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ACADEMY OF MARITIME EDUCATION AND TRAINING
DEEMED TO BE UNIVERSITY
(Under Section 3 of UGC Act 1956)

Title of the Project: Modelling and simulation of Gynastics Bicycle with permanent magnet sychronous Generator

project / **Home Internship Report**

Submitted by: P. Muthu kumar (AMRS 18007)

V. Sentilkumar
Signature of Mentor

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BONAFIDE CERTIFICATE

This is to certify that the home based internship entitled "Modelling and Simulation of Gymnastics Bicycle with permanent magnet Synchronous Generator ....submitted by P. Muthukumar Reg.No: AA9PI 18007 in IV semester during year 2019-20 for the degree of Master of Engineering of is a bonafide record of technical work carried out by him under my supervision.

Signature Mentor | **Signature of Dean/HoD**

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INTERNSHIP ALLOCATION REPORT 2019-20

Name of the Department: Electrical and Electronics Engineering

(in the view of advisory from the AICTE, Internships for the year 2019-20 are offered by the Department of itself to facilitate the students to take up required work from their home itself during the lockdown period due to COVID19 outbreak)

Name of the Programme : Electrical and Electronics Engineering

Year of study and Batch/group: II

Name of the Mentor : Dr V. Karthikeyan

Title of the assigned internship:

Nature of Internship : Individual/ Group ✓

Reg no of the students who are assigned with this internship:

Total No of hours Required to complete the internship: 15 days

Signature of Mentor	Signature of Internal Examiner	Signature of HoD/Dean
V. Karthikeyan	C. [illegible]	V. Karthikeyan

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Name of the student	P. Muthukumar
Register No. and Roll No	AMPS18007
Programme of study	Master of Engg
Year and Batch/Group	II year – IV Sem
Semester	IV
Title of Internship	Modelling and Simulation of Gymnastics Bicycle with PMSG
Duration of Internship	2019-20
Mentor of the student	V. Karthikeyan

Evaluation of the Department:

S.no	Criteria	Max Marks	Marks allotted
1	Regularity in the maintenance of daily	10	10
2	Adequacy and quality of Information recorded	10	10
3	Drawings, sketches, and data recorded	10	10
4	Thought process and data recording techniques used	5	5
5	Organization of information	5	5
6	Originality of information report	20	15
7	Adequacy and purposeful write-up of the internship report	10	10
8	Organization, format, drawing, sketched, style, language etc of internship Report	10	10
9	Practical application, relationship with basic theory and concepts	10	10
10	Presentation skills	10	10
	Total	100	95

Signature of Mentor	Signature of Internal Examiner	Signature of HoD/Dean
V. [signature]	[signature]	V. [signature]

Modelling and Simulation of Gymnastics Bicycle with Permanent Magnet Synchronous Generator

A THESIS

Submitted by

P MUTHUKUMAR (AMPS18007)

In partial fulfillment for the award of the degree of

MASTER OF ENGINEERING IN
POWER SYSTEMS

AMET DEEMED TO BE UNIVERSITY ::CHENNAI 603112

JUN 2020

ACKNOWLEDGEMENT

We wish to express our sincere and humble thanks to our chancellor **Dr. J. RAMACHANDRAN** for providing the necessary facilities in the college premises to carry out the project

We would like to express our sincere thanks towards our beloved Vice – Chancellor, **Col.Dr.G.THIRUVASAGAM** for providing us with an environment to complete the project successfully.

We wish to express our heartiest thanks to **Dr.T. SASILATHA**, Dean and Professor, Department of EEE for her advice and motivation, which helped us to accomplish this project work.

We are grateful to our guide, **Dr.V. Karthikeyan, M.E, Ph.D.,** Professor, and Department of EEE for his valuable and precious guidance to our project.

We would like to thank our parents and friends for moral financial support.

Finally, we thank Almighty for making us capable and giving us the dedication and determination to complete the project on time.

P MUTHUKUMAR

Abstract

This paper presents the modelling and simulation of Manual Pedalling with permanent magnet synchronous generator. In this paper, the modelling and simulations of a variable-speed Manual Pedalling along with permanent magnet synchronous generator is presented. Now a day, the energy production by wind generators and solar energy generation has recently been increasing, because its creation is green; therefore, this proposal also based on the green creation by the Re-Creating the Human Movement in the routine lifecycle and the technology designed for the establishment of energy through Manual Pedalling brings great challenges in the exploration. A mathematical model of Manual Pedalling is necessary to understand the behavior of the Manual Pedalling over its area of operation since it allows for the evolution of inclusive control algorithms that aid in ideal operation of a Manual Pedalling system. Modelling gives us an overview of the proposed system and also allow control of Manual Pedalling system's performance. Outcome results show that the speed regulation was very good. In long lasting system, the imbalance of rotor speed was almost inconsiderable in spite of the uninterrupted imbalance of the Pedalling speed within the interval of 120 to 1000ms.

Keywords— Manual Pedalling, rotor speed, PMSG.

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CHAPTER-1

1. INTRODUCTION:

Wind flow is caused by the uneven heating of the atmosphere by the sunlight, variations in the globe's surface, and rotation of our planet, Mountains, bodies of water, and vegetation all influence wind flow habits. Wind turbines convert the power in wind to electricity by rotating propeller-like cutting blades around a rotor. The rotor turns the drive shaft, which turns the permanent synchronous generator. Through transmission and distribution lines this generated power is transmitted to the grids and then to customers. Globally there are now over two hundred thousand wind flow turbines operating, with an overall total capacity of 432,000 MW as of end 2015. Wind energy as the name suggests, is a renewable source of energy having its own advantages as saving fossil fuels, less air & water pollution etc. and the modern technology enabling it to have a leap forward in recent years.

Similarly a new renewable source of energy having by the energy delivered by human in daily life.

**"Energy can neither be created nor be destroyed,
Which may transfer from one energy state to other"**

This paper proposes the Energy conserved for Daily Life which are may be used to transfer the form of Electrical Energy.

In this paper, the simulation and modelling of variable-speed Manual Pedalling is presented with the use of permanent synchronous generator connected to it. Here the dynamic behavior of variable-speed Manual Pedalling system modelling has been shown in first section followed by the modelling of permanent synchronous generator in second section.

CHAPTER-2

2. Construction & Working of PMSG:

2.1. Construction of PMSG:

The basic construction of PMSG is same as that of synchronous motor. The only difference lies with the rotor. Unlike synchronous motor, there is no filed winding on the rotor of PMSG. Field poles are created by using permanent magnet. These Permanent magnets are made up of high permeability and high coercivity materials like Samarium-Cobalt and Neodium-Iron-Boron. Neodium-Iron-Boron is mostly used due to its ease of availability and cost effectiveness. Theses permanent magnets are mounted on the rotor core.Based on the mounting arrangement of magnet on rotor core, Permanent Magnet Synchronous Motor (PMSG) can be categorized into two types: Surface Mounted PMSGs and Buried or interior PMSGs

In ***Surface Mounted PMSG***, permanent magnet is mounted on the rotor surface as shown in figure below.

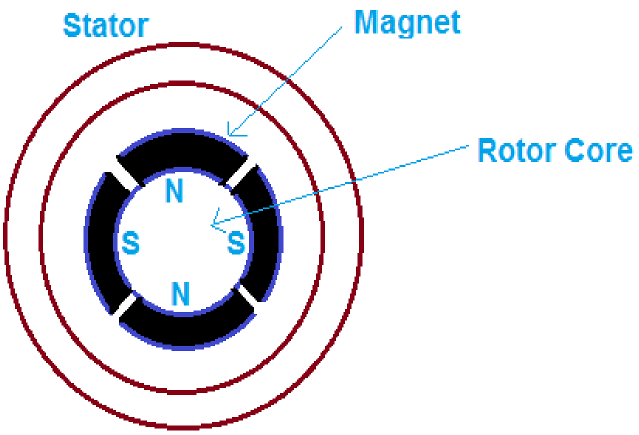


Figure 1 Cross Section View of PMSG

This type of PMSG is not robust and therefore not suited for high speed application. Since the permeability of magnet and air gap is almost same, therefore this type of construction provides a uniform air gap. Therefore, there is no reluctance torque present. Thus the dynamic performance of this motor is superior and hence used in high performance machine tool drives and robotics.

In ***Interior or Buried PMSG***, the permanent magnets are embedded into the rotor instead of mounting on the surface. This provides robustness and hence can be used in high speed applications. Due to presence of saliency, reluctance torque is present in this type of PMSG

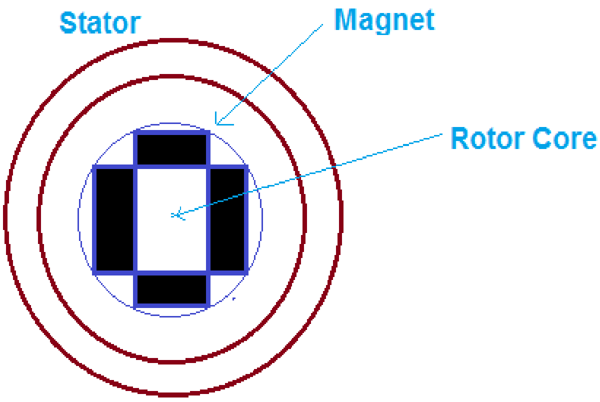


Figure 2Rotor Core

2.1.1. Hall Sensors

Hall sensor provides the information to synchronize stator armature excitation with rotor position. Most PMSG motors incorporate three Hall sensors which are embedded into the stator. Each sensor generates Low and High signals whenever the rotor poles pass near to it. The exact commutation sequence to the stator winding can be determined based on the combination of these three sensor's response.

Hall sensors or rotary encoders are most commonly used to sense the position of the rotor and are positioned around the stator. The rotor position feedback from the sensor helps to determine when to switch the armature current. This electronic commutation arrangement eliminates the commutator arrangement and brushes in a DC motor and hence more reliable and less noisy operation is achieved.

Due to the absence of brushes PMSG motors are capable to run at high speeds. The efficiency of PMSG motors is typically 85 to 90 percent, whereas as brushed type DC motors are 75 to 80 percent efficient. There are wide varieties of PMSG motors available ranging from small power range to fractional horsepower, integral horsepower and large power ranges.

Stator of a PMSG motor made up of stacked steel laminations to carry the windings. These windings are placed in slots which are axially cut along the inner periphery of the stator. These windings can be arranged in either star or delta. However, most PMSG motors have three phase star connected stator.
Each winding is constructed with numerous interconnected coils, where one or more coils are placed in each slot. In order to form an even number of poles, each of these windings is distributed over the stator periphery.

The stator must be chosen with the correct rating of the voltage depending on the power supply capability. For robotics, automotive and small actuating applications, 48 V or less voltage PMSG motors are preferred. For industrial applications and automation systems, 100 V or higher rating motors are used.

2.2 Working Principle of PMSG:

The working principle of permanent magnet synchronous motor is same as that of synchronous motor. When three phase winding of stator is energized from 3 phase supply, rotating magnetic field is set up in the air gap. At synchronous speed, the rotor field poles locks with the rotating magnetic field to produce torque and hence rotor continues to rotate.

As we know that synchronous motors are not self-starting, PMSG needs to be started somehow. Since there is no winding on the rotor, induction windings for starting is not applicable for such motors and therefore variable frequency power supply for this purpose.

PMSM motor works on the principle similar to that of a conventional DC motor, i.e., the Lorentz force law which states that whenever a current carrying conductor placed in a magnetic field it experiences a force. As a consequence of reaction force, the magnet will experience an equal and opposite force. In case PMSM motor, the current carrying conductor is stationary while the permanent magnet moves

When the stator coils are electrically switched by a supply source, it becomes electromagnet and starts producing the uniform field in the air gap. Though the source of supply is DC, switching makes to generate an AC voltage waveform with trapezoidal shape. Due to the force of interaction between electromagnet stator and permanent magnet rotor, the rotor continues to rotate.

Consider the figure below in which motor stator is excited based on different switching states. With the switching of windings as High and Low signals, corresponding winding energized as North and South poles. The permanent magnet rotor with North and South poles align with stator poles causing motor to rotate.

Observe that motor produces torque because of the development of attraction forces (when North-South or South-North alignment) and repulsion forces (when North-North or South-South alignment). By this way motor moves in a clockwise direction. As it act as Generator Reverse the process vice versa.

CHAPTER-3

3. PMSG Drive:

As described above that the electronic controller circuit energizes appropriate motor winding by turning transistor or other solid state switches to rotate the motor continuously.

The figure below shows the **simple PMSG motor drive circuit** which consists of MOSFET Bridge (also called as Inverter Bridge), electronic controller, Hall Effect sensor and PMSG motor. Here, Hall-effect sensors are used for position and speed feedback.

The electronic controller can be a microcontroller unit or microprocessor or DSP processor or FPGA unit or any other controller. This controller receives these signals, processes them and sends the control signals to the MOSFET driver circuit.

In addition to the switching for a rated speed of the motor, additional electronic circuitry changes the motor speed based on required application.

These speed control units are generally implemented with PID controllers to have precise control. It is also possible to produce four-quadrant operation from the motor whilst maintaining good efficiency throughout the speed variations using modern drives.

CHAPTER-4

4. SYSTEM CONFIGURATION

In the present scenario, the world is shifting toward the renewable energy sources as like wind energy, solar energy, etc. To suppress electricity shortage and to control the fast end of fossil fuels. Being a part of this a variable-speed Manual Pedalling generation system modelling is presented with its simulation by using PMSG [4]. The purpose of this paper is to analyze the dynamics of the variable-speed Manual Pedalling. In the following section, an overview of the model is presented by utilizing the mathematical modelling equations of variable-speed Manual Pedalling system and PMSG respectively.

Fig.1 shows the block diagram of the system as variable-speed Manual Pedalling connected to gear drive train block followed by PMSG and load. MATLAB/simulation is used for modelling and analysis.

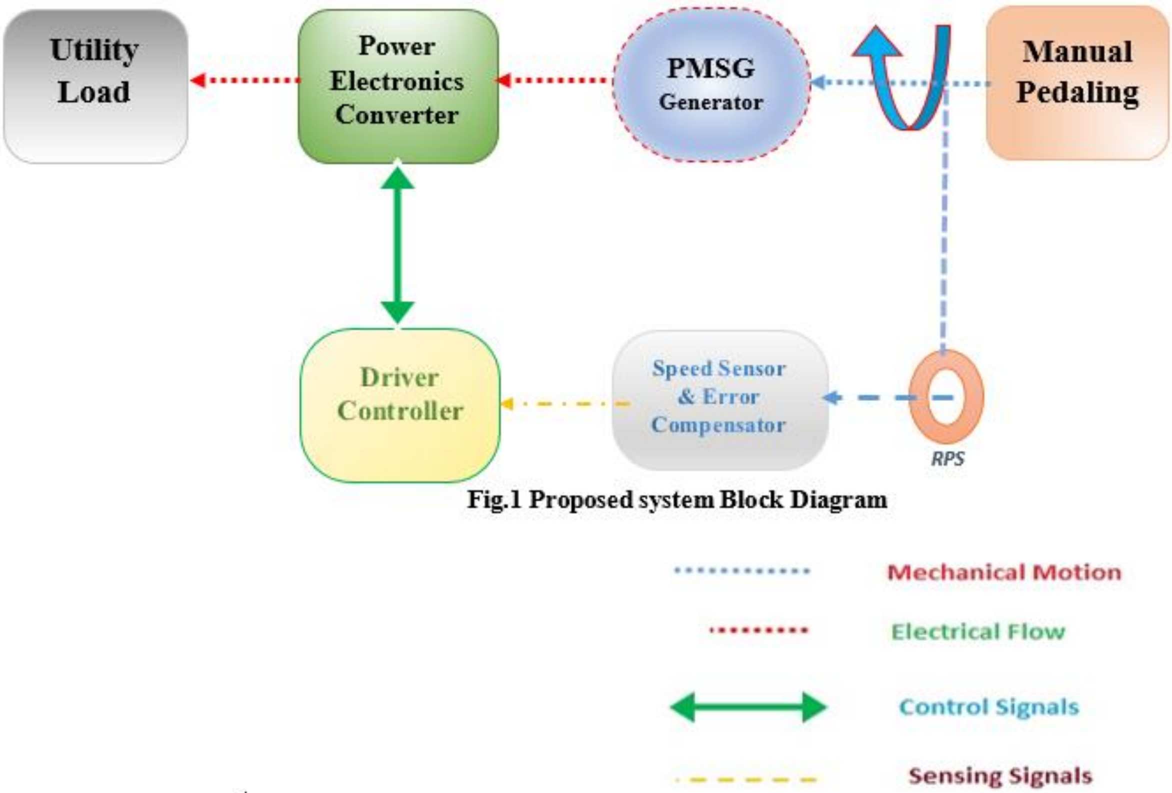
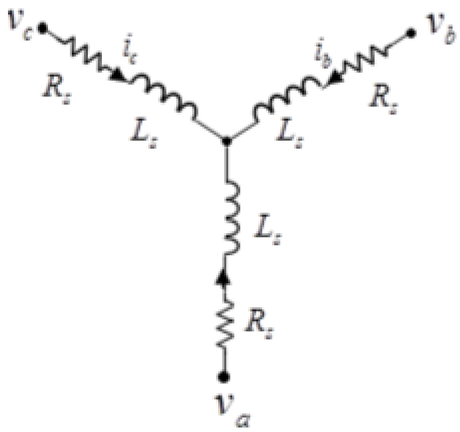


Figure 3 Proposed system Block Diagram

4.1. Description:

The PMSM block models a permanent magnet synchronous motor with a three-phase wye-wound stator.



