in terms of current from fig 5.3and 5.4 can be written as follows:

$\lambda_{qs} = L_{1s}i_{qs} + L_m(i_{qs} + i_{qr})$

$= L_m i_{qs} + L_m i_{qr}$

$\lambda_{ds} = L_{1s}i_{ds} + L_m(i_{ds} + i_{dr})$

$= L_m i_{ds} + L_m i_{dr}$

$\lambda_{qr} = L_{1r}i_{qr} + L_m(i_{qs} + i_{qr})$

$= L_r i_{qr} + L_m i_{qs}$

$\lambda_{dr} = L_{1r}i_{dr} + L_m(i_{ds} + i_{dr})$

$= L_r i_{dr} + L_m i_{ds}$

$\lambda_{qm} = L_m(i_{qs} + i_{qr})$

$\lambda_{dm} = L_m(i_{ds} + i_{dr})$ (5.4)

Eq. (5.2) to (5.4) describes the complete electrical modeling of DFIG. Whereas Eq. (6.4) express the relations of mechanical parameters which are essential part of the modeling.

The electrical speed ω_r cannot be treated as constant in the above equations. It can be connected to the torque as

$T_e = 1.5\rho(\phi_{ds}i_{qs} - \phi_{qs}i_{qs})$

Table 2.1 Configuration of DFIG

Rotor type	wound
Mechanical input	Speed w
Reference frame	Rotor

Table 5.2 - Parameters of DFIG

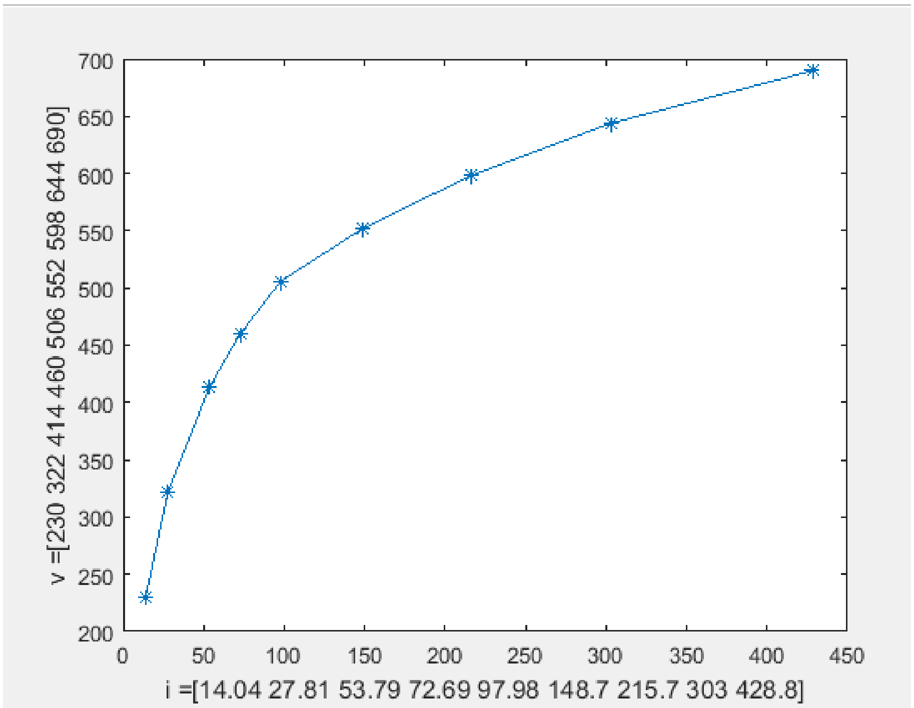
Nominal power (Pn)	3730(VA)
Voltage(line-line)(Vn)	230 (Vrms)
Frequency(fn)	50 (hz)
Stator resistance[Rs(ohm)]	1.32Ω
Stator inductance [Lls(H)]	$2*6.832*10^{-3}$ H
Rotor resistance[Rr(ohm)]	1.708Ω
Rotor inductance[Llr(H)]	$2*6.832*10^{-3}$ H
Mutual Inductance Lm(H)	0.219*2 H
Pole pairs p()	4

Table 5.3 Saturation Parameters and Measurements

Saturation Parameters		**Measurements**	
Vsat (Vrms L-L)	**Isat (peak A)**	**Vrms L-L**	**Is_A (peak A)**
-	-	120	7.322
230	14.04	230	14.03
-	-	250	16.86
-	-	300	24.04
322	27.81	322	28.39
-	-	351	35.22
-	-	382	43.83
414	53.79	414	54.21
-	-	426	58.58
-	-	449	67.94
460	72.69	460	73.01
-	-	472	79.12
-	-	488	88.43
506	97.98	506	100.9
-	-	519	111.6
-	-	535	126.9
-	-	546	139.1
552	148.68	552	146.3
-	-	569	169.1
-	-	581	187.4

Saturation Parameters		Measurements	
Vsat (Vrms L-L)	**Isat (peak A)**	**Vrms L-L**	**Is_A (peak A)**
598	215.74	598	216.5
-	-	620	259.6
-	-	633	287.8
644	302.98	644	313.2
-	-	659	350
-	-	672	383.7
-	-	681	407.9
690	428.78	690	432.9

The next graph illustrates these results and shows the accuracy of the saturation model. The measured operating points fit well the curve that is plotted from the Saturation Parameters data.



5.3 Summary

In this Chapter we discussed that transformation is necessary from ABC to DQ and inverse transformation because it will reduce the complexity of the desired outcome and AC values are transformed to DC values, Coupling factor is neglected so that we get the constant voltage at DC load and match with the reference value .DFIG output is also derived to simulate the output of Va,Vb,Vc,Ia,Ib,Ic at 500 V and 80 Amp.

Chapter 6

MICRO GRID CONTROL

6.1 Overall working of micro grid

The concept of microgrid is considered as a collection of loads and microsources which functions as a single controllable system that provides both power and heat to its local area. This idea offers a new paradigm for the definition of the distributed generation operation. To the utility the microgrid can be thought of as a controlled cell of the power system. For example this cell could be measured as a single dispatchable load, which can reply in seconds to meet the requirements of the transmission system. To the customer the microgrid can be planned to meet their special requirements; such as,

- enhancement of local reliability,
- reduction of losses,
- local voltages support,
- increased efficiency through use waste heat

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 .The microgrid or distribution network subsystem will create less trouble to the utility network than the conventional micro generation if there is proper and intelligent coordination of micro generation and loads.

The configuration of the hybrid system shown in this paper where various AC and DC sources and loads are connected to the corresponding AC and DC networks. The AC and DC links are linked together through two transformers and two four quadrant operating three phase converters. The AC bus of the hybrid grid is tied to the utility grid.

The AC bus is connected to the utility grid through a transformer and circuit breaker. In the proposed system, fuel cells are connected to the DC bus through boost converter to simulate DC sources. A DFIG wind generation system is connected to AC bus to simulate AC sources. A battery with bidirectional DC/DC converter is connected to DC bus as energy storage. A variable DC and AC load are connected to their DC and AC buses to simulate various loads.

A capacitor C_{fc} is added to the fuel cell terminal in order to suppress high frequency ripples of the fuel cell output voltage. The bidirectional DC/DC converter is designed to maintain the stable DC bus voltage through charging or discharging the battery when the system operates in the autonomous operation mode. The three converters (boost converter, main converter, and bidirectional converter) share a common DC bus. A wind generation system consists of doubly fed induction generator (DFIG) with back to back AC/DC/AC PWM converter connected between the rotor through slip rings and AC bus. The AC and DC buses are coupled through a three phase transformer and a main bidirectional power flow converter to exchange smooth power between DC and AC sides. The transformer helps to step up the AC voltage of the main converter to utility voltage level and to isolate AC and DC grids.

Table 6.1 Parameters for Modelling of Hybrid Grid

Symbol	Value
C_{fc}	1mH
L_1	1mF
C_d	100 μF
L_2	1mH
R_2	1 ohm
C_2	0.1mF
L_3	0
R_3	0.001 ohm
f	50 Hz
f_s	10 kHz
V_d	500 V
V_{Ac_rms}	230V

Component parameters for hybrid grid

The parameters used for the modelling of hybrid grid are show in the table

6.2 Modeling and control of boost converter

The main objective of the boost converter is to track the maximum power point of the fuel cell stack by regulating the terminal voltage using the power voltage characteristic curve.

For the boost converter the input output equations can be written as

$$V_{fc} - V_T = L_1 \frac{di_1}{dt} + R_1 i_1$$

$$I_{fc} - i_1 = C_{fc} \frac{dVfc}{dt}$$

$$V_T = V_d(1 - d_1)$$

A reference value i.e. Vfc* is calculated which mainly depends upon fuel cell stack .Here the control objective is to provide a high quality DC voltage with good dynamic response. The outer voltage loop helps in tracking of reference voltage with zero steady state error.