The figure shows the equivalent electrical circuit for the stator windings.

4.2. Mathematical Expressions:

$$V_a = i_a R_a + L_a \frac{di_a}{d_t} + M_{ab} \frac{di_b}{d_t} + M_{ac} \frac{di_c}{dt} + e_a \rightarrow Eq.(1)$$

$$V_b = i_b R_b + L_b \frac{di_b}{d_t} + M_{ba} \frac{di_a}{d_t} + M_{bc} \frac{di_c}{dt} + e_b \rightarrow Eq.(2)$$

$$V_c = i_c R_c + L_c \frac{di_c}{d_t} + M_{cb} \frac{di_b}{d_t} + M_{ca} \frac{di_a}{dt} + e_c \rightarrow Eq.(3)$$

Where, R_a, R_b, R_c - Stator resistance of phase a, b and c.

L_a, L_b, L_c - Stator inductance of phase a, b and c.

i_a, i_b, i_c -Stator current of phase a, b and c.

V_a, V_b, V_c -Voltages of phase a, b and c.

$R_a = R_b = R_c = R$ -Mutual inductance between phases

L_a, L_b, L_c -Stator self inductance of phase a, b and c.

In this case, $L_a = L_b = L_c = L$

$M_{ab} = M_{ac} = M_{bc} = M_{ba} = M_{ca} = M_{cb} = M$

Assuming three phase balanced system, all phase resistance are equal.

$R_a = R_b = R_c = R$

Let us rearrange the above equations 1, 2 and 3. We get,

$$V_a = i_a R + L\frac{di_a}{d_t} + M\frac{di_b}{d_t} + M\frac{di_c}{dt} + e_a \rightarrow Eq.(4)$$

$$V_b = i_b R + L\frac{di_b}{d_t} + M\frac{di_a}{d_t} + M\frac{di_c}{dt} + e_b \rightarrow Eq.(5)$$

$$V_c = i_c R + L\frac{di_c}{d_t} + M\frac{di_b}{d_t} + M\frac{di_a}{dt} + e_c \rightarrow Eq.(6)$$

Let us neglect mutual inductance in equations 4, 5 and 6. We get,

$$V_a = i_a R + L\frac{di_a}{d_t} + e_a \rightarrow Eq.(7)$$

$$V_b = i_b R + L\frac{di_b}{d_t} + e_b \rightarrow Eq.(8)$$

$$V_c = i_c R + L\frac{di_c}{d_t} + e_c \rightarrow Eq.(9)$$

Voltages across the stator windings are defined by:

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} \frac{d\psi_a}{dt} \\ \frac{d\psi_b}{dt} \\ \frac{d\psi_c}{dt} \end{bmatrix},$$

where:

- v_a, v_b , and v_c are the individual phase voltages across the stator windings.
- R is the equivalent resistance of each stator winding.
- i_a, i_b, and i_c are the currents flowing in the stator windings.
- $\frac{d\Psi a}{dt}$ $\frac{d\Psi b}{dt}$, $\frac{d\Psi c}{dt}$, are the rates of change of magnetic flux in each stator winding.

- The permanent magnet and the three windings contribute to the total flux linking each winding.

The total flux is defined by:

$$\begin{bmatrix} \psi_a \\ \psi_b \\ \psi_c \end{bmatrix} = \begin{bmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{ba} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} \psi_{am} \\ \psi_{bm} \\ \psi_{cm} \end{bmatrix},$$

where:

- ψ_a, ψ_b, and ψ_c care the total fluxes linking each stator winding.
- L_a , L_b , and L_c are the self-inductances of the stator windings.
- L_{aa}, L_{bb} , L_{cc} , and so on, are the mutual inductances of the stator windings.
- ψ , ψ , and ψ are the permanent magnet fluxes linking the stator windings.

The inductances in the stator windings are functions of rotor electrical angle, defined by:

$$\theta_e = N\theta_r,$$

$$L_{aa} = L_s + L_m \cos(2\theta_e),$$

$$L_{bb} = L_s + L_m \cos(2(\theta_e - 2\pi/3)),$$

$$L_{cc} = L_s + L_m \cos(2(\theta_e + 2\pi/3)),$$

$$L_{ab} = L_{ba} = -M_s - L_m \cos(2(\theta_e + \pi/6)),$$

$$L_{bc} = L_{cb} = -M_s - L_m \cos(2(\theta_e + \pi/6 - 2\pi/3)),$$

and

$$L_{ca} = L_{ac} = -M_s - L_m \cos(2(\theta_e + \pi/6 + 2\pi/3)),$$

where:

- θ_r is the rotor mechanical angle.
- θ_e is the rotor electrical angle.
- L_s is the stator self-inductance per phase. This value is the average self-inductance of each of the stator windings.
- L_m is the stator inductance fluctuation. This value is the amplitude of the fluctuation in self-inductance and mutual inductance with changing rotor angle.

- M_s is the stator mutual inductance. This value is the average mutual inductance between the stator windings.

The permanent magnet flux linking winding a is a maximum when θ_e = 0° and zero when θ_e = 90°. Therefore, the linked motor flux is defined by:

$$\begin{bmatrix} \psi_{am} \\ \psi_{bm} \\ \psi_{cm} \end{bmatrix} = \begin{bmatrix} \psi_m \cos\theta_e \\ \psi_m \cos(\theta_e - 2\pi/3) \\ \psi_m \cos(\theta_e + 2\pi/3) \end{bmatrix}.$$

where ψ_m is the permanent magnet flux linkage.

Simplified Electrical Equations

Applying Park's transformation to the block electrical equations produces an expression for torque that is independent of the rotor angle.

Park's transformation is defined by:

$$P = 2/3\begin{bmatrix} \cos\theta_e & \cos(\theta_e - 2\pi/3) & \cos(\theta_e + 2\pi/3) \\ -\sin\theta_e & -\sin(\theta_e - 2\pi/3) & -\sin(\theta_e + 2\pi/3) \\ 0.5 & 0.5 & 0.5 \end{bmatrix}.$$

where θ_e is the electrical angle defined as $N\theta_r$. N is the number of pole pairs.

Using Park's transformation on the stator winding voltages and currents transforms them to the dq0 frame, which is independent of the rotor angle:

$$\begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} = P\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

and

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = P\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}.$$

Applying Park's transformation to the first two electrical equations produces the following equations that define the block behavior:

$$v_d = R_s i_d + L_d\frac{di_d}{dt} - N\omega i_q L_q,$$

$$v_q = R_s i_q + L_q\frac{di_q}{dt} + N\omega(i_d L_d + \psi_m),$$

$$v_0 = R_s i_0 + L_0\frac{di_0}{dt},$$

and

$$T = \frac{3}{2}N(i_q(i_d L_d + \psi_m) - i_d i_q L_q),$$

where
L = L + M + 3/2 L . L is the stator d-axis inductance.
L = L + M − 3/2 L . L is the stator q-axis inductance.
L = L – 2M . L is the stator zero-sequence inductance.
ω is the rotor mechanical rotational speed.
N is the number of rotor permanent magnet pole pairs.
T is the rotor torque. Torque flows from the motor case (block physical port C) to the motor rotor (block physical port R).
The PMSM block uses the original, non-orthogonal implementation of the Park transform. If you try to apply the alternative implementation, you get different results for the dq0 voltage and currents.

Chapter-5

5. Alternative Flux Linkage Parameterization

You can parameterize the motor using the back EMF or torque constants which are more commonly given on motor datasheets by using the **Permanent magnet flux linkage** option.

The back EMF constant is defined as the peak voltage induced by the permanent magnet in each of the phases per unit rotational speed.

It is related to peak permanent magnet flux linkage by:

$$ke = N\psi m.$$

From this definition, it follows that the back EMF e_{ph} for one phase is given by:

$$eph = ke\omega.$$

The torque constant is defined as the peak torque induced by each of the phases per unit current.

It is numerically identical in value to the back EMF constant when both are expressed in SI units:

$$kt = N\psi m$$

When L_d=L_q, and when the currents in all three phases are balanced, it follows that the combined torque T is given by:

$$e_{ph} = k_e \omega.$$

The torque constant is defined as the peak torque induced by each of the phases per unit current. It is numerically identical in value to the back EMF constant when both are expressed in SI units:

$$k_t = N\psi_m.$$

When L_d=L_q, and when the currents in all three phases are balanced, it follows that the combined torque T is given by:

$$T = \frac{3}{2}k_t i_q = \frac{3}{2}k_t I_{pk},$$

where I_{pk} is the peak current in any of the three windings.

The factor 3/2 follows from this being the steady-state sum of the torques from all phases. Therefore the torque constant k_t could also be defined as:

$$k_t = \frac{2}{3}\left(\frac{T}{I_{pk}}\right),$$

where T is the measured total torque when testing with a balanced three-phase current with peak line voltage I_{pk}. Writing in terms of RMS line voltage:

$$k_t = \sqrt{\frac{2}{3}}\left(\frac{T}{i_{line,rms}}\right).$$

The Permanent Magnet Synchronous Machine block operates in either generator or motor mode. The mode of operation is dictated by the sign of the mechanical torque (positive for motor mode, negative for generator mode). The electrical and mechanical parts of the machine are each represented by a second-order state-space model.

The sinusoidal model assumes that the flux established by the permanent magnets in the stator is sinusoidal, which implies that the electromotive forces are sinusoidal.

The trapezoidal model assumes that the winding distribution and flux established by the permanent magnets produce three trapezoidal back EMF waveforms.

The block implements the following equations.

5.1. Three-Phase Sinusoidal Model Electrical System

These equations are expressed in the rotor reference frame (qd frame). All quantities in the rotor reference frame are referred to the stator.

$$\frac{d}{dt}i_d = \frac{1}{L_d}v_d - \frac{R}{L_d}i_d + \frac{L_q}{L_d}p\omega_m i_q$$

$$\frac{d}{dt}i_q = \frac{1}{L_q}v_q - \frac{R}{L_q}i_q - \frac{L_d}{L_q}p\omega_m i_d - \frac{\lambda p\omega_m}{L_q}$$

$$T_e = 1.5p[\lambda i_q + (L_d - L_q)i_d i_q]$$

L_q, L_d	q and d axis inductances
R	Resistance of the stator windings
i_q, i_d	q and d axis currents
v_q, v_d	q and d axis voltages
ω_m	Angular velocity of the rotor
λ	Amplitude of the flux induced by the permanent magnets of the rotor in the stator phases
p	Number of pole pairs
T_e	Electromagnetic torque

The L_q and L_d inductances represent the relation between the phase inductance and the rotor position due to the saliency of the rotor. For example, the inductance measured between phase a and b (phase c is left open) is given by:

$$L_{ab} = L_d + L_q + (L_q - L_d)\cos\left(2\theta_e + \frac{\pi}{3}\right)$$

Θ_e represents the electrical angle.

The next figure shows the variation of the phase to phase inductance in function of the electrical angle of the rotor.

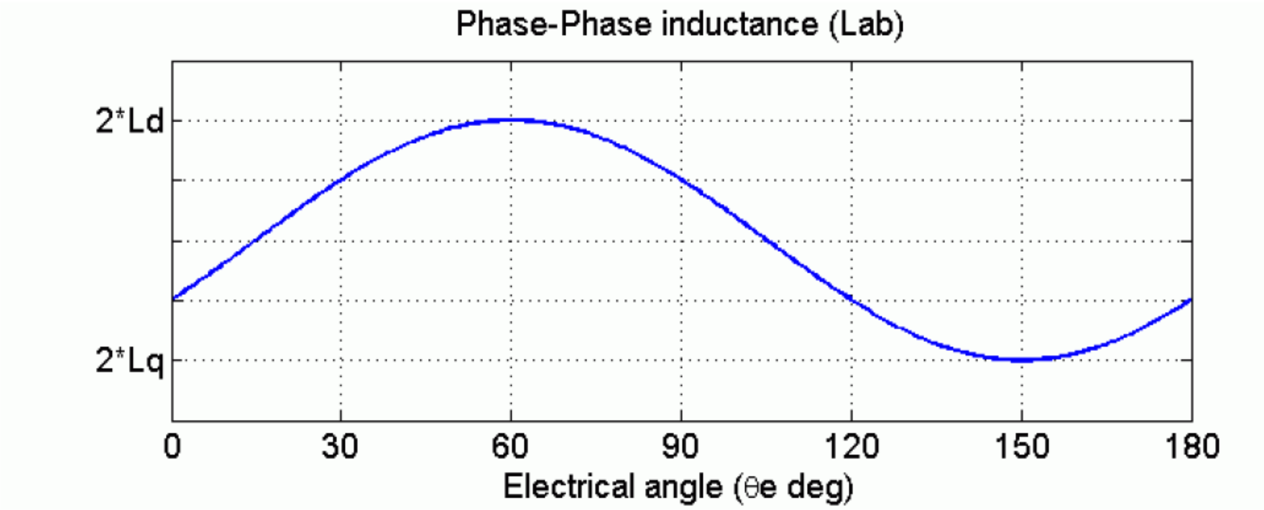


Figure 4Phase-Phase Inductance

- For a round rotor, there is no variation in the phase inductance.

$$L_d = L_q = \frac{L_{ab}}{2}$$

- For a salient round rotor, the dq inductances are given by:

$$L_d = \frac{\max(L_{ab})}{2}$$

and

$$L_q = \frac{\min(L_{ab})}{2}$$

5.2. Three-Phase Trapezoidal Model Electrical System

These equations are expressed in the phase reference frame (abc frame). Note that the phase inductance L_s is assumed constant and does not vary with the rotor position.

$$\frac{d}{dt}i_a = \frac{1}{3L_s}\left(2v_{ab} + v_{bc} - 3R_s i_a + \lambda p\omega_m\left(-2\Phi'_a + \Phi'_b + \Phi'_c\right)\right)$$

$$\frac{d}{dt}i_b = \frac{1}{3L_s}\left(-v_{ab} + v_{bc} - 3R_s i_b + \lambda p\omega_m\left(\Phi'_a - 2\Phi'_b + \Phi'_c\right)\right)$$

$$\frac{d}{dt}i_c = -\left(\frac{d}{dt}i_a + \frac{d}{dt}i_b\right)$$

$$T_e = p\lambda\left(\Phi'_a \cdot i_a + \Phi'_b \cdot i_b + \Phi'_c \cdot i_c\right),$$

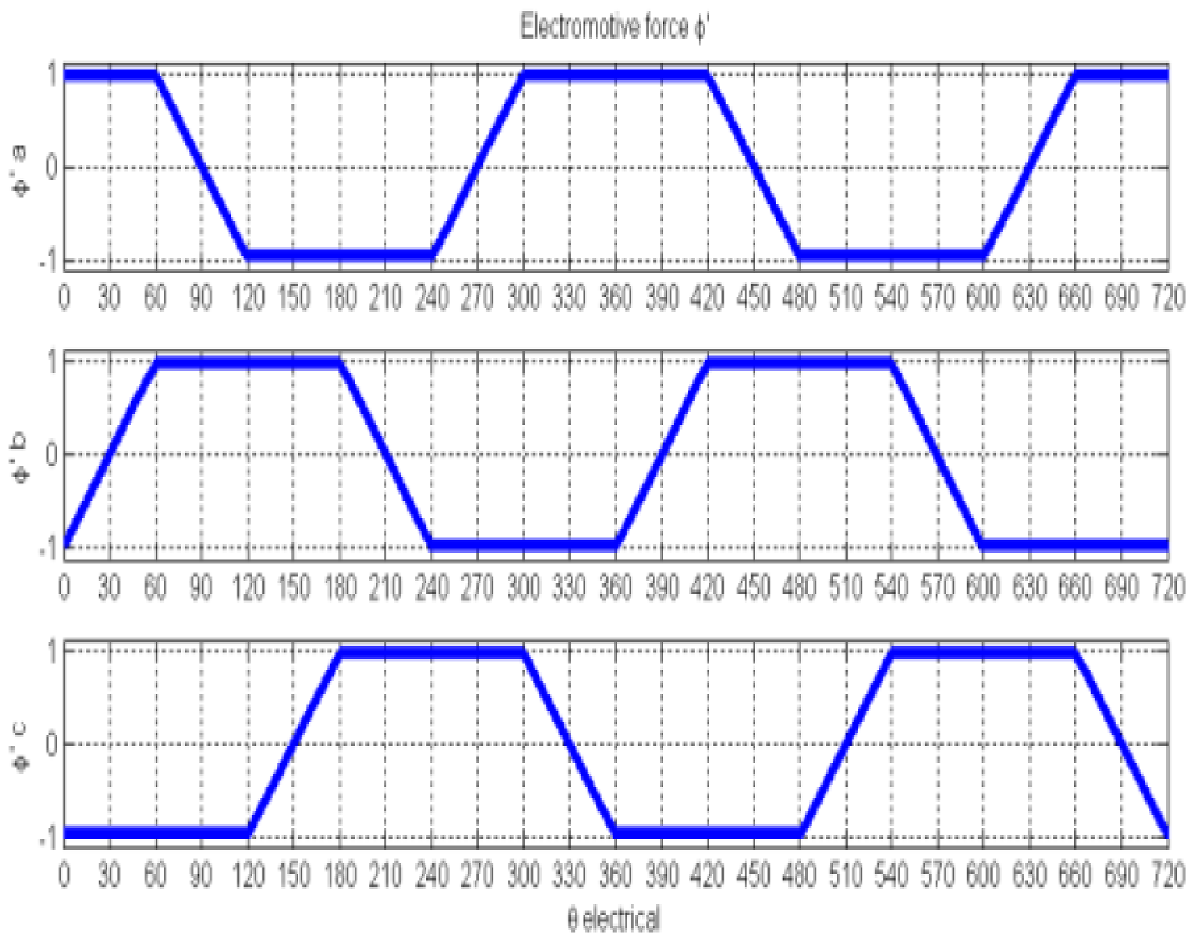


Figure 5Trapezoidal Waveform

and

L_s	Inductance of the stator windings
R	Resistance of the stator windings
i_a, i_b, i_c	a, b and c phase currents
Φ_a', Φ_b', Φ_c'	a, b and c phase electromotive forces, in per-unit value to the amplitude of the flux λ.
v_{ab}, v_{bc}	ab and bc phase to phase voltages
ω_m	Angular velocity of the rotor
λ	Amplitude of the flux induced by the permanent magnets of the rotor in the stator phases
p	Number of pole pairs
T_e	Electromagnetic torque

5.3. Mechanical System (for all models):

$$\frac{d}{dt}\omega_m = \frac{1}{J}(T_e - T_f - F\omega_m - T_m)$$

$$\frac{d\theta}{dt} = \omega_{m,}$$

J	Combined inertia of rotor and load
F	Combined viscous friction of rotor and load
θ	Rotor angular position
T_m	Shaft mechanical torque
T_f	Shaft static friction torque
ω_m	Angular velocity of the rotor (mechanical speed)

Configuration Tab

Number of phases

Select between a three-phase machine model or a five-phase machine model. Default is `3`. This parameter is disabled when the **Back EMF waveform** parameter is set to `Trapezoidal`, or when the **Rotor type** parameter is set to `Salient-pole`.