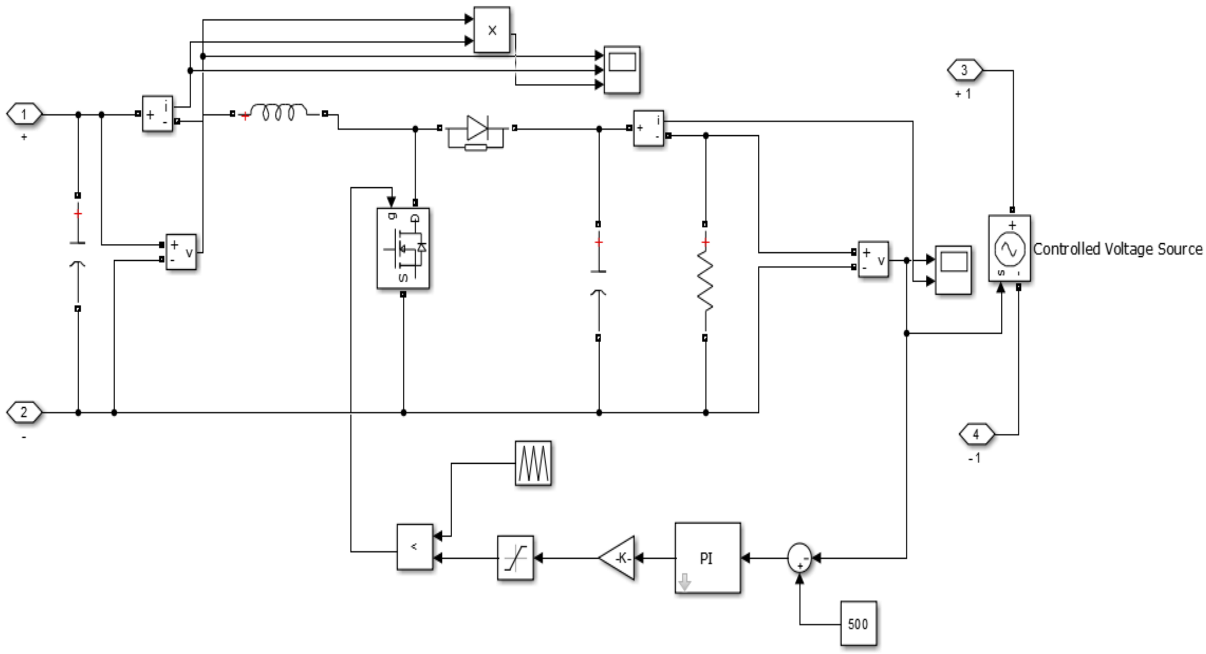


Figure 6.1 Control block diagram of Boost converter

Boosted Voltage

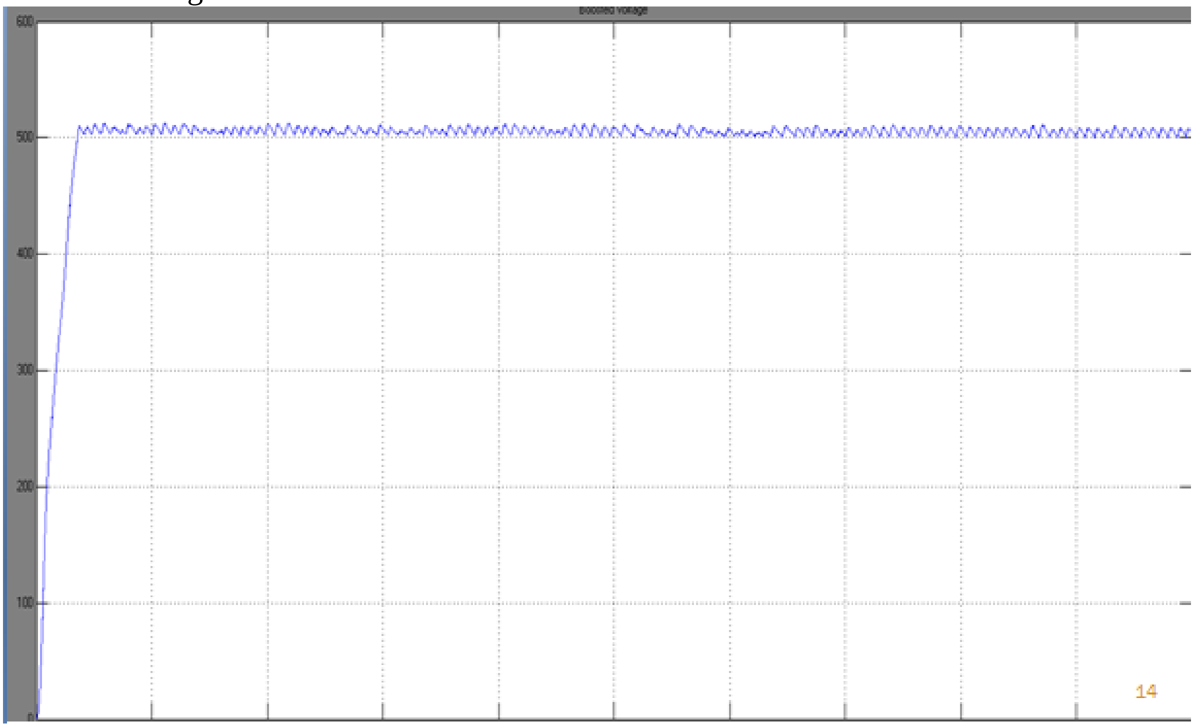


Figure 6.2 Boosted DC Voltage

6.3 Modelling and control of main converter

The role of the main converter is to exchange power between AC and DC bus. The key purpose of main converter is to maintain a stable DC-link voltage in grid tied mode. When the converter operates in grid tied mode, it has to supply a given active and reactive power. Here PQ control scheme is used for the control of main converter. The PQ control is achieved using a current controlled voltage source. Two PI controllers are used for real and reactive power control. When resource conditions or load capacities change, the DC bus voltage is settled to constant through PI regulation. The PI controller is set as the instantaneous active current i_{dm}- reference and the instantaneous reactive current i_{qm} reference is determined by reactive power compensation command. The model of the converter can be represented in ABC coordinate as

$$L_2\frac{d}{dt}\begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} + R_2\begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} = \begin{pmatrix} V_{SA} \\ V_{SB} \\ V_{SC} \end{pmatrix} - \begin{pmatrix} V_{CA} \\ V_{CB} \\ V_{CC} \end{pmatrix}$$

The above equation can be written in d-q coordinate as

$$L_2\frac{d}{dt}\begin{pmatrix} i_{dm} \\ i_{qm} \end{pmatrix} = \begin{pmatrix} -R_2 & \omega L_2 \\ -\omega L_2 & -R_2 \end{pmatrix}\begin{pmatrix} i_{dm} \\ i_{qm} \end{pmatrix} + \begin{pmatrix} V_{sd} \\ V_{sq} \end{pmatrix} - \begin{pmatrix} V_{cd} \\ V_{cq} \end{pmatrix}$$

Where ($i_a i_b i_c$) ,and ($V_{CA} V_{CB} V_{CC}$)are three phase current and voltages of the main converter. Three phase voltage of AC bus voltage are represented by the notations as ($V_{SA} V_{SB} V_{SC}$)The variables ($i_{dm} i_{qm}$),($V_{cd} V_{cq}$),($V_{sd} V_{sq}$). are d-q coordinates of three phase currents, voltages of main converter and voltage of AC bus respectively.

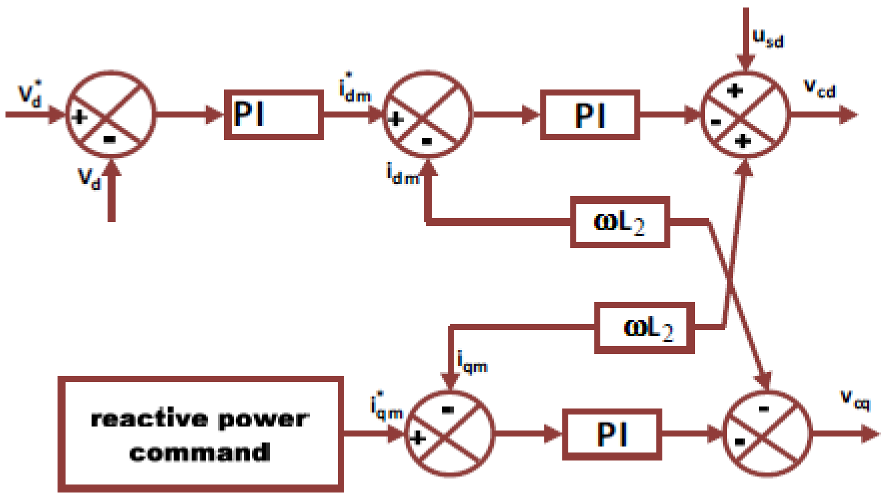


Figure 6.3 Control block diagram of main converter

In case of sudden DC load drop, there is power surplus at DC side and the main converter is controlled to transfer power from DC to AC side. The active power absorbed by the capacitor C_d leads to rising of DC-link voltage V_d. The negative error caused by the increase of V_d produces a higher active current reference i_{dm}^*through PI control. A higher positivereference i_{dm}^*will force active current reference i_{dm} to increase through the inner current control loop. Therefore the power surplus of the DC grid can be transferred to the AC side. Also a sudden increase of DC load causes the power shortage and V_d drop at the DC grid. The main converter is controlled to supply power from the AC to DC side. The positive voltage error caused by V_d drop makes the magnitude of i_{dm}^*increase through the PI control.Since i_{dm} and$i_{dm}^*$are both negative, the magnitude of i_{dm} increased through the inner current control loop. Hence power is transferred from AC grid to the DC side.