Back EMF waveform

Select between the `Sinusoidal` (default) and the `Trapezoidal` electromotive force. This parameter is disabled when the **Number of phases** parameter is set to `5`.

Rotor type

Select between the `Salient-pole` and `Round`, the round (cylindrical) rotor. Default is `Round`. This parameter is disabled when the **Number of phases** parameter is set to `5` or when the **Back EMF waveform** parameter is set to `Trapezoidal`.

Mechanical input

Select the torque applied to the shaft, the rotor speed as a Simulink® input of the block, or to represent the machine shaft by a Simscape™ rotational mechanical port.

Select `Torque Tm` (default) to specify a torque input, in N.m., and change labeling of the block input to `Tm`. The machine speed is determined by the machine Inertia J and by the difference between the applied mechanical torque Tm and the internal electromagnetic torque Te. The sign convention for the mechanical torque is when the speed is positive, a positive torque signal indicates motor mode and a negative signal indicates generator mode.

Select `Speed w` to specify a speed input, in rad/s, and change labeling of the block input to `w`. The machine speed is imposed and the mechanical part of the model (Inertia J) is ignored. Using the speed as the mechanical input allows modeling a mechanical coupling between two machines.

The next figure indicates how to model a stiff shaft interconnection in a motor-generator set when friction torque is ignored in machine 2. The speed output of machine 1 (motor) is connected to the speed input of machine 2 (generator), while machine 2 electromagnetic torque output Te is applied to the mechanical torque input Tm of machine 1. The Kw factor takes into account speed units of both machines (pu or rad/s) and gear box ratio `w2/w1`. The KT factor takes into account torque units of both machines (pu or N.m) and machine ratings. Also, as the inertia J2 is ignored in machine 2, J2 referred to machine 1 speed must be added to machine 1 inertia J1.

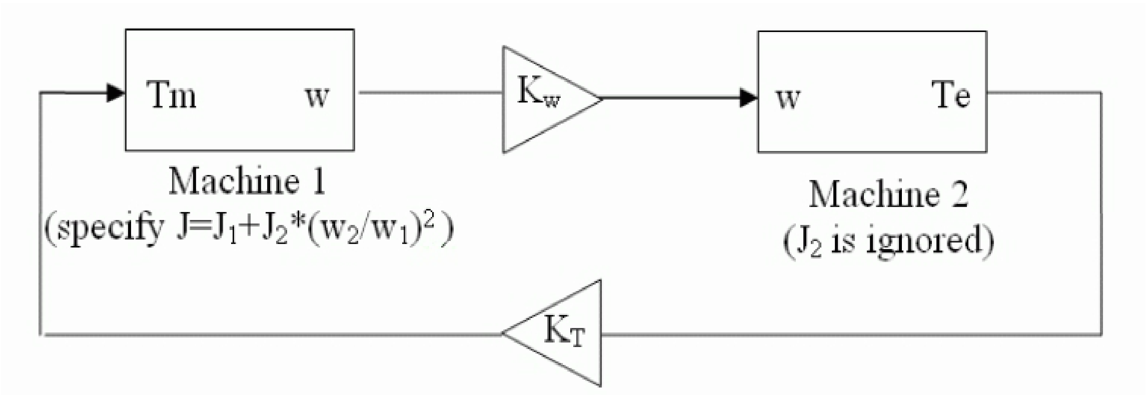
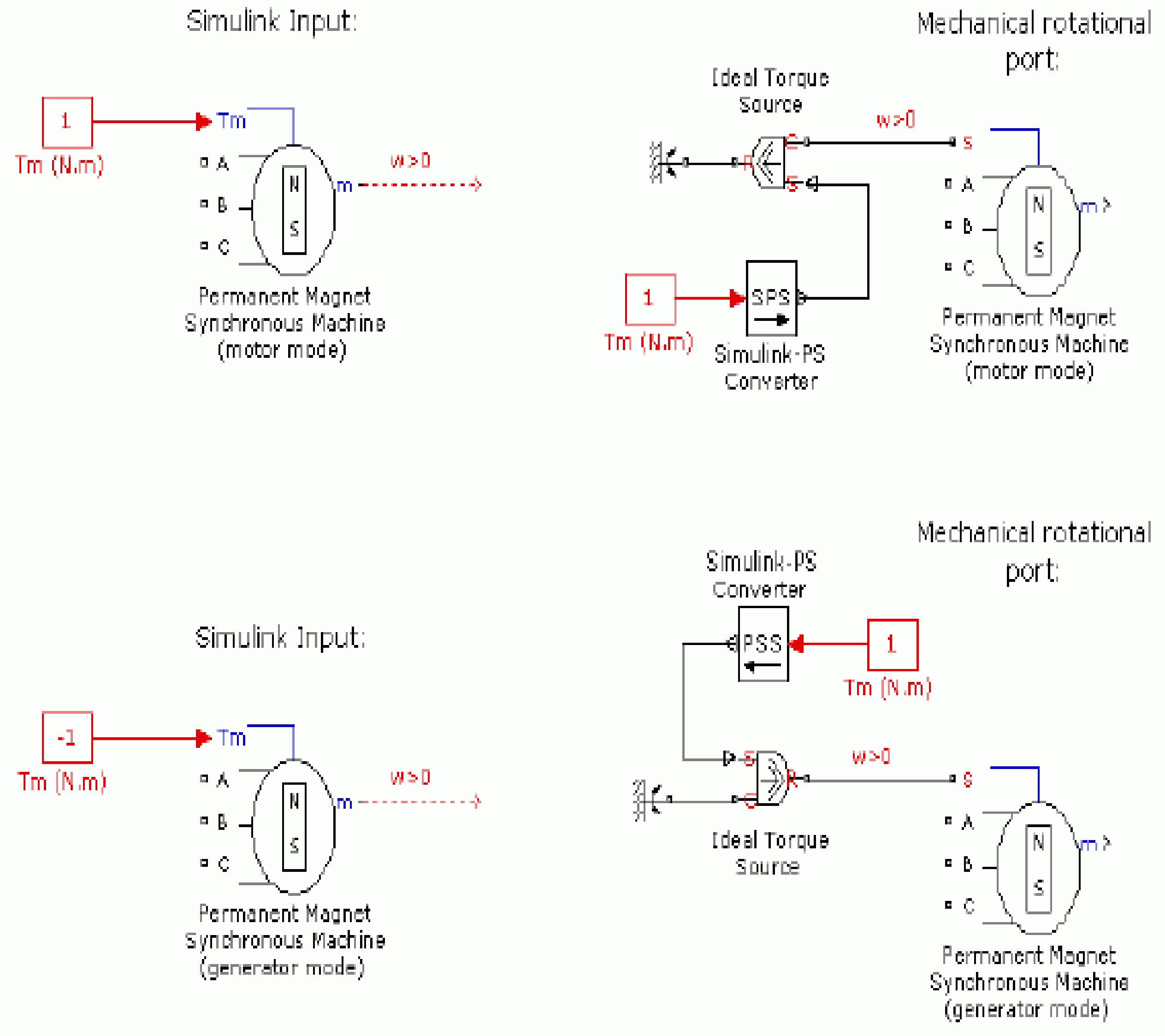


Figure 6Mechanical Block Diagram

Select `Mechanical rotational port` to add to the block a Simscape mechanical rotational port that allows connection of the machine shaft with other Simscape blocks with mechanical rotational ports. The Simulink input representing the mechanical torque `Tm` or the speed `w` of the machine is then removed from the block.

The next figure indicates how to connect an Ideal Torque Source block from the Simscape library to the machine shaft to represent the machine in motor mode, or in generator mode, when the rotor speed is positive.



Preset Model

Provides a set of predetermined electrical and mechanical parameters for various permanent magnet synchronous motor ratings of torque (N.m), DC bus voltage (V), rated speed (rpm), and continuous stall torque (N.m).

The **Preset Model** parameter is enabled only when the **Back EMF waveform** parameter is set to `Sinusoidal`, and the **Rotor type** parameter is set to `Round`.

CHAPTER-6

6. MATHEMATICAL MODELLING:

6.1. Modelling of Pedalling Gymnastics Bicycle:

Mechanical torque developed by Pedal,

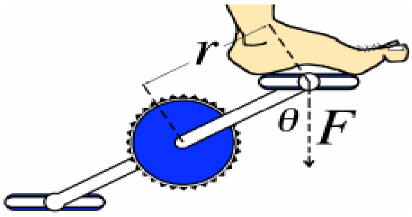


Figure 7Torque developed by pedal

The length of a bicycle pedal arm is r =0.152m, and a downward force of F = 111N is applied by the foot.

$$\tau = r\,F\,\sin\,\theta$$

Where,

r = length of bicycle pedal arm
F = Applied Force
θ = angle between arm and vertical line

i) When θ = 90 degree, sin θ = 1 at the time only the Force completely appeared to Pedal.

ii) But, When θ = 180 degree, sin θ = 0 so the force exerts no torque on the pedal. This is the situation when the pedal is at the bottom; no amount of pushing down at this point can produce any torque on the pedal.

6.2 Modelling of PMSG:

The permanent magnet synchronous machine (PMSG) is interesting for a generator coupled to any system; despite the high cost which is its major drawback, PMSG presents many advantages compared to other types of electric machines(performance, robustness ... etc.).The PMSG transforms the mechanical energy applied to the shaft by the pedal-based emulator to electrical power; it is sent to the network via the DC bus or battery storage.

A model in the d-q reference (using Park transformation) of this machine will be used. The d-q reference is a two-phase marker, equivalent phase marker, easier to handle because electrical quantities evolve as continuous variables.

The equations of the synchronous machine with permanent magnets in the d-q reference are the following:

6.2.1 Flow equations:

$$\psi_{s_d} = L_d\, i_{s_d} + K_A$$
$$\psi_{s_q} = L_q\, i_{s_q}$$

Where KA is the constant power corresponding to the excitation flux in the d-q reference.

6.2.2 Voltage equations:

$$v_{s_d} = R_s\, i_{s_d} + \frac{d\psi_{sd}}{dt} - \omega_s\, \psi_{s_q}$$
$$v_{s_q} = R_s\, i_{s_q} + \frac{d\psi_{sd}}{dt} + \omega_s\, \psi_{s_d}$$

The permanent magnets are uniformly distributed in the rotor, smooth poles machine will be considered in modelling ($L_s = L_d = L_q$).

$$v_{s_d} = R_s\, i_{s_d} + L_s \frac{di_{sd}}{dt} - \omega_s\, L_s\, i_{s_q}$$
$$v_{s_q} = R_s\, i_{s_q} + L_s \frac{di_{sq}}{dt} + \omega_s\, L_s\, i_{s_d} + \omega_s \psi_M$$

Electromagnetic torque (with $L_s = L_d = L_q$):

$$T_{em_{PMSM}} = p\,(\psi_{s_d}\, i_{s_q} - \psi_{s_q}\, i_{s_d})$$
$$T_{em_{PMSM}} = p\left((L_d\, i_{s_d} + K_A)\, i_{s_q} - L_q\, i_{s_q}\, i_{s_d} \right)$$
$$= p\left(L_d\, i_{s_d}\, i_{s_q} + K_A\, i_{s_q} - L_q\, i_{s_q}\, i_{s_d} \right)$$
$$T_{em_{PMSM}} = p\, K_A\, i_{s_q}$$

Where i_{sq}, i_{sd} are the stator currents in d-q reference (A) and V_{Sd}' V_{Sq} are the stator voltages in the d-q reference (V), R_s and Ls are respectively the stator resistance (Q) and the stator
ring induction (H), ρ and ω_s are the number of pairs of poles of the machine and the pulse voltages (rad Is).

CHAPTER-7

7. Control Strategy for Generating System:

To control the electrical power generator P_{ge}, it is sufficient to control the electromechanical torque Tern by controlling the stator currents, knowing the rotation speed of the shaft. Speed is limited by the guidance system of the pedals which is activated by reaching the nominal speed of the machine. The electromechanical reference torque may be developed in two different ways: Operating at maximum power: To improve the pedaling efficiency to extract the maximum energy. Fixed power operation: In order to limit the generator power at its nominal value by reducing the torque acting on the pitch angle (speed reduction).

The maximum power $P_{ge\ max}$ is continuously calculated and compared with the reference power $P_{ge\ ref}$

$$P_{ge_{max}} = \frac{\rho\, \pi\, R_T^{\ 5}\, C_{p_{max}}}{2\, \lambda_{opt}^{\ 3}}\, \Omega_T^{\ 3} = k\, \Omega_T^{\ 3}$$

i) If $P_{ge\ ref} > P_{ge\ max}$: the pedaling performance is able to generate the required power.

ii) If $P_{ge\ ref} < P_{ge\ max}$: the pedaling performance cannot generate $P_{ge\ ref}$, then the generator will charge the maximum power that can be extracted from the pedaling.