6.4 Summary

In this Chapter we discuss about the control system of the main converter when the DC load is less than 500 volts and the power sources from Fuel Cell Stack and Battery is not providing sufficient power to the DC load then the power is taken from AC load but it cannot take randomly from AC as it depends on the voltage at DC load ,to provide constant voltage at DC load PQ control is done which will compensate power from AC load.

6.5 PQ Control

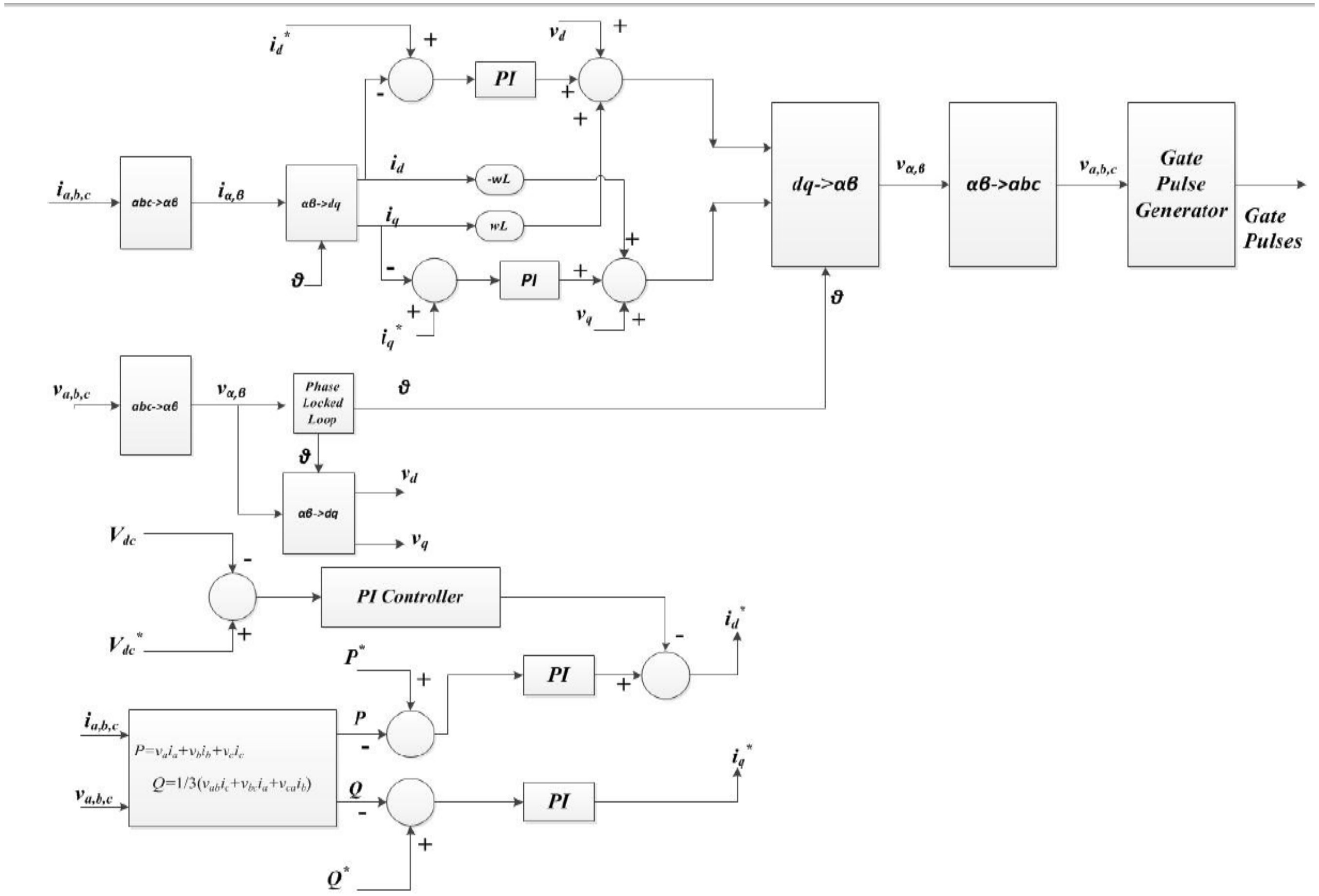
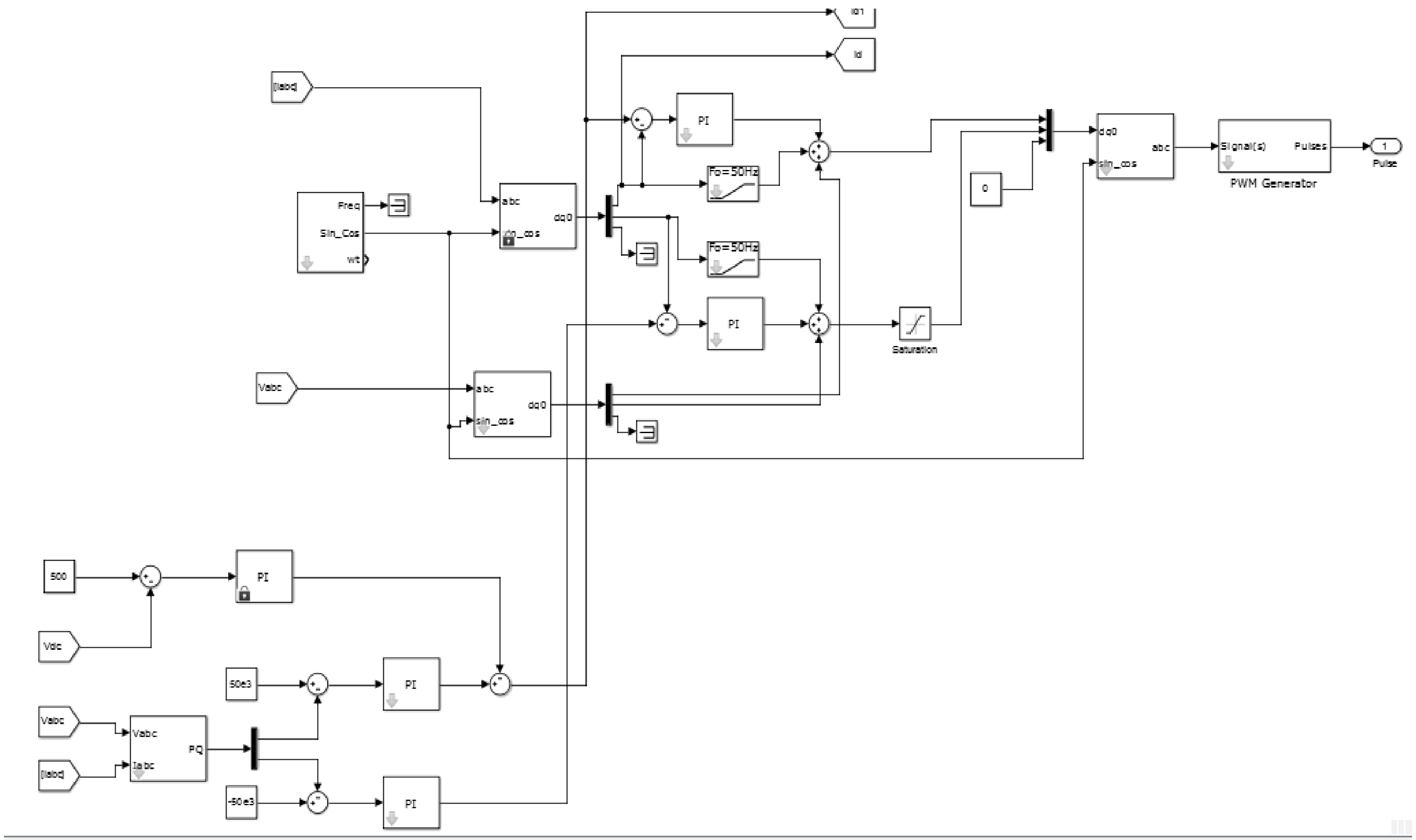


Figure 6.4 PQ control scheme for the main converter

Matlab block of the simulation



Chapter 7

CONCLUSION

Results and Simulation

a)Fuel Cell voltage b)Fuel Cell Power c)DC Bus Voltage

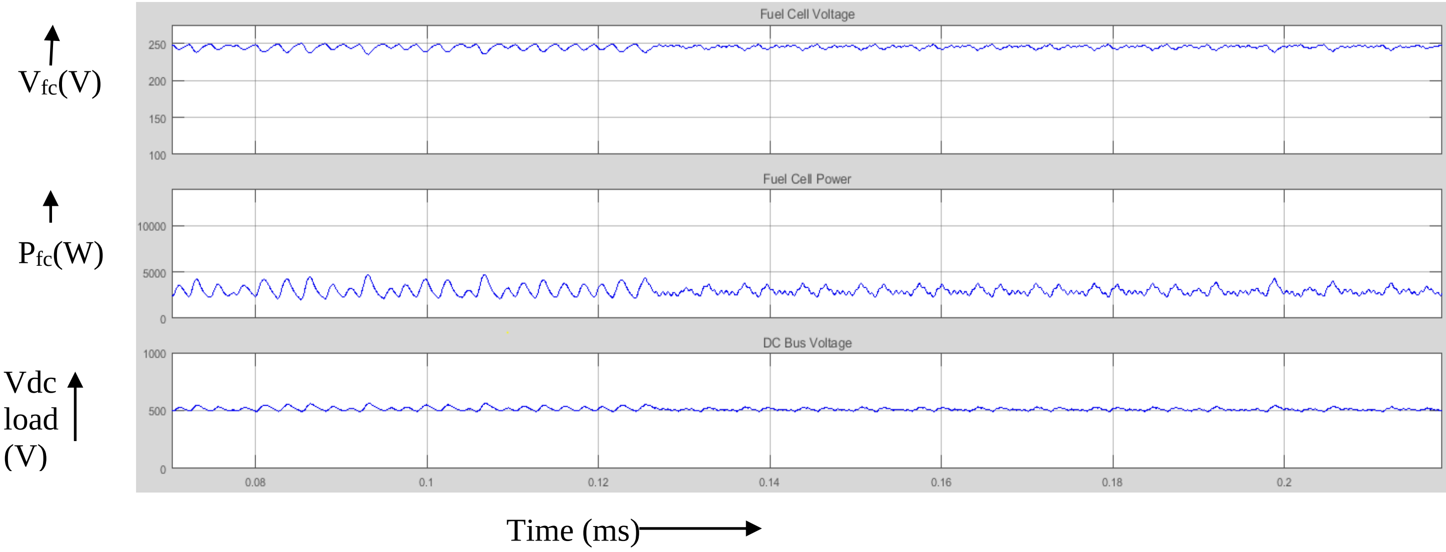


Figure 7.1 Fuel cell voltage and DC bus voltage

The first graph shows the voltage at fuel cell Vfc=250V

The second graph represents the fuel cell stack power = 3KW

The third graph Represents the constant DC output at Dc load terminal=500V

AC Power=50KW

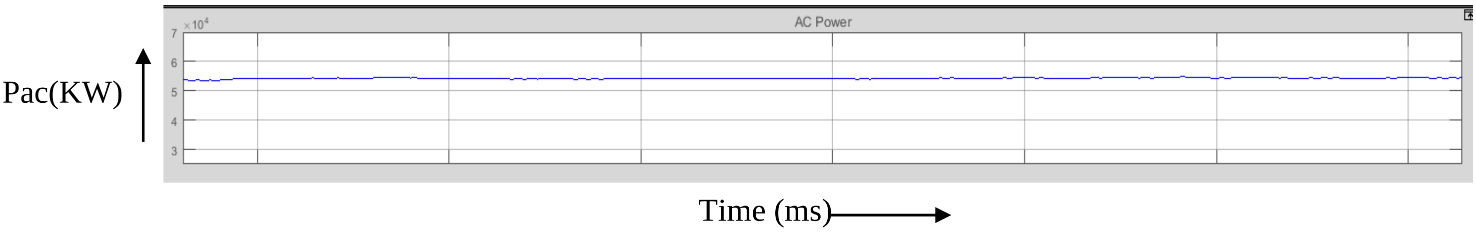


Figure 7.2 AC power

Active DC current and Reactive DC current

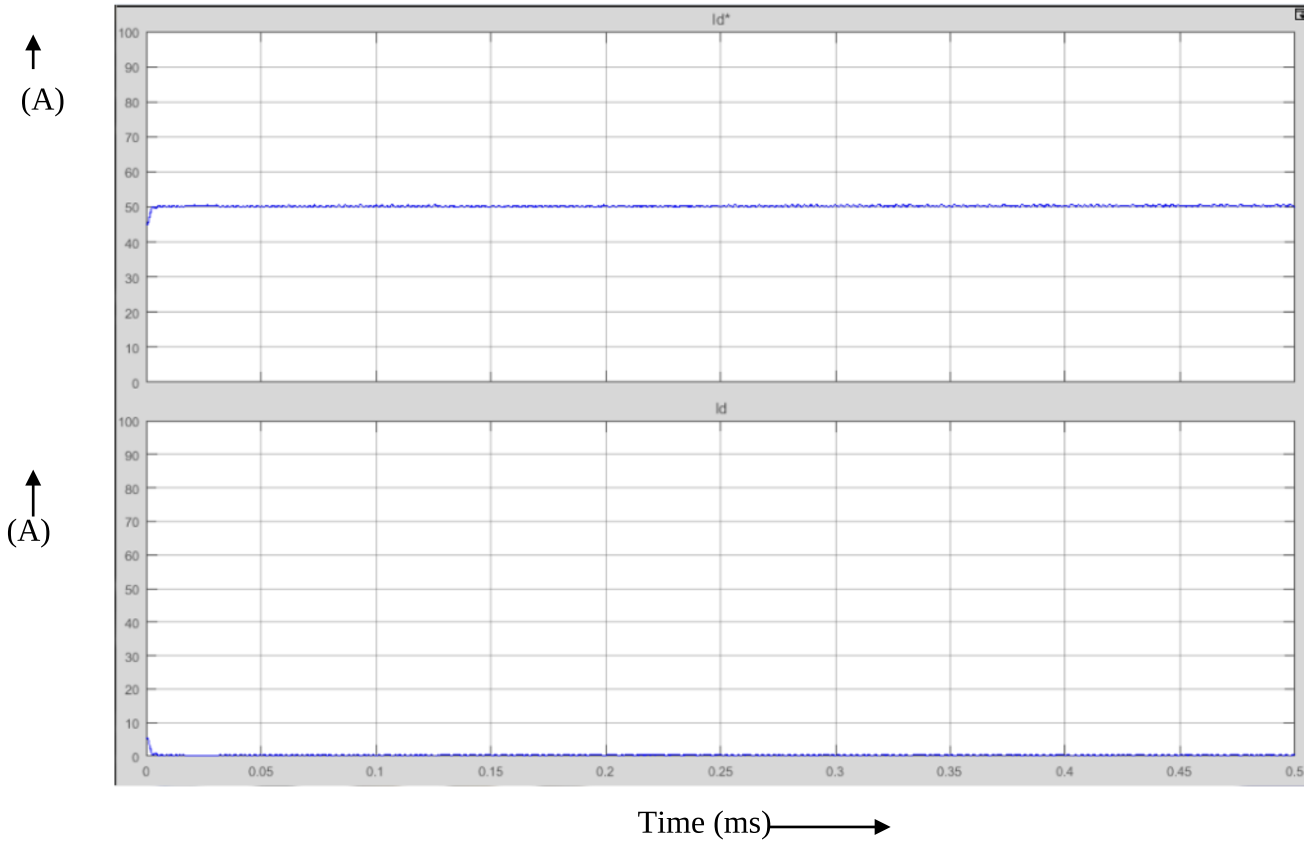


Figure 7.3 Active DC current and Reactive DC current