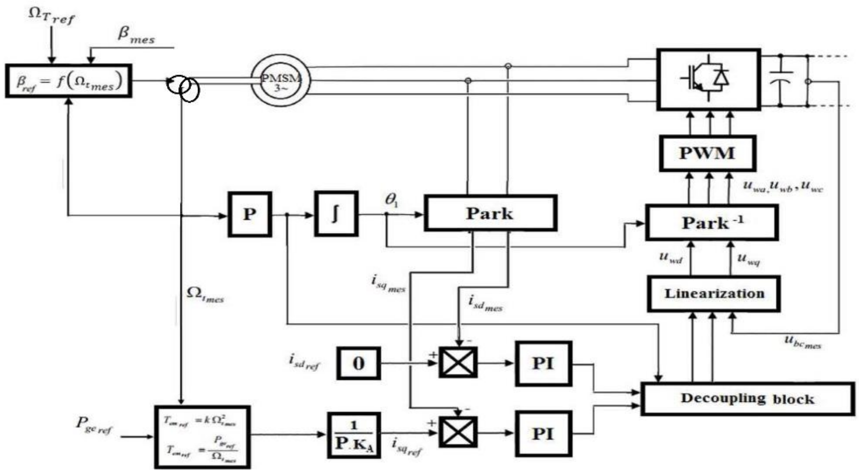


Figure 8Control Strategy

TABLE I. THE CONTROL STRATEGY

Condition	$P_{ge_{ref}} \leq P_{ge_{max}}$	$P_{ge_{ref}} > P_{ge_{max}}$
$T_{em_{ref}}$	$\frac{P_{ge_{ref}}}{\Omega_T}$	$k\, \Omega_T^{\ 2}$

CHAPTER-8

8. MATLAB Simulations:

A Simulink model of a Bicycle Pedaling with permanent magnet synchronous generator (PMSG) built up using MATLAB /SIMULINK software. In this model, Bicycle Pedaling shaft is mechanically connected with permanent magnet synchronous (drive Train PMSG) which is connected to grid through three phase series RLC branch .Waveform of voltage and current is sinusoidal and the simulation waveform for output mechanical power and torque (T_e & T_m) is also shown which are showing normal behavior after attaining a good value for system.

a) Main Simulation:

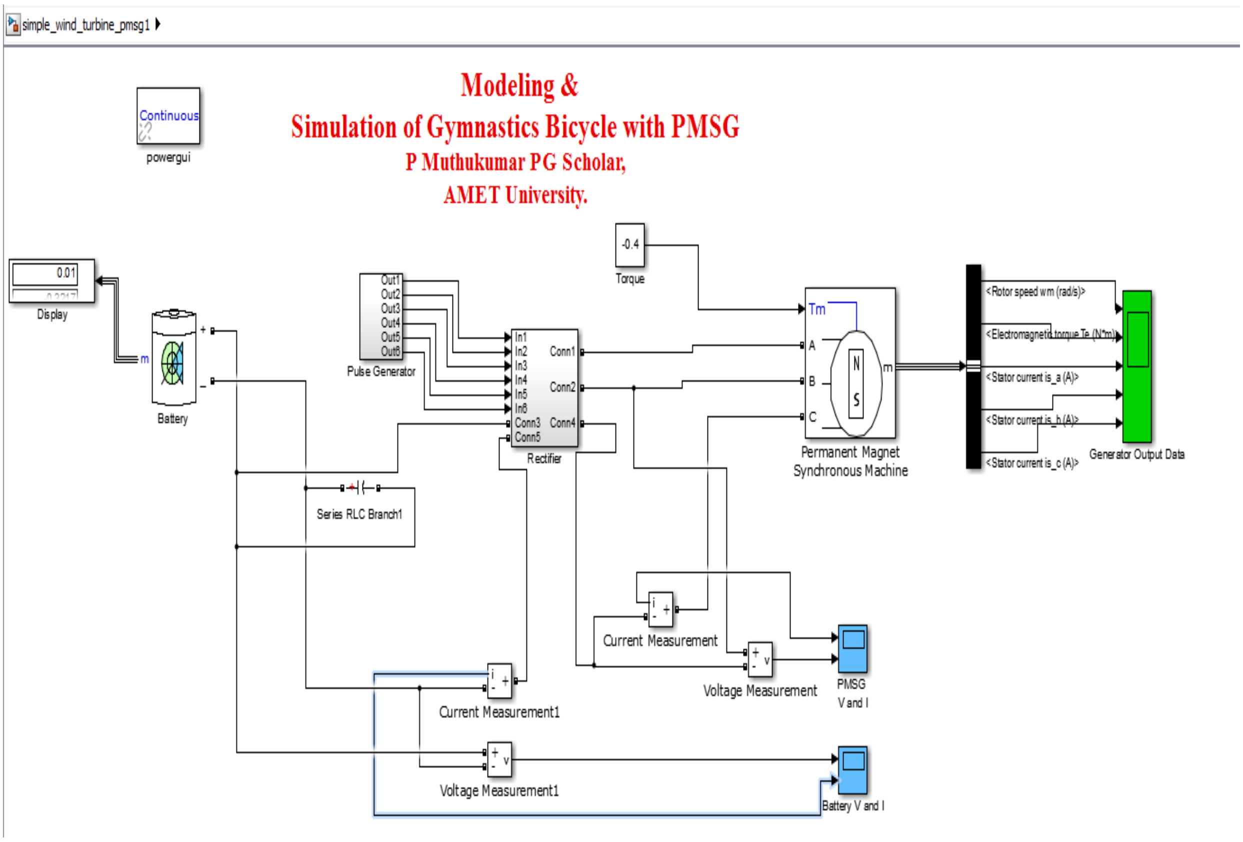
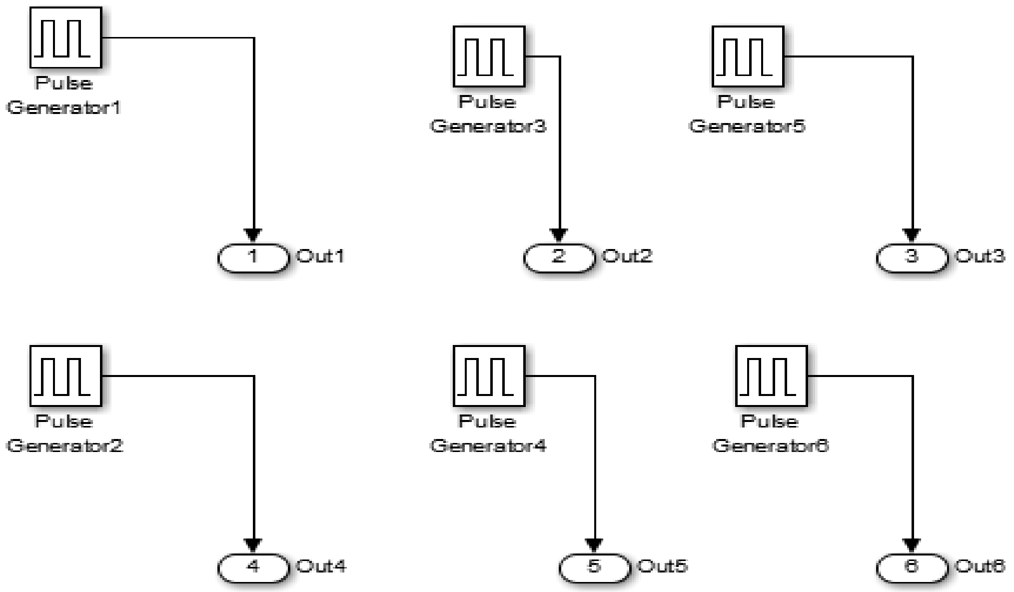


Figure 9MATLAB Simulation

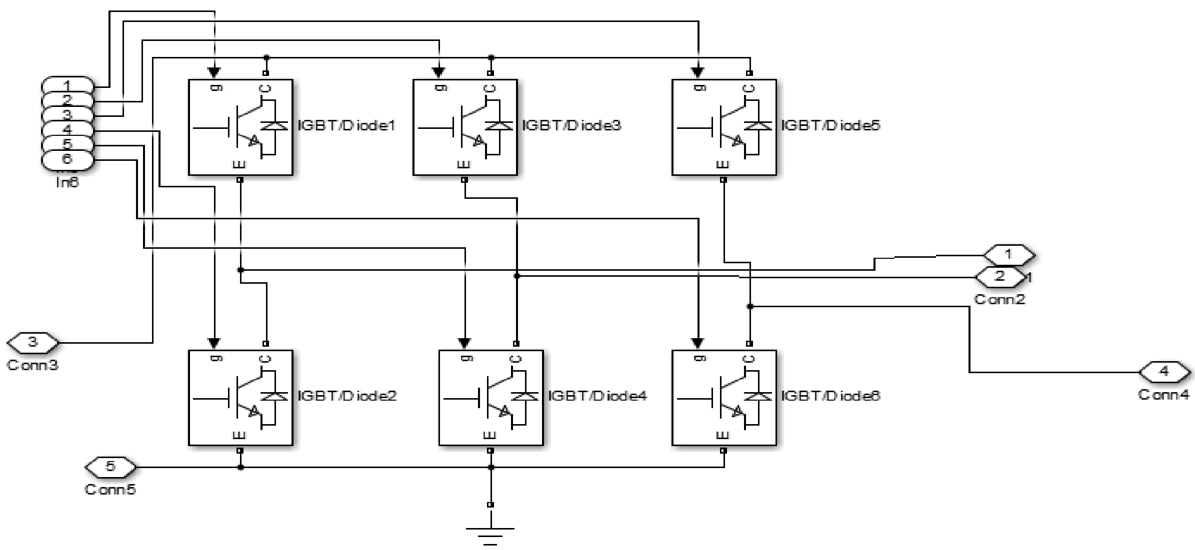
Pulse Generator Section:

Switching Frequency of IGBT = 15 KHz

Technique = SVPWM



Rectifier Section:



PMSG Specification:

In MATLAB Model

Number of Poles: 3

Back EMF waveform: Sinusoidal

Rotor Type: Round

Mechanical Input: Torque, T_m

Present Model:

T_m = 1.0 Nm;

V_{dc}=250 Volt;

Speed =1000 RPM;

Stator Phase resistance R_s (Ohm) =18.7 Ohm

Armature inductance (H) = 0.02682 H

Machine constant:

Specify: Flux linkage established by magnets (V.s)

Flux linkage: 0.1717

If Apply Torque = 0.5 Nm ,Will Get Speed = 500 RPM with 250 Vdc.

CHAPTER-9

9. Characteristics Waveforms:

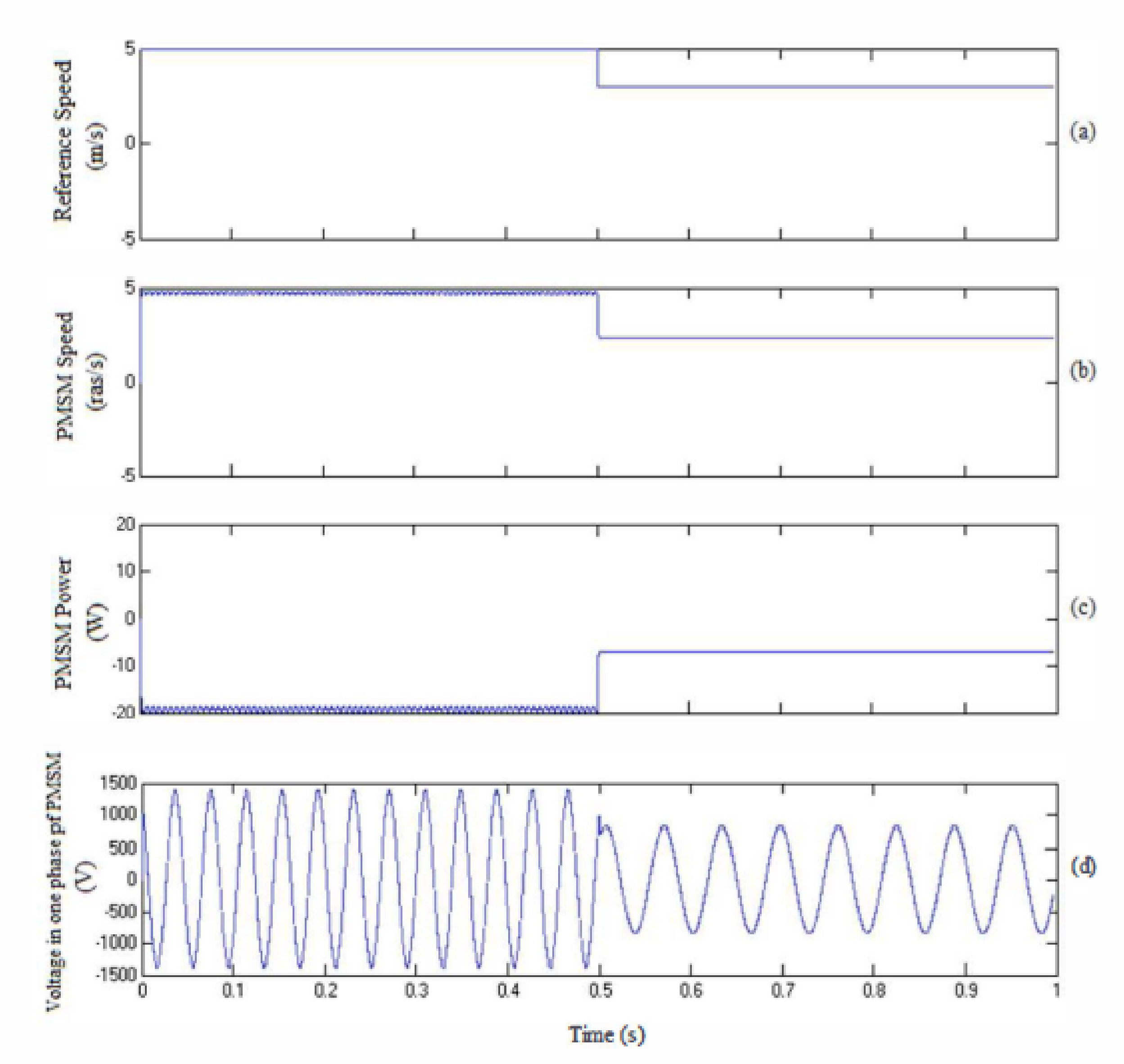


Figure 10 Simulation Output Waveforms

Graph shows the variation of Speed (b), Power (c) and Voltage in any one phase (d) with time for a stepped input variation (a) using MATLAB/Simulink

CHAPTER-10

10. Conclusion:

The modelling of a variable speed Bicycle Pedaling with a permanent magnet synchronous generator has been treated. The model has been implemented in MATLAB/Simulink in order to validate the theoretical study. The generator has been modelled in the d-q synchronous rotating reference frame, taking into account different simplifications. There is therefore a real interest to be able to generalize the use of the bond graph tool in electrical networks. So, in future work, we will model the global production chain by using the bond graph energetic approach, make the simulations in MATLAB software and draw a comparison between the different methods.

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Title of the Project: Energy management system Based on DC-DC converter for micro grid using Hybrid energy

Project / **Home Internship Report**

Submitted by:

A. RAMYA. (AMPS 18008)

Signature of Mentor

AMET

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(Under Section 3 of UGC Act 1956)

BONAFIDE CERTIFICATE

This is to certify that the home based internship entitled "....Energy management System Based on DC-DC Converter for micro Grid Hybrid energy.... submitted by........A. RAMYA..............Reg.No:..AM.PS.18008..... in ....IV........ semester during year ......2019-20.................. for the degree of ...Master of Engineering............ of is a bonafide record of technical work carried out by him under my supervision.

V. Senthilkumar
Signature Mentor

V. Senthilkumar
Signature of Dean/HoD

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Project / INTERNSHIP ALLOCATION REPORT 2019-20

Name of the Department: Electrical and Electronics Engineering

(in the view of advisory from the AICTE, Internships for the year 2019-20 are offered by the Department of itself to facilitate the students to take up required work from their home itself during the lockdown period due to COVID19 outbreak)

Name of the Programme : Electrical and Electronics Engineering

Year of study and Batch/group: II year

Name of the Mentor : V. Karthikeyan

Title of the assigned internship:

Nature of Internship : Individual ✓/ Group

Reg no of the students who are assigned with this internship:

Total No of hours Required to complete the internship:

Signature of Mentor	Signature of Internal Examiner	Signature of HoD/Dean
V. Sathish Kumar	C. SX	V. Sathish Kumar

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Name of the student	A. Ramya
Register No. and Roll No	AMPS18008
Programme of study	2019-20
Year and Batch/Group	II
Semester	IV
Title of Internship / Project	Energy management system based DC-DC converter for micro grid
Duration of Internship	2019-20
Mentor of the student	A. RAMYA

Evaluation of the Department:

S.no	Criteria	Max Marks	Marks allotted
1	Regularity in the maintenance of daily	10	10
2	Adequacy and quality of Information recorded	10	10
3	Drawings, sketches, and data recorded	10	10
4	Thought process and data recording techniques used	5	5
5	Organization of information	5	5
6	Originality of information report	20	15
7	Adequacy and purposeful write-up of the internship report	10	10
8	Organization, format, drawing, sketched, style, language etc of internship Report	10	10
9	Practical application, relationship with basic theory and concepts	10	10
10	Presentation skills	10	10
	Total	100	95

Signature of Mentor	Signature of Internal Examiner	Signature of HoD/Dean
V. Senthil	C. [illegible]	V. Senthil

ENERGY MANAGEMENT SYSTEM BASED ON DC-DC CONVERTER FOR MICRO GRID USING HYBRID ENERGY SOURCES

PROJECT REPORT

Submitted by

A. RAMYA (AMPS18008)

In partial fulfillment for the award of the degree

Of

MASTER OF ENGINEERING

IN

POWER SYSTEMS

AMET DEEMED TO BE UNIVERSITY :: CHENNAI 603112

JUNE 2020

ACKNOWLEDGEMENT

We wish to express our sincere thanks to our chancellor **Dr. J. RAMACHANDRAN** for providing the necessary facilities in the college premises to carry out the project

We would like to express our sincere thanks towards our beloved Vice – Chancellor, **Col.Dr.G.THIRUVASAGAM** for providing us with an environment to complete the project successfully.

We wish to express our heartiest thanks to **Dr.T.SASILATHA**, Dean and Professor, Department of EEE for her advice and motivation, which helped us to accomplish this project work.

We are grateful to our guide, **R.K.PADMASHINI,** Assistant Professor, Department of EEE for his valuable and precious guidance to our project.

We would like to thank our parents and friends for moral financial support.

Finally, we thank Almighty for making us capable and giving us the dedication and determination to complete the project on time.

ABSTRACT

This project presents a control of a micro-grid at an isolated location fed from wind and solar based hybrid energy sources. The machine used for wind energy conversion is doubly fed induction generator (DFIG) and a battery bank is connected to a common DC bus of them. A solar photovoltaic (PV) array is used to convert solar power, which is evacuated at the common DC bus of DFIG using a DC-DC Luo converter in a cost effective way. The voltage and frequency are controlled through an indirect vector control of the line side converter, which is incorporated with droop characteristics. It alters the frequency set point based on the energy level of the battery, which slows down over charging or discharging of the battery. The system is also able to work when wind power source is unavailable. Both wind and solar energy blocks, have maximum power point tracking (MPPT) in their control algorithm. The system is designed for complete automatic operation taking consideration of all the practical conditions. The system is also provided with a provision of external power support for the battery charging without any additional requirement. Neuro Fuzzy logic algorithm is used to track the power from PV system. A simulation model of system is developed in Matlab environment and simulation results are presented for various conditions e.g. unviability of wind or solar energies, unbalanced and nonlinear loads, low state of charge of the battery.

CHAPTER-1

INTRODUCTION

1.1INTRODUCTION

As electric distribution technology steps into the next century, many trends are becoming noticeable that will change the requirements of energy delivery. These modifications are being driven from both the demand side where higher energy availability and efficiency are desired and from the supply side where the integration of distributed generation and peaks having technologies must be accommodated. Power systems currently undergo considerable change in operating requirements mainly as a result of deregulation and due to an increasing amount of distributed energy resources (DER). In many cases DERs include different technologies that allow generation in small scale (micro source) and some of them take advantage of renewable energy resources (RES) such as solar, wind or hydro energy. Having micro sources close to the load has the advantage of reducing transmission losses as well as preventing network congestions. Moreover, the possibility of having a power supply interruption of end-customers connected to a low voltage (LV) distribution grid (in Europe 230 V and in the USA 110 V) is diminished since adjacent micro sources, controllable loads and energy storage systems can operate in the islanded mode in case of severe system disturbances. This is identified nowadays as a microgrid. Figure1.1 depicts a typical microgrid. The distinctive microgrid has the similar size as a low voltage distribution feeder and will rare exceed a capacity of 1 MVA and a geographic span of 1 km. Generally more than 90% of low voltage domestic customers are supplied by underground cable when the rest is supplied by overhead lines. The microgrid often supplies both electricity and heat to the customers by means of combined heat and power plants (CHP), gas turbines, fuel cells, photovoltaic (PV) systems, wind turbines, etc. The energy storage systems usually include batteries and flywheels. The storing device in the microgrid is equivalent to the rotating reserve of large generators in the conventional grid which ensures the balance between energy generation and consumption especially during rapid changes in load or generation . From the customer point of view, microgrids deliver both thermal and electricity requirements and in addition improve local reliability, reduce emissions, improve power excellence by supportive voltage and reducing voltage dips and potentially lower costs of energy supply. From the utility viewpoint, application of distributed energy sources can potentially reduce the demand for distribution and transmission facilities. Clearly, distributed generation located close to loads will reduce flows in transmission and distribution circuits with two important effects: loss reduction and ability to potentially substitute for network assets. In addition, the presence of generation close to demand could increase service quality seen by end customers. Microgrids can offer network support during the time of stress by relieving congestions and aiding restoration after faults. The development of microgrids can contribute to the reduction of emissions and the mitigation of climate changes. This is due to the availability and developing technologies for distributed generation units are based on renewable sources and micro sources that are characterized by very low emissions. There are various advantages offered by microgrids to end-consumers, utilities and society, such as: improved energy efficiency, minimized overall energy consumption, reduced greenhouse gases and pollutant emissions, improved service quality and reliability, cost efficient electricity infrastructure replacement. Technical challenges linked with the operation and controls of microgrids are immense. Ensuring stable operation during network disturbances, maintaining stability and power quality in the islanding mode of operation necessitates the improvement of sophisticated control strategies for microgrids inverters in order to provide stable frequency and voltage in the presence of arbitrarily varying loads. In light of these, the microgrid concept has stimulated many researchers and attracted the attention of governmental organizations in Europe, USA and Japan. Nevertheless, there are various technical issues associated with the integration and operation of microgrids. 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 micro source 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. Mainly, there are two main issues concerning the protection of microgrids, first is related to a number of installed DER units in the microgrid and second is related to an availability of a sufficient level of short-circuit current in the islanded operating mode of microgrid since this level may substantially drop down after a disconnection from a stiff main grid. In the authors have made short-circuit current calculations for radial feeders with DER and studied that short-circuit currents which are used in over-current (OC) protection relays depend on a connection point of and a feed-in power from DER. The directions and amplitudes of short circuit currents will vary because of these conditions. In reality the operating conditions of microgrid are persistently varying because of the intermittent micro sources (wind and solar) and periodic load variation. Also the network topology can be changed frequently which aims to minimize loss or to achieve other economic or operational targets. In addition controllable islands of different size and content can be formed as a result of faults in the main grid or inside microgrid. In such 4 situations a loss of relay coordination may happen and generic OC protection with a single setting group may become insufficient, i.e. it will not guarantee a selective operation for all possible faults. Hence, it is vital to ensure that settings chosen for OC protection relays take into account a grid topology and changes in location, type and amount of generation. Otherwise, unwanted operation or failure may occur during necessary condition. To deal with bi-directional power flows and low short-circuit current levels in microgrids dominated by micro sources with power electronic interfaces a new protection philosophy is essential, where setting parameters of relays must be checked/updated periodically to make sure that they are still appropriate.

1.2 MOTIVATION

The microgrid concept acts as a solution to the conundrum of integrating large amounts of micro generation without disrupting the operation of the utility network. With intelligent coordination of loads and micro-generation, the distribution network subsystem (or 'microgrid') would be less trouble some to the utility network, than conventional micro generation. The net microgrid could even provide ancillary services such as local voltage control. In case of disturbances on the main network, microgrids could potentially disconnect and continue to operate separately. This operation improves power quality to the customer. From the grid’s perception, the benefit of a microgrid is that can be considered as a controlled entity within the power system that can be functioned as a single aggregated load. Customers can get benefits from a microgrid because it is designed and operated to meet their local needs for heat and power as well as provide uninterruptible power, enhance local reliability, reduce feeder losses, and support local voltages/correct voltage sag. In addition to generating technologies, microgrid also includes storage, load control and heat recovery equipment. The ability of the microgrid to operate when connected to the grid as well as smooth transition to and from the island mode is another important function.

1.3 OBJECTIVE

- To implement hybrid energy system based three phase micro grid.
- To maintain constant voltage to the DC grid using Modified LUO converter with Neuro fuzzy logic based MPPT algorithm.
- To achieve grid synchronization using hysteresis current controller.

CHAPTER-2

LITERATURE SURVEY

The popularity of distributed generation systems is growing faster from last few years because of their higher operating efficiency and low emission levels. Distributed generators make use of several microsources for their operation like photovoltaic cells, batteries, micro turbines and fuel cells. During peak load hours DGs provide peak generation when the energy cost is high and stand by generation during system outages. Microgrid is built up by combining cluster of loads and parallel distributed generation systems in a certain local area. Microgrids have 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 [1]-[5].

To realize the emerging potential of distributed generation, a system approach i.e. microgrid is proposed which considers generation and associated loads as a subsystem. This approach involves local control of distributed generation and hence reduces the need for central dispatch. During disturbances by islanding generation and loads, local reliability can be higher in microgrid than the whole power system. This application makes the system efficiency double. The current implementation of microgrid incorporates sources with loads, permits for intentional islanding and use available waste heat of power generation systems [6].

Microgrid operates as a single controllable system which offers both power and heat to its local area. This concept offers a new prototype for the operation of distributed generation. To the utility microgrid can be regarded as a controllable cell of power system. In case of faults in microgrid, the main utility should be isolated from the distribution section as fast as necessary to protect loads. The isolation depends on customer's load on the microgrid. Sag compensation can be used in some cases with isolation from the distribution system to protect the critical loads [2].

The microgrid concept lowers the cost and improves 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 [7].

The microgrid concept acts as solution to the problem of integrating large amount of micro generation without interrupting the utility network's operation. 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. In case of disturbances on the main network, microgrid could potentially disconnect and continue to operate individually, which helps in improving power quality to the consumer [8].

With advancement in DGs and microgrids there is development of various essential power conditioning interfaces and their associated control for tying multiple micro sources 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 micro source 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 micro source 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 [9].

The installation of distributed generators involves technical studies of two major fields. First one is the dealing with the influences induced by distributed generators without making large modifications to the control strategy of conventional distribution system and the other one is generating a new concept for utilization of distributed generators. The concept of the microgrid follows the later approach. There includes several advantages with the installation of microgrid. Efficiently microgrid can integrate distributed energy resources with loads.Microgrid considered as a ‘grid friendly entity” and does not give undesirable influence to the connecting distribution network i.e. operation policy of distribution grid does not have to be modified. It can also operate independently in the occurrence of any fault. In case of large disturbances there is possibility of imbalance of supply and demand as microgrid does not have large central generator. Also microgrid involves different DERs. Even if energy balance is being maintained there continues undesirable oscillation [10].

For each component of the microgrid, a peer-to-peer and plug-and-play model is used to improve the reliability of the system. The concept of peer-to-peer guarantees that with loss of any component or generator, microgrid can continue its operation. Plug-and-play feature implies that without re-engineering the controls a unit can be placed at any point on the electrical system thereby helps to reduce the possibilities of engineering errors [11].

The economy of a country mainly depends upon its electric energy supply which should be secure and with high quality. The necessity of customer’s for power quality and energy supply is fulfilled by distributed energy supply. The distribution system mainly includes renewable energy resources, storage systems small size power generating systems and these are normally installed close to the customer’s premises. The benefits of the DERs include power quality with better supply, higher reliability and high efficiency of energy by utilization of waste heat. It is an attractive option from the environmental considerations as there is generation of little pollution. Also it helps the electric utility by reducing congestion on the grid, reducing need for new generation and transmission and services like voltage support and demand response. Microgrid is an integrated system. The integration of the DERs connected to microgrid is critical. Also there is additional problem regarding the control and grouping and control of DERs in an efficient and reliable manner [12].

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 [13].

Renewable energy resources are integrated with microgrid to reduce the emission of CO2 and consumption of fuel. The renewable resources are very fluctuant in nature, and also the production and consumption of these sources are very difficult. Therefore new renewable energy generators should be designed having more flexibility and controllability [14].

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 [15].

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 [16].

CHAPTER-3

MICRO GRID COMPONENTS & EXISTING SYSTEM

3.1 INTRODUCTION

In 1839, a French physicist Edmund Becquerel proposed that few materials have the ability to produce electricity when exposed to sunlight. But Albert Einstein explained the photoelectric effect and the nature of light in 1905. Photoelectric effect state that when photons or sunlight strikes to a metal surface flow of electrons will take place. Later photoelectric effect became the basic principle for the technology of photovoltaic power generation. The first PV module was manufactured by Bell laboratories in 1954.

3.1.1 PV CELL

Photovoltaic cell is the building block of the PV system and semiconductor material such as silicon and germanium are the building block of PV cell. Silicon is used for photovoltaic cell due to its advantages over germanium. When photons hit the surface of solar cell, the electrons and holes are generated by breaking the covalent bond inside the atom of semiconductor material and in response electric field is generated by creating positive and negative terminals. When these terminals are connected by a conductor an electric current will start flowing. This electricity is used to power a load.

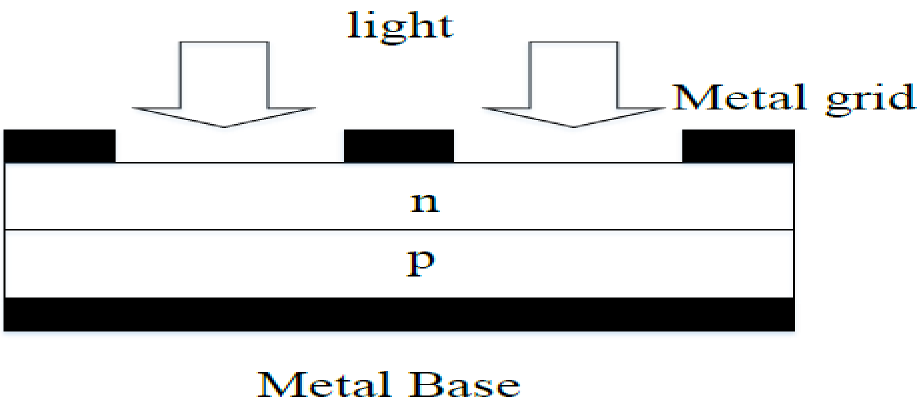


Fig.3.1 Structure of PV cell

3.1.2 PV MODULE

A single cell generate very low voltage (around 0.4), so more than one

PV cells can be connected either in serial or in parallel or as a grid (both serial and parallel) to form a PV module as shown in fig.3.3. When we need higher voltage, we connect PV cell in series and if load demand is high current then we connect PV cell in parallel. Usually there are 36 or 76 cells in general PV modules. Module we are using having 54 cells. The front side of the module is transparent usually buildup of low-iron and transparent glass material, and the PV cell is encapsulated. The efficiency of a module is not as good as PV cell, because the glass cover and frame reflects some amount of the incoming radiation.

3.1.2 PV ARRAY

A photovoltaic array is simply an interconnection of several PV modules in serial and/or parallel. The power generated by individual modules may not be sufficient to meet the requirement of trading applications, so the modules are secured in a grid form or as an array to gratify the load demand. In an array, the modules are connected like as that of cells connected in a module. While making a PV array, generally the modules are initially connected in serial manner to obtain the desired voltage, and then strings so obtained are connected in parallel in order to produce more current based on the requirement.

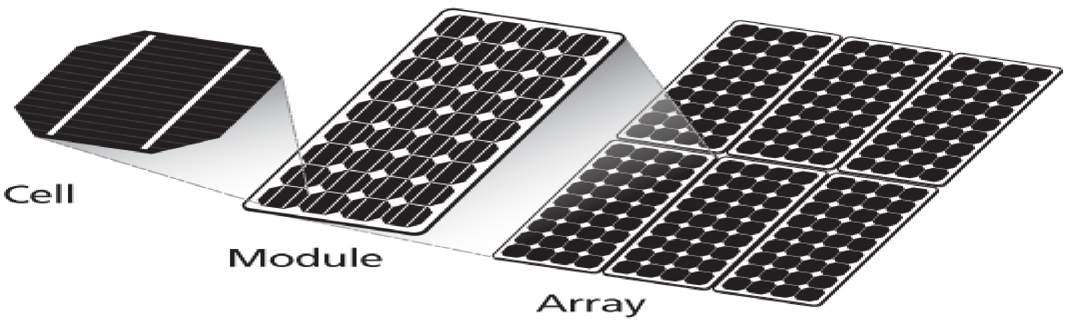


Fig.3.2 Photovoltaic system

3.3 WORKING OF PV CELL

The basic theory involved in working of an individual PV cell is the Photoelectric effect according to which, when a photon particle hits a PV cell, after receiving energy from sunbeam the electrons of the semiconductor get excited and hop to the conduction band from the valence band and become free to move. Movement of electrons create positive and negative terminal and also create potential difference across these two terminals. When an external circuit is connected between these terminals an electric current start flowing through the circuit.

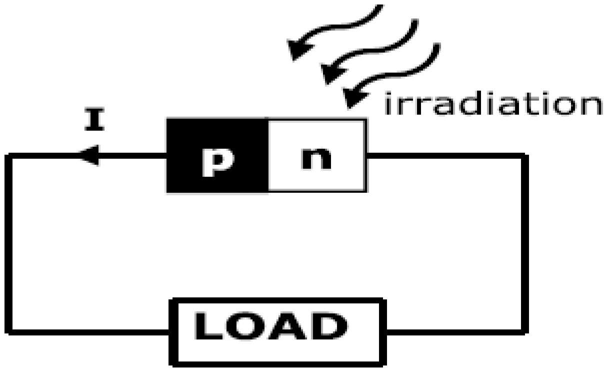


Fig 3.3 Working of PV cell

3.4 MODELING OF PV CELL

The photovoltaic system converts sunlight directly to electricity without having any disastrous effect on our environment. The basic segment of PV array is PV cell, which is just a simple p-n junction device. The fig.3.4 manifests the equivalent circuit of PV cell . Equivalent circuit has a current source (photocurrent), a diode parallel to it, a resistor in series describing an internal resistance to the flow of current and a shunt resistance which expresses a leakage current. The current supplied to the load can be given as.

$$I = I_{PV} - I_O\left[\exp\left(\frac{V + IR_S}{aV_T}\right) - 1\right] - \left(\frac{V + IR_S}{R_P}\right)$$

Where

IPV–Photocurrent current,

IO–diode’s Reverse saturation current,

V–Voltage across the diode,

a– Ideality factor

VT –Thermal voltage

Rs– Series resistance

Rp–Shunt resistance

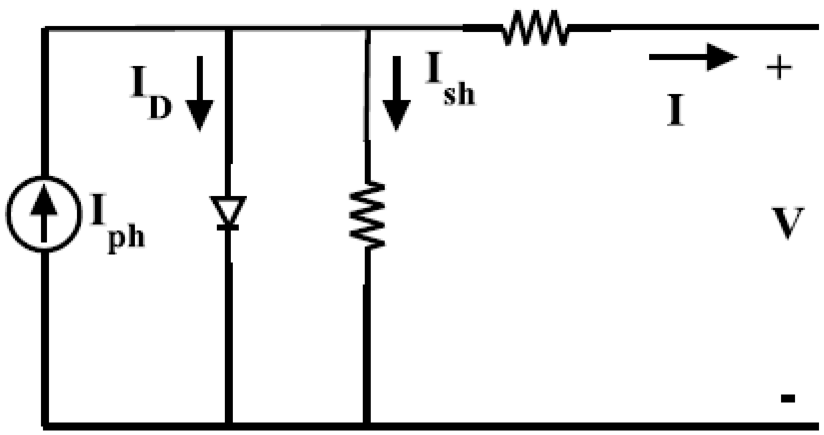


Fig 3.4 Equivalent circuit of Single diode modal of a solar cell

PV cell photocurrent, which depends on the radiation and temperature, can be expressed as.

$$I_{PV} = \left(I_{PV\_STC} + K_I \Delta T\right)\frac{G}{G_{STC}}$$

Where

KI– cell's short circuit current temperature coefficient

G–solar irradiation in W/m3

GSTC–nominal solar irradiation in W/m3

IPV_STC– Light generated current under standard test condition

The reverse saturation current varies as a cubic function of temperature, which is represented as

$$I_O = I_{O\_STC}\left(\frac{T_{STC}}{T}\right)^3 \exp\left[\frac{qE_g}{aK}\left(\frac{1}{T_{STC}} - \frac{1}{T}\right)\right]$$

Where

I0_STC– Nominal saturation current

Eg – Energy band gap of semiconductor

TSTC–temperature at standard test condition

q – Charge of electrons

The reverse saturation current can be further improved as a function of temperature as follows

$$I_O = \frac{\left(I_{SC\_STC} + K_I \Delta T\right)}{\exp\left[\frac{\left(V_{OC\_STC} + K_V \Delta T\right)}{a V_T}\right] - 1}$$

Where,

ISC_STC– short circuit current at standard test condition

VOC_STC– short circuit voltage at standard test condition

KV– temperature coefficient of open circuit voltage

Many authors proposed more developed models for better accuracy and for different purposes. In some of the models, the effect of the recombination of carriers is represented by an extra diode. Some authors also used three diode models which included influences of some other effects that are not considered in previous models. But due to simplicity we use single diode model for our work.