This graph represents the Id*=50 Amp reference current and Iq=0

Voltage & Current Waveform Of Wind

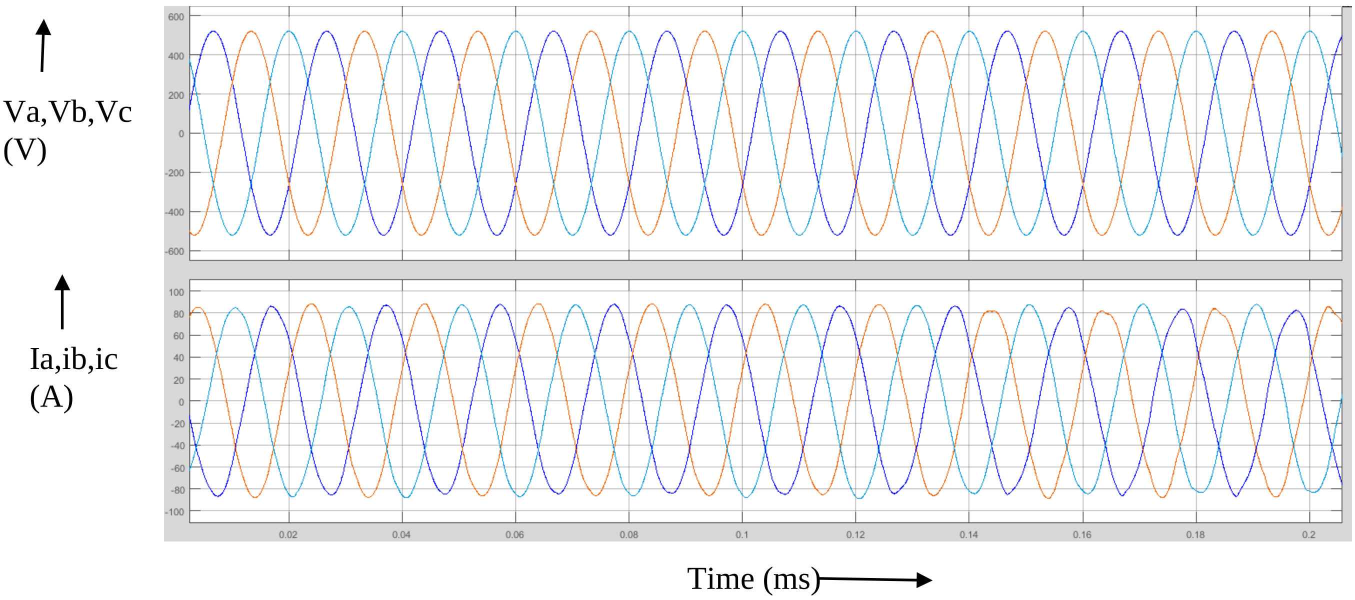


Figure 7.4 Voltage and current waveform of wind

The above graph represents the output voltage of DFIG ,Va,Vb,Vc=500V

The below graph represents the output current of DFIG ,ia,ib,ic=80 A

Voltage & Current Waveform Across AC load

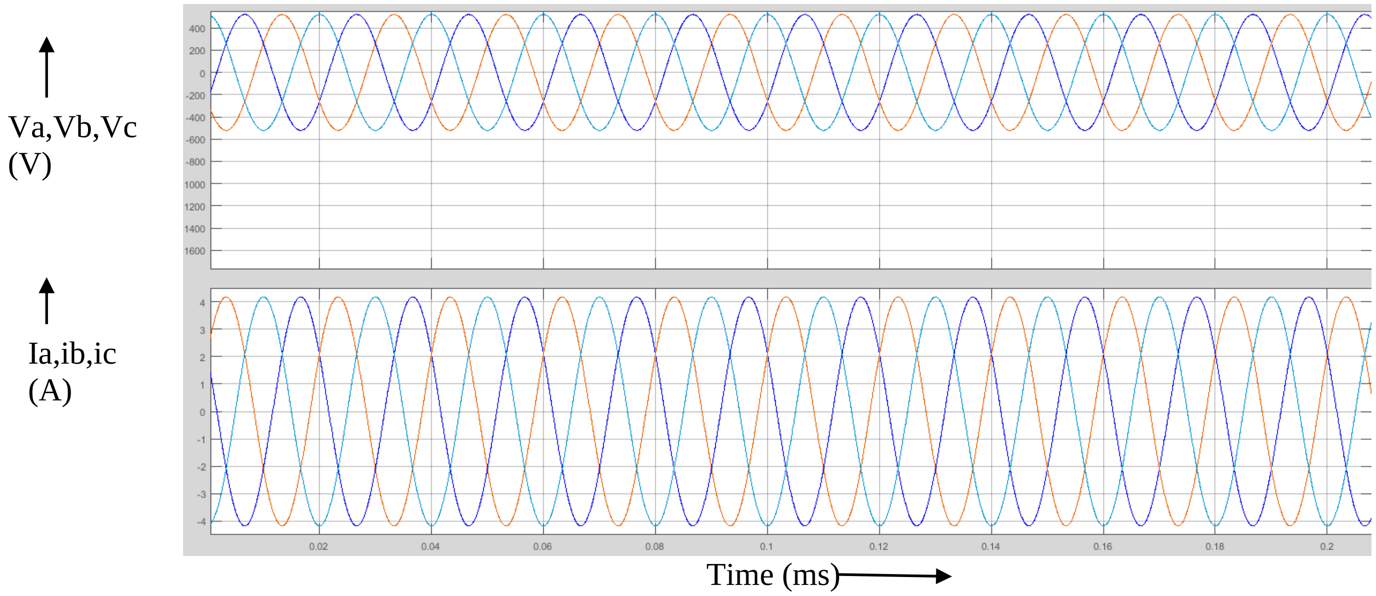


Figure 7.5 Voltage & Current Waveform Across AC load

This graph shows the DFIG when there is power exchange from AC to DC The voltage Va,Vb,Vc is constant

Ia Ib Ic is 4A ,when we compare with the previous graph ,the rest 76 A is given to the DC load .

Actual real and reactive power from AC : P,Q

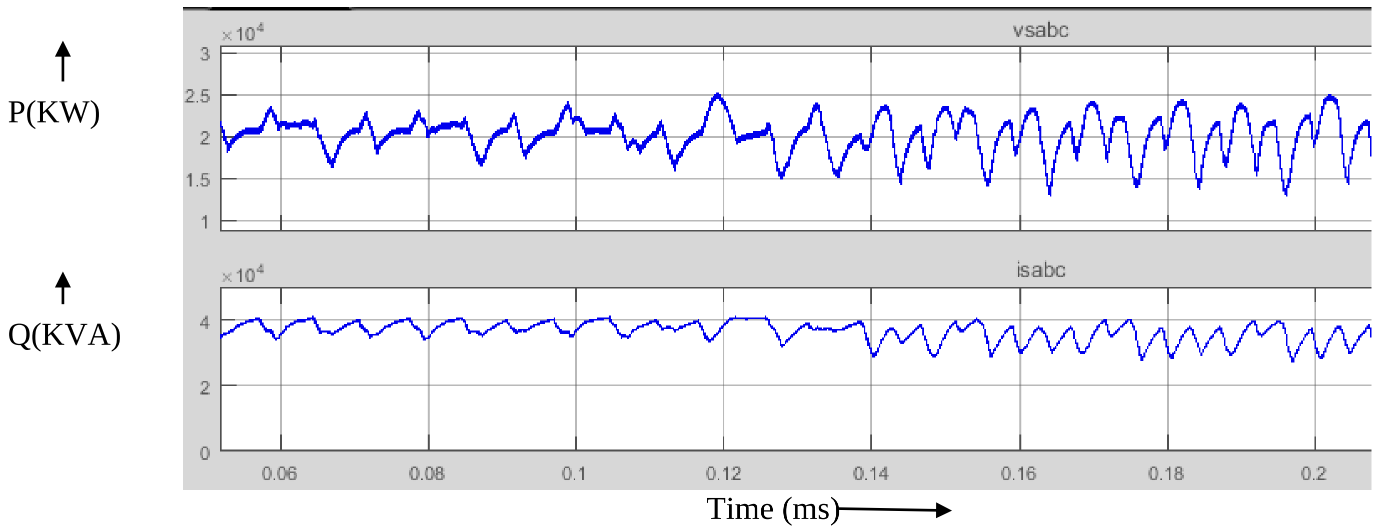


Figure 7.6 Actual real and reactive power

Total Ac power Q=3KVA
P=2KW

Battery Voltage

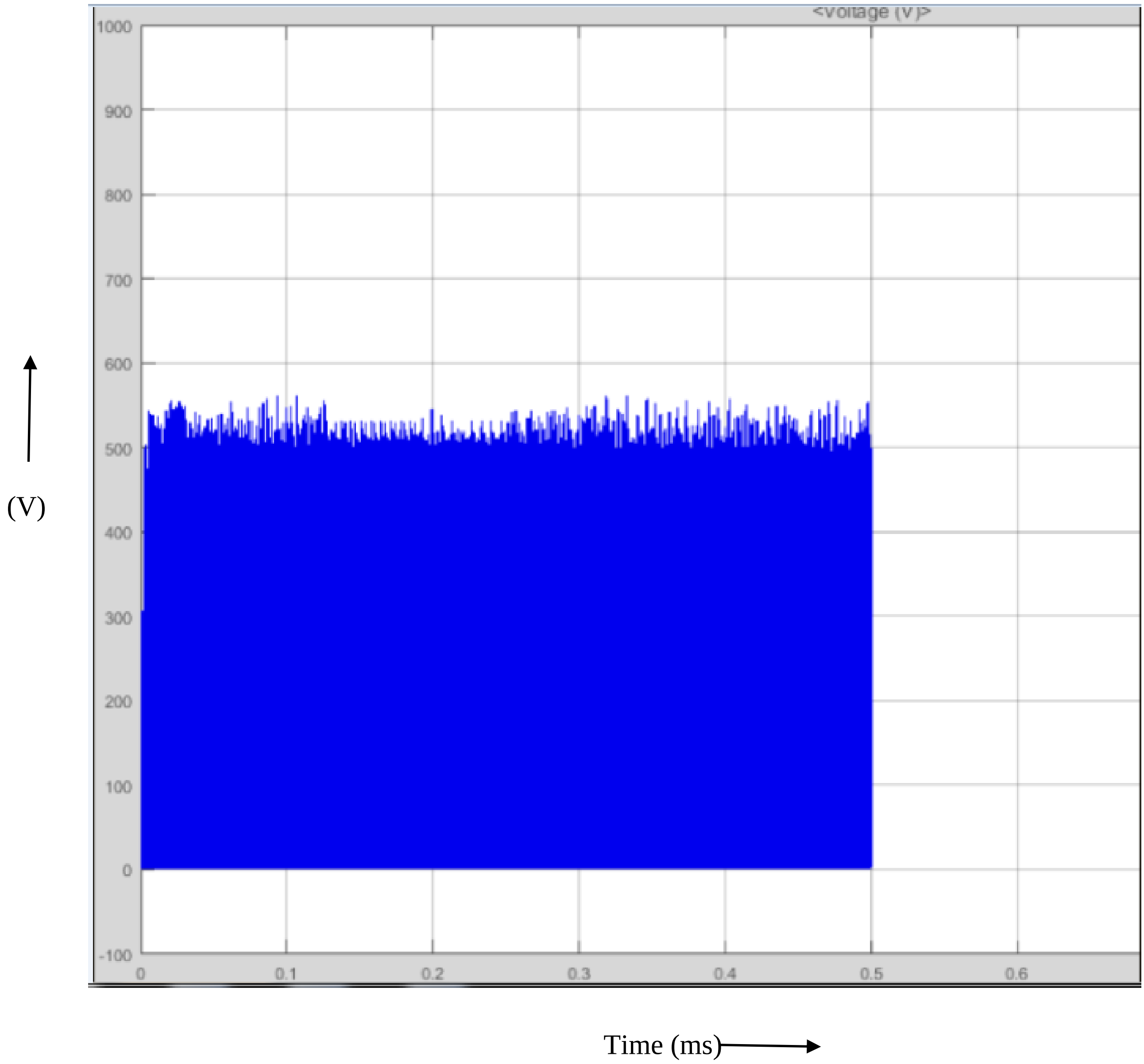


Figure 7.7 Battery Charged

Battery Charged at 500V when Ps>Pload

Summary

In this chapter simulation results are discussed briefly. Also various characteristics of fuel cell stack, doubly fed induction generator, battery and converters are studied in this chapter and the waveforms are traced

Conclusion

The modelling of hybrid microgrid for power system configuration is done in MATLAB/SIMULINK environment. The models are developed for all the converters to maintain stable system under various loads and resource conditions and also the control mechanism are studied. To harness maximum power from DC sources and to coordinate the power exchange between DC and AC grid. Although the hybrid grid can diminish the processes of DC/AC and AC/DC conversions in an individual AC or DC grid, there are many practical problems for the implementation of the hybrid grid based on the current AC dominated infrastructure. The efficiency of the total system depends on the diminution of conversion losses and the increase for an extra DC link. The hybrid grid can provide a reliable, high quality and more efficient power to consumer. The hybrid grid may be feasible for small isolated industrial plants with both fuel cell stack and wind turbine generator as the major power supply.

Scope of future work

a. The modelling and control can be done for the islanded mode of operation.

b. The control mechanism can be developed for a microgrid containing unbalanced and nonlinear loads with a DC source as PV panel

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