Efficiency of a PV cell does not depend on the variation in the shunt resistance Rp of the cell but efficiency of a PV cell greatly depends on the variation in series resistance Rs. As Rp of the cell is inversely proportional to the shunt leakage current to ground so it can be assumed to be very large value for a very small leakage current to ground.

As the total power generated by a single PV cell is very low, we used a combination of PV cells to fulfill our desired requirement. This grid of PV cells is knows as PV array. The equations of the PV array can be represented as

$$I = I_{PV} N_P - I_O N_P \left[\exp\left(\frac{V + IR_S\left(\frac{N_S}{N_P}\right)}{a V_T N_S}\right) - 1\right] - \left(\frac{V + IR_S\left(\frac{N_S}{N_P}\right)}{R_P\left(\frac{N_S}{N_P}\right)}\right)$$

NS– Number of series cells

NP– Number of parallel cells

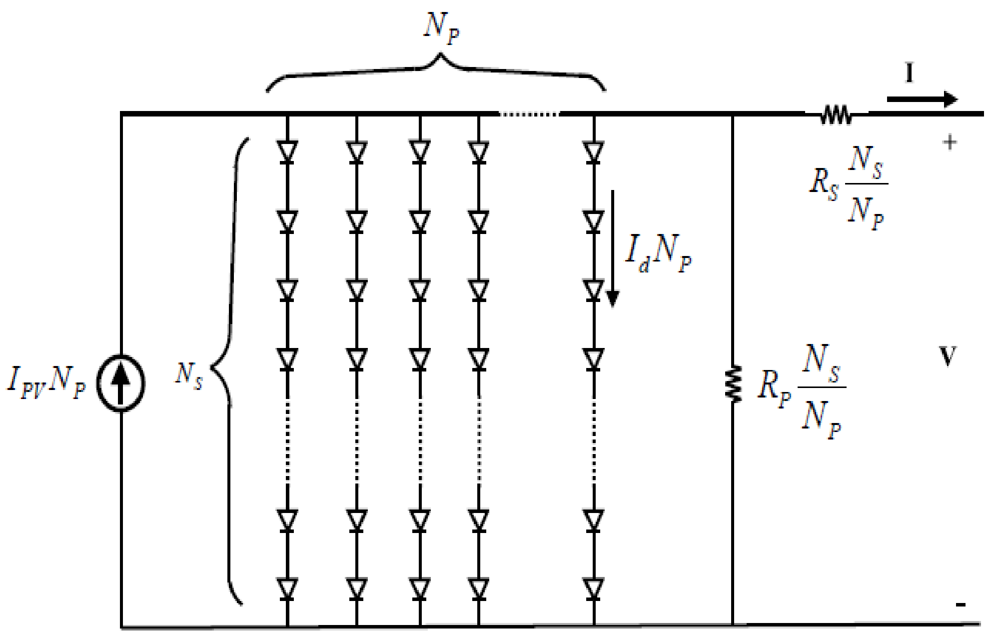
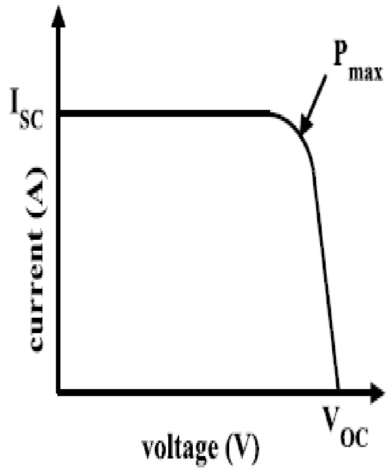


Fig.3.5 Representation of PV module

A small change in series resistance can affect more on the efficiency of a PV cells but variation in shunt resistance does not affect more. For very small leakage current to ground, shunt resistance assumed to be infinity and can be treated as open. After considering shunt resistance infinity, the mathematical equation of the model can be expressed as.

$$I = I_{PV} N_P - I_O N_P \left[\exp\left(\frac{V + IR_S \left(\frac{N_S}{N_P} \right)}{a V_T N_S} \right) - 1 \right]$$

I-V and P-V characteristics of PV module are shown in figures 3.7 and 3.8 respectively.



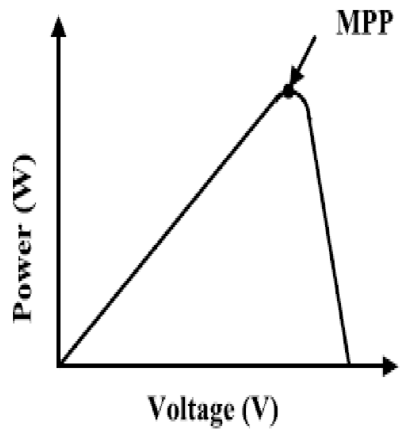


Fig. 3.6 IV characteristics

Fig. 3.7 PV characteristics

The two key parameters which are used to relate the electrical performance are the open-circuit voltage of the cell VOC and short-circuit current of the cell Isc. The maximum power can be stated as

$$P_{max} = V_{max} I_{max}$$

3.5. SHADING EFFECT

When a module or a part of it is shaded it starts generating less voltage or current as compared to unshaded one. When modules are connected in series, same current will flow in entire circuit but shaded portion cannot able to generate same current but have to allow the same current to flow, so shaded portion starts behaving like load and starts consuming power. When shaded portion starts to act as load this condition is known as hot-spot problem. Without appropriate protection, problem of hot-spot may arise and, in severe cases, the system may get damaged. To reduce the damage in this condition we generally use a bypass diode . Block diagram of PV array in shaded condition is shown below.

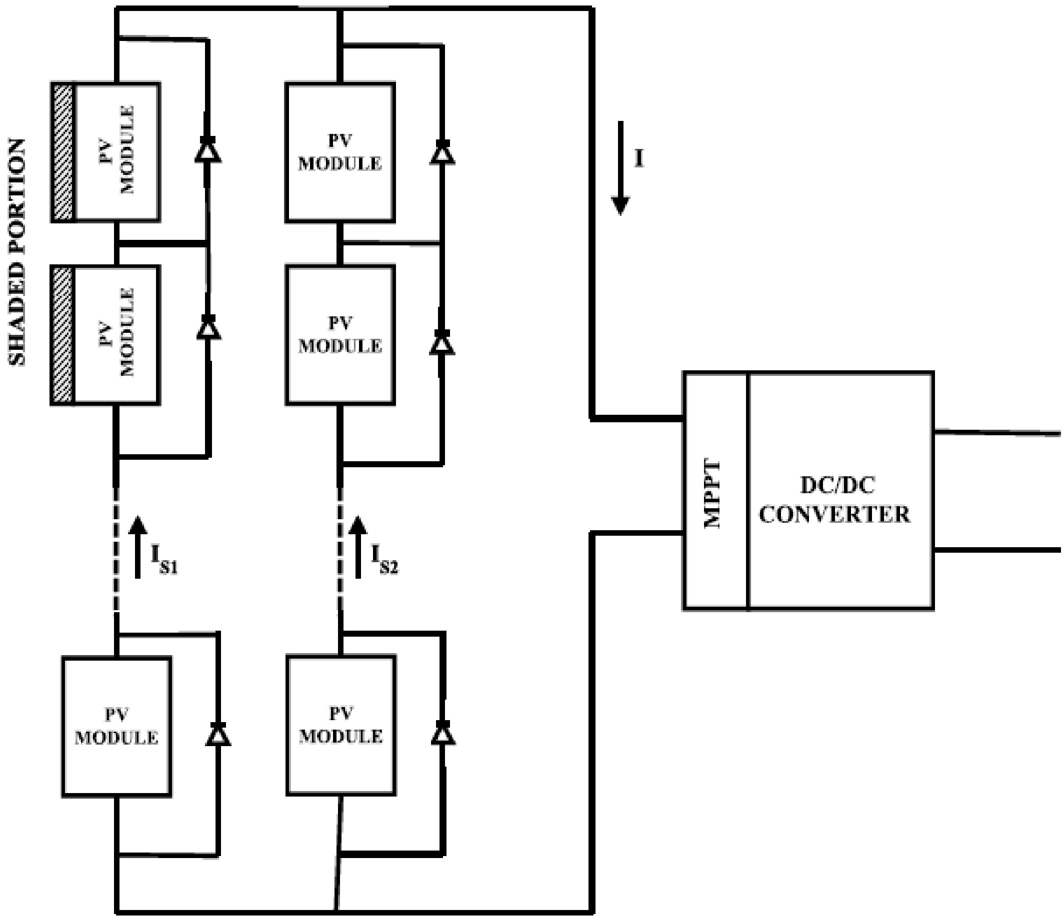


Fig 3.8 PV Array in Shaded condition

Due to partial shading or total shading PV characteristic become more non-linear, having more than one maximum power point. So for this condition tracking of the maximum power point become very tedious. We can easily see the effect of shading on PV characteristics in the fig shown below.

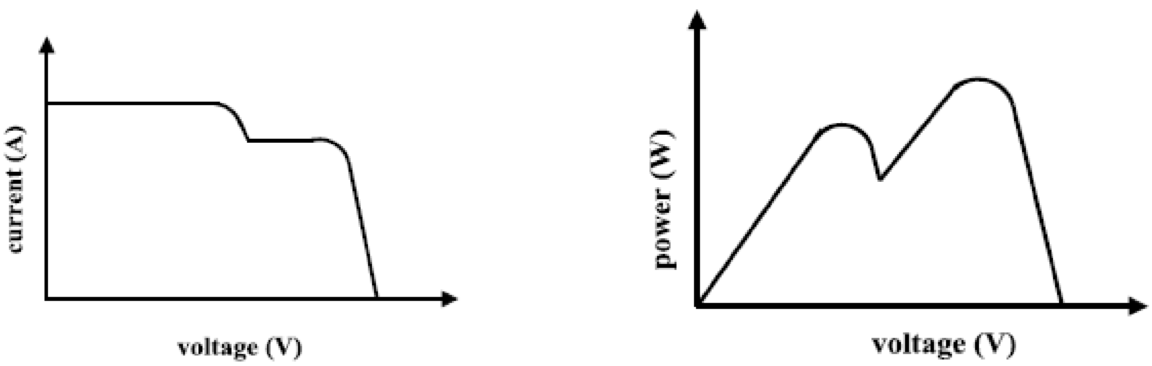


Fig. 3.9 Effect of partial shading on I-V & P-V characteristics

There is wastage of power due to the loss contributed by reverse current which results in overheating of shaded cell.

3.6 MAXIMUM POWER POINT TRACKING

Maximum power point tracing (MPPT) system is an electronic control system that can be able to coerce the maximum power from a PV system. It does not involve a single mechanical component that results in the movement of the modules changing their direction and make them face straight towards the sun. MPPT control system is a completely electronic system which can deliver maximum allowable power by varying the operating point of the modules electrically.

3.6.1 NECESSITY OF MAXIMUM POWER POINT TRACKING

In the Power Vs Voltage characteristic of a PV module shown in fig 3.9 we can observe that there exist single maxima i.e. a maximum power point associated with a specific voltage and current that are supplied. The overall efficiency of a module is very low around 13%. So it is necessary to operate it at the crest power point so that the maximum power can be provided to the load irrespective of continuously changing environmental conditions. This increased power makes it better for the use of the solar PV module. A DC/DC converter which is placed next to the PV module extracts maximum power by matching the impedance of the circuit to the impedance of the PV module and transfers it to the load. Impedance matching can be done by varying the duty cycle of the switching elements.

3.6.2. MPPT algorithm

There are many algorithms which help in tracing the maximum power point of the PV module. They are following:

a. P&O algorithm

b. IC algorithm

c. Parasitic capacitance

d. Voltage based peak power tracking

e. Current Based peak power tracking

3.7 TYPES OF DC-DC CONVERTER

DC-DC converter is an electrical circuit whose main application is to transform a dc voltage from one level to another level. It is similar to a transformer in AC source, it can able to step the voltage level up or down. The variable dc voltage level can be regulated by controlling the duty ratio (on-off time of a switch) of the converter.

There are various types of dc-dc converters that can be used to transform the level of the voltage as per the supply availability and load requirement. Some of them are discussed below.

1. Buck converter

3. Boost converter

3. Buck-Boost converter

Each of them is explained below.

3.7.1 BUCK CONVERTER

The functionality of a buck converter is to reduce the voltage level. The circuit diagram of the buck converter is manifested in figure 3.10.

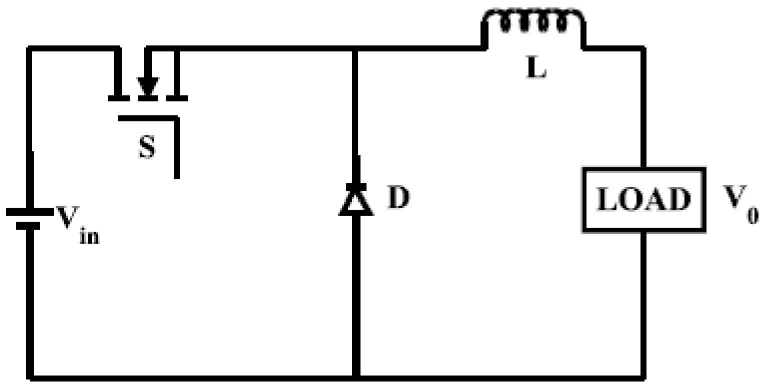


Fig. 3.10 Circuit diagram of buck converter

When the switching element is in state of conduction the voltage appearing across the load is Vin and the current is supplied from source to load. When the switch is off the load voltage is zero and the direction of current remains the same. As the power flows from source side to load side, the load side voltage remains less than the source side voltage. The output voltage is determined as a function of source voltage using the duty ratio of the gate pulse given to the switch. It is the product of the duty ratio and the input voltage

3.7.2 BOOST CONVERTER

The functionality of boost converter is to increase the voltage level. The circuit configuration of the boost converter is manifested in figure 3.11.

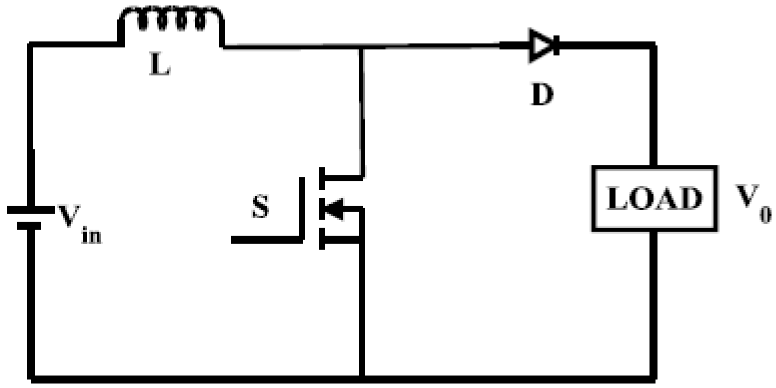


Fig. 3.11 Circuit diagram of boost converter

The current carried by the inductor starts rising and it stores energy during ON time of the switching element. The circuit is said to be in charging state. During OFF condition, the reserve energy of the inductor starts dissipating into the load along with the supply. The output voltage level exceeds that of the input voltage and is dependent on the inductor time constant. The load side voltage is the ratio of source side voltage and the duty ratio of the switching device.

3.7.3 BUCK BOOST CONVERTER

The functionality of a buck-boost converter is to set the level of load side voltage to either greater than or less than that of the source side voltage. The circuit configuration of the buck-boost converter is manifested in figure 3.12.

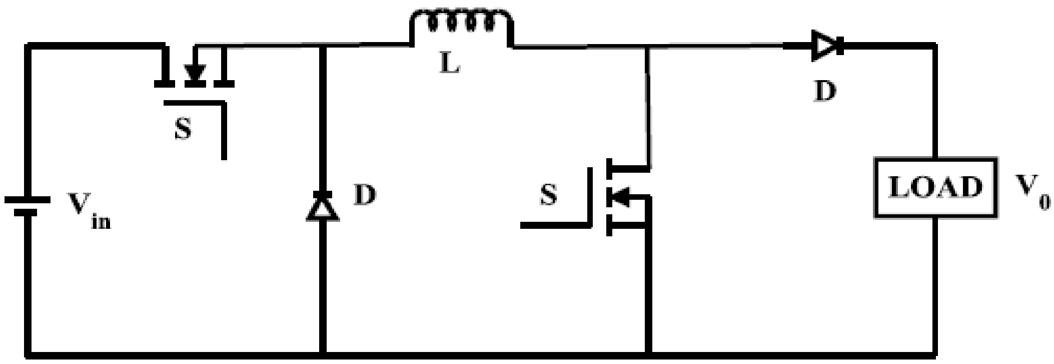


Fig. 3.12 Circuit diagram of buck-boost converter

When the switches are in the state of conduction, the current carried by the inductor starts rising and it stores energy. The circuit is said to be in charging state. While the switches are in the OFF state, this stored energy of the inductor is dissipated to the load through the diodes. The output voltage can be varied based on the On-time of the switches.

The buck-boost converter acts as both buck and boost converters depending on the duty cycle of the switches. For the duty ratio less than 50% it acts as a buck converter and for the duty ratio exceeds than 50% it acts as boost converter.

3.8 WIND ENERGY CONVERSION SYSTEMS

Wind energy conversion systems (WECS) convert the kinetic energy of the wind into electricity or other forms of energy. Wind power generation has experienced a tremendous growth in the past decade, and has been recognized as an environmentally friendly and economically competitive means of electric power generation. The availability of renewable energy sources has strong daily and seasonal patterns and the power demand by the consumers could have a very different characteristic. Therefore, it is difficult to operate a power system installed with only renewable generation units due to the characteristic differences and the high uncertainty in the availability of the renewable energy sources. Modern wind turbines have lot of commercially available topologies, among that the variable speed wind turbines are more attractive, as they can extract maximum power at different wind velocities, and thus, reduce the mechanical stress on WECS by absorbing the wind power fluctuations. For a variable-speed wind turbine the generator is controlled by power electronic equipment.

The advantages of Wind Energy over other Non-Conventional Sources are:

- It is available throughout the day unlike solar energy.
- After solar energy it is the second largest source of non-conventional source of energy
- In India during the mid summer due to the lack of hydel power generation there is desperate need for energy. This can be met to

some extent by wind energy as there are very high winds during this period.

- By using photo voltaic, the power generated is DC .So it must be converted to AC to feed it to grid. But by using wind energy we can directly produce AC.
- In coastal areas, the cost of power generation from wind has become lower than diesel power and compared to thermal power.
- From the study of wind distribution, it is estimated that about 27% of the land surface is exposed to an annual wind speed higher than 18.36kmph at 10m above the surface.

3.1 WIND TURBINES

A wind turbine is a rotating machine which converts the kinetic energy of wind into mechanical energy. The mechanical energy is then converted into electricity by using wind generator. Wind turbines can be separated into two types based by the axis in which the turbine rotates. Turbines that rotate around a horizontal axis are more common. Vertical-axis turbines are less frequently used.

3.1.1 Modelling of Wind Turbine

The aerodynamic power of wind is converted into mechanical energy by wind turbine i.e. the blades obtain kinetic energy from the wind which is transformed to mechanical torque at the rotor shaft of the wind turbine. The wind power can be calculated by the following equation

$$P_t = 1/2 \rho C_p A V^3 \quad (3.1)$$

Where

P_t is the rotor mechanical power (W)

V the wind speed (m/s)

$A = \pi R^2$ the rotor surface (m^2)

R is the rotor radius (m)

ρ the air density (kg/m^3)

C_p is the power coefficient.

The rotor aerodynamic power coefficient, C_p, is the function of blade pitch angle (β) and tip speed ration (λ)

λ= Tip speed/Wind speed

$$\lambda = \omega_r R/V \qquad (3.2)$$

Sub eqn (3.2) in (3.1) we get

$$P_t = 1\backslash 2\ C_p\ (\lambda)\rho A(R/\lambda)^3\omega^3 \qquad (3.3)$$

The output torque of the wind turbine T_t is calculated by the following equation

$$T_t = 1/2\ \rho C_p A(V/\lambda) \qquad (3.4)$$

Variable speed turbines are made to capture the maximum energy of the wind by operating them at a blade speed that gives the optimum tip speed ratio. This may be done by changing the speed of the turbine in proportion to the change in wind speed. Figure 3.1 shows how variable speed operation will allow a wind turbine to capture more energy from the wind.

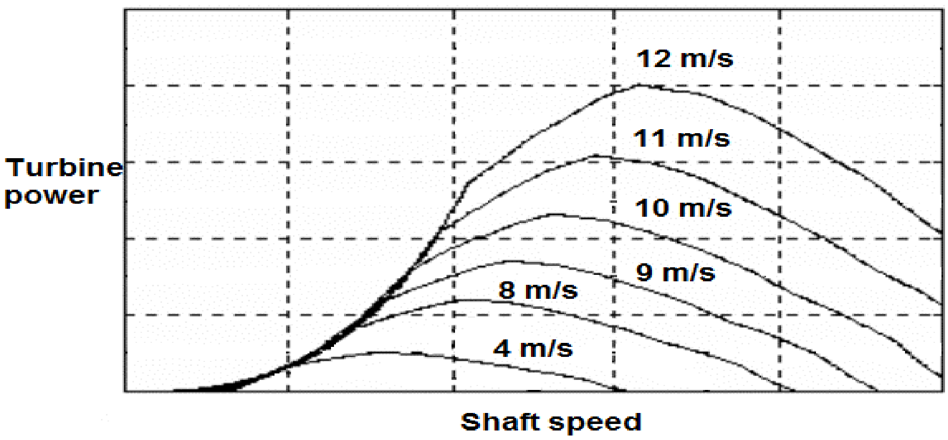


Fig 3.1 Power speed characteristics

3.1.2 Horizontal Axis Wind Turbines

Horizontal-axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator. Since a tower produces turbulence behind it, the turbine is usually pointed upwind of the tower. Turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted up a small amount. Downwind machines have been built, despite the problem of turbulence, because they don't need an additional mechanism for keeping them in line with the wind, and because in high winds the 3 blades can be allowed to bend which reduces their swept area and thus their wind resistance. Since cyclic (that is repetitive) turbulence may lead to fatigue failures most HAWTs are upwind machines. Figure 3.2 shows the horizontal axis wind turbine.

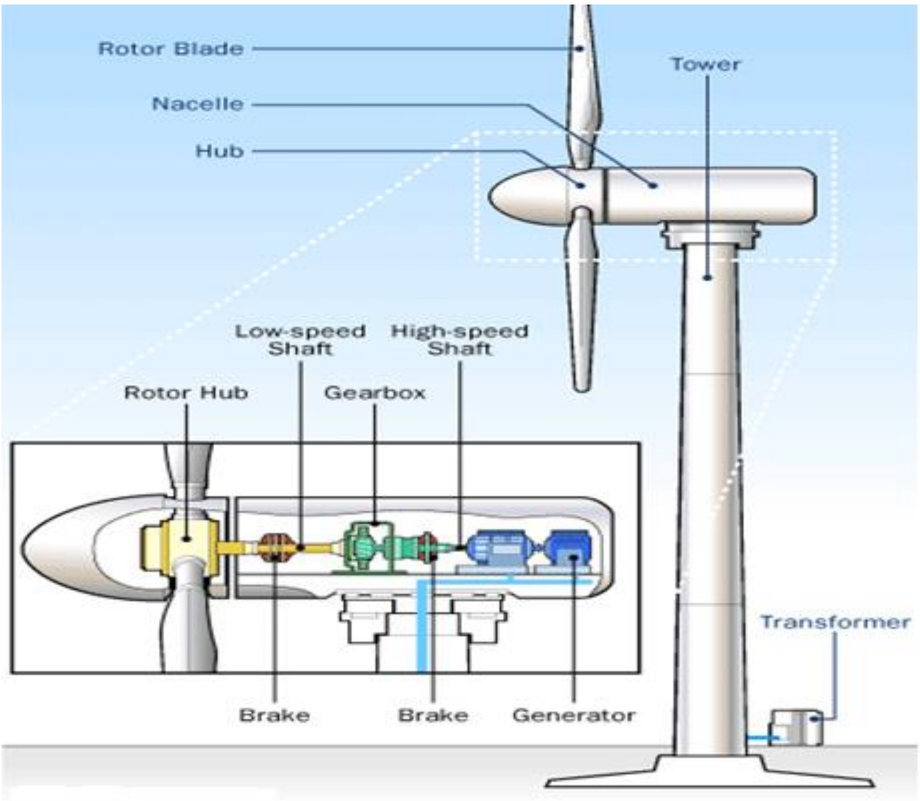


Fig 3.2 Horizontal axis wind turbine

The advantages of Horizontal axis wind turbines are:

- Variable blade pitch, which gives the turbine blades the optimum angle of attack. Allowing the angle of attack to be remotely adjusted gives greater control, so the turbine collects the maximum amount of wind energy for the time of day and season.

- The tall tower base allows access to stronger wind in sites with wind shear. In some wind shear sites, every ten meters up, the wind speed can increase by 20% and the power output by 34%.
- High efficiency, since the blades always moves perpendicularly to the wind, receiving power through the whole rotation. In contrast, all vertical axis wind turbines, and most proposed airborne wind turbine designs, involve various types of reciprocating actions, requiring airfoil surfaces to backtrack against the wind for part of the cycle. Backtracking against the wind leads to inherently lower efficiency.

The disadvantages of Horizontal axis wind turbines are:

- The tall towers and blades up to 90 meters long are difficult to transport. Transportation can now cost 20% of equipment costs.
- Tall HAWTs are difficult to install, needing very tall and expensive cranes and skilled operators.
- Massive tower construction is required to support the heavy blades, gearbox, and generator.
- Reflections from tall HAWTs may affect side lobes of radar installations creating signal clutter, although filtering can suppress it.
- Downwind variants suffer from fatigue and structural failure caused by turbulence when a blade passes through the tower's wind shadow (for this reason, the majority of HAWTs use an upwind design, with the rotor facing the wind in front of the tower).
- HAWTs require an additional yaw control mechanism to turn the blades toward the wind.

3.1.3 Vertical Axis Wind Turbines

Vertical-axis wind turbines (or VAWTs) have the main rotor shaft arranged vertically. Key advantages of this arrangement are that the turbine does not need to be pointed into the wind to be effective. This is an advantage on sites where the wind direction is highly variable. VAWTs can utilize winds from varying directions. With a vertical axis, the generator and gearbox can be placed near the ground, so the tower doesn't need to support it, and it is more accessible for maintenance. Drawbacks are that some designs produce pulsating torque. Drag may be created when the blade rotates into the wind. Figure 3.3 shows the vertical axis wind turbines.

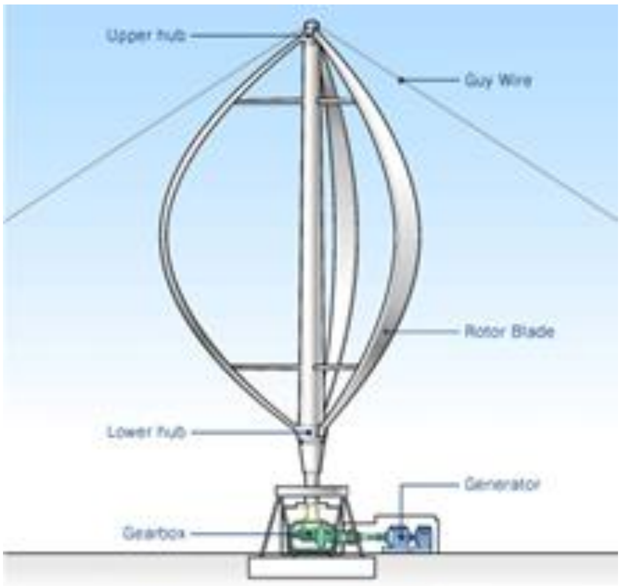


Fig 3.3 Vertical axis wind turbine

The advantages of Vertical-axis wind turbines are:

A massive tower structure is less frequently used, as VAWTs are more frequently mounted with the lower bearing mounted near the ground.

- Designs without yaw mechanisms are possible with fixed pitch rotor designs.
- A VAWT can be located nearer the ground, making it easier to maintain the moving parts.
- VAWTs have lower wind startup speeds than HAWTs. Typically, they start creating electricity at 6 M.P.H. (10 km/h).
- VAWTs may have a lower noise signature.

The disadvantages of Vertical-axis wind turbines are:

- Most VAWTs produce energy at only 50% of the efficiency of HAWTs in large part because of the additional drag that they have as their blades rotate into the wind.

- While VAWTs' parts are located on the ground, they are also located under the weight of the structure above it, which can make changing out parts nearly impossible without dismantling the structure if not designed properly.
- Having rotors located close to the ground where wind speeds are lower due to wind shear, VAWTs may not produce as much energy at a given site as a HAWT with the same footprint or height.

3.1.4 Wind Turbine Glossary

The Figure 3.4 shows the parts present in a wind turbine. The details of the parts are showed and explained.

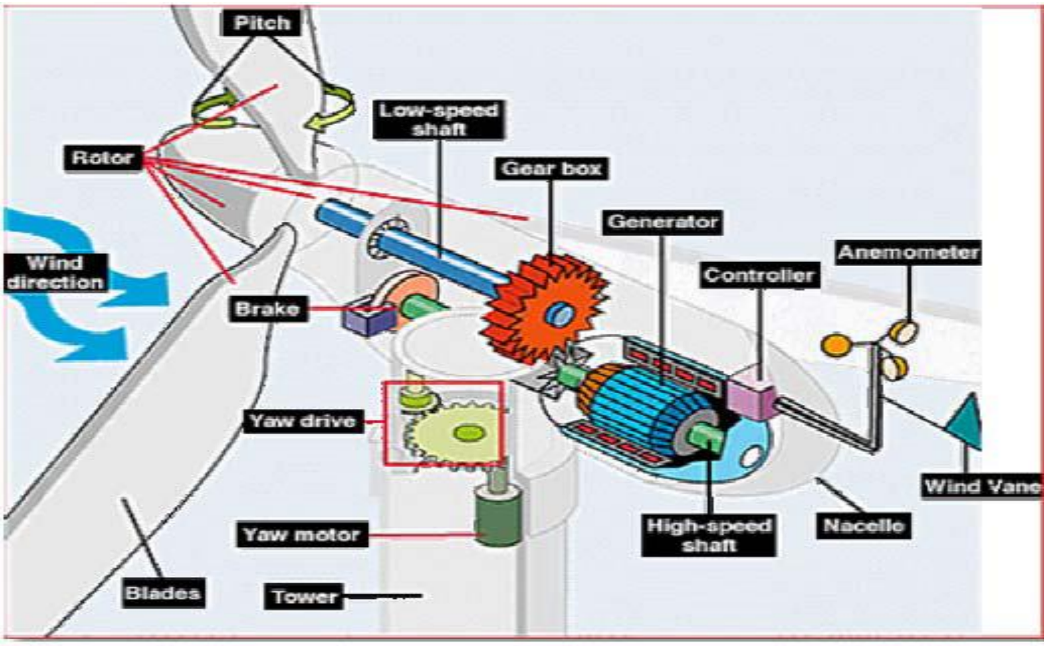


Figure 3.4 Parts of wind turbine

Anemometer: Measures the wind speed and transmits wind speed data to the controller.

Blades: Most turbines have either two or three blades. Wind blowing over the blades causes the blades to "lift" and rotate.

Brake: A disc brake which can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies.

Controller: The controller starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 65 mph. Turbines cannot operate at wind speeds above about 65 mph because their generators could overheat.

Gear box: Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1200 to 1500 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.

Generator: Usually an off-the-shelf induction generator that produces 60-cycle AC electricity.

High-speed shaft: It is used to Drives the generator.

Low-speed shaft: The rotor turns the low-speed shaft at about 30 to 60 rotations per minute.

Nacelle: The rotor attaches to the nacelle, which sits atop the tower and includes the gear box, low- and high-speed shafts, generator, controller, and brake. A cover protects the components inside the nacelle. Some nacelles are large enough for a technician to stand inside while working.

Pitch: Blades are turned, or pitched, out of the wind to keep the rotor from turning in winds that are too high or too low to produce electricity.

Rotor: The blades and the hub together are called the rotor.

Tower: Towers are made from tubular steel or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.

Wind direction: This is an "upwind" turbine, so-called because it operates facing into the wind. Other turbines are designed to run "downwind", facing away from the wind.

Wind vane: Measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.

Yaw drive: Upwind turbines face into the wind, the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive.

Wind turbines typically have two degrees of freedom to optimize power generation.

1. The ability to change their yaw or compass orientation by turning the entire nacelle unit so the rotor is pointed directly into the wind. This process is controlled by wind direction information from nearby wind vanes which are located to minimize the effect due to wake turbulence from the wind turbines.
2. The pitch of the blades which can be changed to keep a near-constant rotation rate under varying wind speeds, where the rotation rate is chosen to optimize the power-generation efficiency of the turbine. Another purpose of both the blade pitch control and yaw Mechanisms is to act as a brake under extremely strong wind condition. Cut- in speed: The lowest wind speed at which a wind turbine begins producing usable power is called cut-in speed. It is about 3m/s Cut-out speed: The highest wind speed at which a wind turbine stops producing power is called cut-out speed. It is about 30m/s.

3.2WIND SPEED CONTROL

3.2.1 Power Control

A wind turbine is designed to produce a maximum of power at wide spectrum of wind speeds.

The wind turbines have three modes of operation:

- Below rated wind speed operation
- Around rated wind speed operation
- Above rated wind speed operation

If the rated wind speed is exceeded the power has to be limited. There are various ways to achieve this.

3.2.2 Stall Control

Stalling works by increasing the angle at which the relative wind strikes the blades (angle of attack), and it reduces the induced drag (drag associated with lift). Stalling is simple because it can be made to happen passively (it increases automatically when the winds speed up), but it increases the cross-section of the blade face-on to the wind, and thus the ordinary drag. A fully stalled turbine blade, when stopped, has the flat side of the blade facing directly into the wind. A fixed-speed HAWT inherently increases its angle of attack at higher wind speed as the blades speed up. A natural strategy, then, is to allow the blade to stall when the wind speed increases. This technique was successfully used on many early HAWTs. However, on some of these blade sets, it was observed that the degree of blade pitch tended to increase audible noise levels.

3.2.3 Pitch Control

Furling works by decreasing the angle of attack, which reduces the induced drag from the lift of the rotor, as well as the cross-section. One major problem in designing wind turbines is getting the blades to stall or furl quickly enough should a gust of wind cause sudden acceleration. A fully furled turbine blade, when stopped, has the edge of the blade facing into the wind. Standard modern turbines all pitch the blades in high winds. Since pitching requires acting against the torque on the blade, it requires some form of pitch angle control. Many turbines use hydraulic systems. These systems are usually spring loaded, so that if hydraulic power fails, the blades automatically furl. Other turbines use an electric servomotor for every rotor blade. They have a small battery-reserve in case of an electric-grid breakdown. Small wind turbines (fewer than 50 kW) with variable-pitching generally use systems operated by centrifugal force, either by flyweights or geometric design, and employ no electric or hydraulic controls.

3.3 GENERATOR

The working principle of a wind turbine encompasses two conversion processes, which are carried out by its components, the rotor that extracts kinetic energy from the wind and converts it into a generator torque and the generator that converts this torque into electric power and feeds it into the grid. A generator is a device which converts mechanical energy into electrical energy. Wind generators have traditionally been wind turbines, i.e. a propeller attached to an electric generator attached to appropriate electronics to attach it to the electrical grid. Generators can be classified broadly into two categories: a) Synchronous Generators b) Asynchronous Generators. The basis of this categorization is the speed at which the generators are run. Synchronous generators are run at synchronous speed (1500 rpm for a 4 pole machine at 50Hz frequency) while asynchronous generators run at a speed more than the synchronous speed.

3.3.1 Synchronous Generator

Synchronous generators are doubly fed machines which generate electricity by the principle when the magnetic field around a conductor changes, a current is induced in the conductor. Typically, a rotating magnet called the rotor turns within a stationary set of conductors wound in coils on an iron core, called the stator. The field cuts across the conductors, generating an electrical current, as the mechanical input causes the rotor to turn.

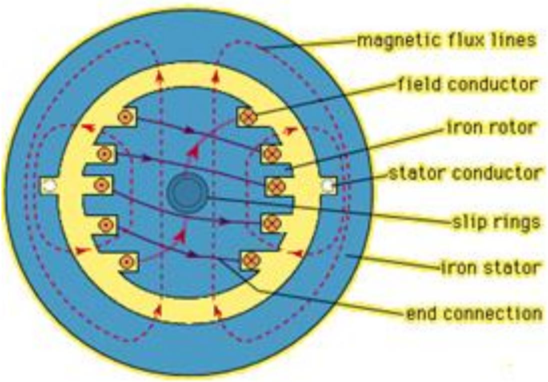


Figure 3.5 Synchronous generator

The rotating magnetic field induces an AC voltage in the stator windings. Often there are three sets of stator windings, physically offset so that the rotating magnetic field produces three phase currents, displaced by one-third of a period with respect to each other. The rotor magnetic field may be produced by induction by permanent magnets (in very small machines), or by a rotor winding energized with direct current through slip rings and brushes. The rotor magnetic field may even be provided by stationary field winding, with moving poles in the rotor. Automotive alternators invariably use a rotor winding, which allows control of the alternator generated voltage by varying the current in the rotor field winding. Permanent magnet machines avoid the loss due to magnetizing current in the rotor, but are restricted in size, owing to the cost of the magnet material. Since the permanent magnet field is constant, the terminal voltage varies directly with the speed of the generator.

3.3.2 Asynchronous Generator

Asynchronous generators or Induction generators are singly excited A.C machine. Its stator winding is directly connected to the ac source whereas its rotor winding receives its energy from stator by means of induction. Balanced currents produce constant amplitude rotating mmf wave. The stator produced mmf and rotor produced mmf wave, both rotate in the air gap in the same direction at synchronous speed. These two mmf s combine to give the resultant air-gap flux density wave of constant amplitude and rotating at synchronous speed. This flux induces currents in the rotor and an electromagnetic torque is produced which rotates the rotor. Asynchronous generators are mostly used as wind turbines as they can be operated at variable speed unlike synchronous generator. Two kinds of asynchronous generators are used namely Squirrel Cage Induction Generator (SCIG) and Doubly Fed Induction Generator (DFIG)

A squirrel cage rotor is the rotating part shown in figure 3.6. In overall shape, it is a cylinder mounted on a shaft. Internally it contains longitudinal conductive bars (usually made of aluminum or copper) set into grooves and connected together at both ends by shorting rings forming a cage-like shape. The core of the rotor is built of a stack of iron laminations.

Figure 3.6 Cage rotor

The field windings in the stator of an induction motor set up a rotating magnetic field around the rotor. The relative motion between this field and the rotation of the rotor induces electric current in the conductive bars. In turn these currents lengthwise in the conductors react with the magnetic field of the motor to produce force acting at a tangent to the rotor, resulting in torque to turn the shaft. In effect the rotor is carried around with the magnetic field but at a slightly slower rate of rotation. The difference in speed is called slip and increases with load.

3.4 GENERATING SYSTEMS

A wind turbine is a complex system in which knowledge from the areas of the aerodynamics and mechanical, electrical and control engineering is applied.

For the generating system, nearly all wind turbines currently installed use either one of the following systems.

1. Squirrel cage induction generator systems
2. Doubly fed induction generator systems
3. Direct drive synchronous generator systems

In which first one is a fixed speed or constant speed while others are variable speed turbine. Figure 3.7 shows the schematic diagram of a generator.

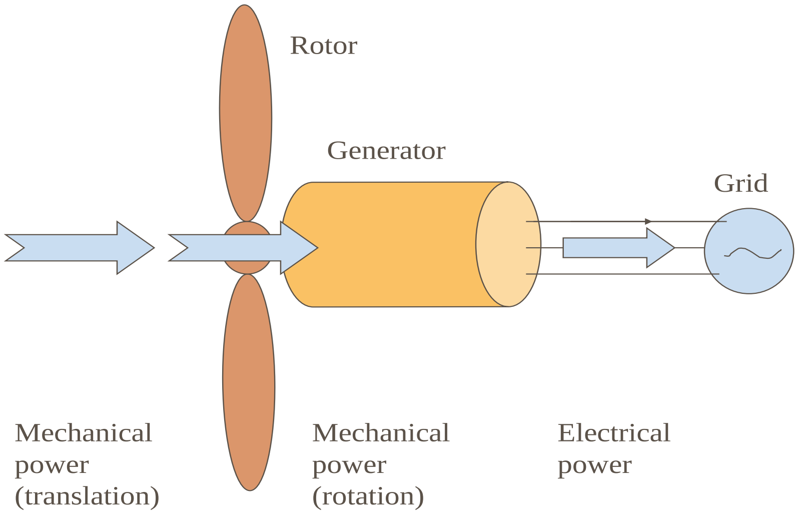


Figure 3.7 Schematic diagram of generator systems

3.4.1 Squirrel Cage Induction Generator Systems

The squirrel cage induction generator based wind energy conversion system is shown in Figure 3.8

- It is the oldest one.
- It consists of a conventional, directly grid coupled squirrel cage induction generator.
- The slip and the rotor speed varies with the amount of power generated
- Its drawback is it always consumes reactive power, which is undesirable in most of the cases, particularly in the case of large turbines and weak grid.
- It can be always be partly or fully compensated by capacitors in order to achieve a power factor close to one.

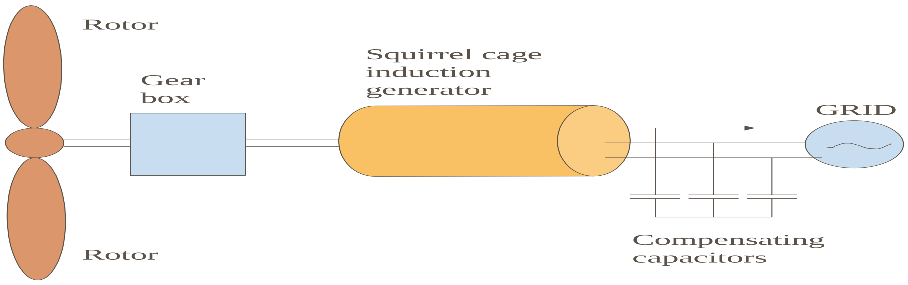


Figure 3.8 Squirrel cage induction generator systems

3.4.2 Doubly Fed Induction Generator Systems

The doubly fed induction generator based wind energy conversion system is shown in Figure 3.9.

- It is a variable speed turbine
- In this case a back-to-back voltage source converter feeds the three-phase rotor winding. So the mechanical and electrical rotor frequencies are decoupled and the electrical stator and rotor frequency can match, independently of the mechanical rotor speed.

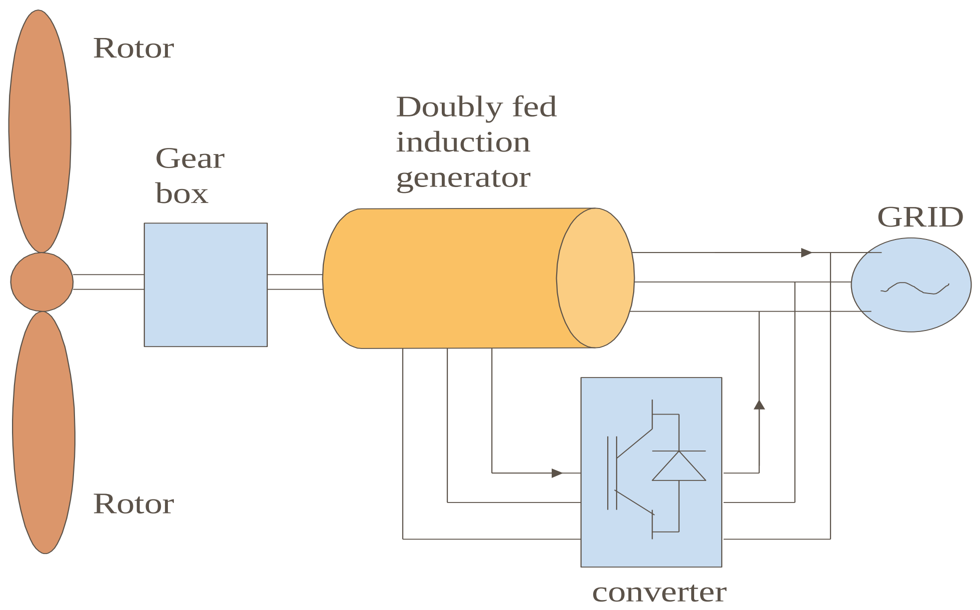


Figure 3.9 Doubly fed induction generator system

3.4.2.1 Operating principle of DFIG

Power flow diagram of DFIG is shown in figure 3.10. The stator is directly connected to the AC mains, whilst the wound rotor is fed from the Power Electronics Converter via slip rings to allow DIFG to operate at a variety of speeds in response to changing wind speed. Indeed, the basic concept is to interpose a frequency converter between the variable frequency induction generator and fixed frequency grid. The DC capacitor linking stator- and rotor-side converters allows the storage of power from induction generator for further generation. To achieve full control of grid current, the

DC-link voltage must be boosted to a level higher than the amplitude of grid line-to-line voltage.

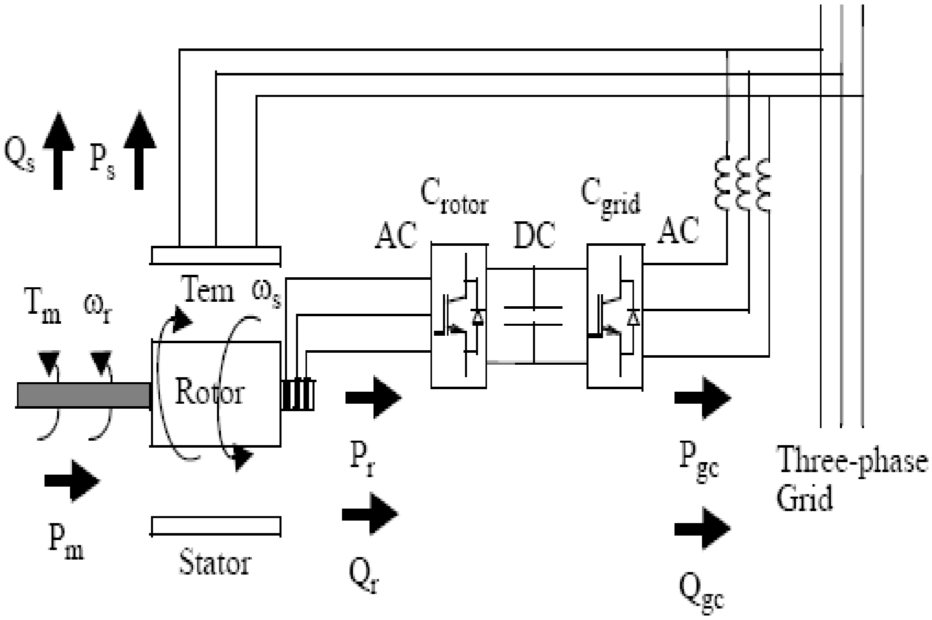


Figure 3.10 Power flow diagram of DFIG

The slip power can flow in both directions, i.e. to the rotor from the supply and from supply to the rotor and hence the speed of the machine can be controlled from either rotor- or stator-side converter in both super and sub-synchronous speed ranges. As a result, the machine can be controlled as a generator or a motor in both super and sub-synchronous operating modes realizing four operating modes. Below the synchronous speed in the motoring mode and above the synchronous speed in the generating mode, rotor-side converter operates as a rectifier and stator-side converter as an inverter, where slip power is returned to the stator. Below the synchronous speed in the generating mode and above the synchronous speed in the motoring mode, rotor-side converter operates as an inverter and stator side converter as a rectifier, where slip power is supplied to the rotor. At the synchronous speed, slip power is taken from supply to excite the rotor windings and in this case machine behaves as a synchronous machine. The mechanical power and the stator electric power output are computed as follows:

$$P_r = T_m * \omega_r \quad (3.5)$$

$$P_s = T_{em} * \omega_s \quad (3.6)$$

For a loss less generator the mechanical equation is:

$$J\frac{d\omega r}{dt}=T_m - T_{em} \qquad (3.7)$$

In steady-state at fixed speed for a loss less generator

$$T_m = T_{em} \quad \text{and } P_m = P_s + P_r \qquad (3.8)$$

and it follows that:

$$P_r = P_m - P_s = T_m - \omega_r - T_{em}\omega_s = -sP_s \qquad (3.9)$$

$s = (\omega_s - \omega_r)/\ \omega_s$ is defined as the slip of the generator

Generally the absolute value of slip is much lower than 1 and, consequently, Pr is only a fraction of P_s. Since Tm is positive for power generation and since ω_s is positive and constant for a constant frequency grid voltage, the sign of Pr is a function of the slip sign. Pr is positive for negative slip (speed greater than synchronous speed) and it is negative for positive slip (speed lower than synchronous speed). For super synchronous speed operation, Pr is transmitted to DC bus capacitor and tends to raise the DC voltage. For sub-synchronous speed operation, Pr is taken out of DC bus capacitor and tends to decrease the DC voltage. C_{grid} is used to generate or absorb the power P_{gc} in order to keep the DC voltage constant. In steady-state for a lossless AC/DC/AC converter P_{gc} is equal to P_r and the speed of the wind turbine is determined by the power Pr absorbed or generated by C_{rotor}. The phase-sequence of the AC voltage generated by C_{rotor} is positive for sub-synchronous speed and negative for super synchronous speed. The frequency of this voltage is equal to the product of the grid frequency and the absolute value of the slip. C_{rotor} and C_{grid} have the capability for generating or absorbing reactive power and could be used to control the reactive power or the voltage at the grid terminals.

3.4.3 Direct Drive Synchronous Generator Systems

Figure 3.11 shows the direct drive synchronous generator systems

- In this case, generator is completely decoupled from the grid by a power electronics converter connected to the stator winding.

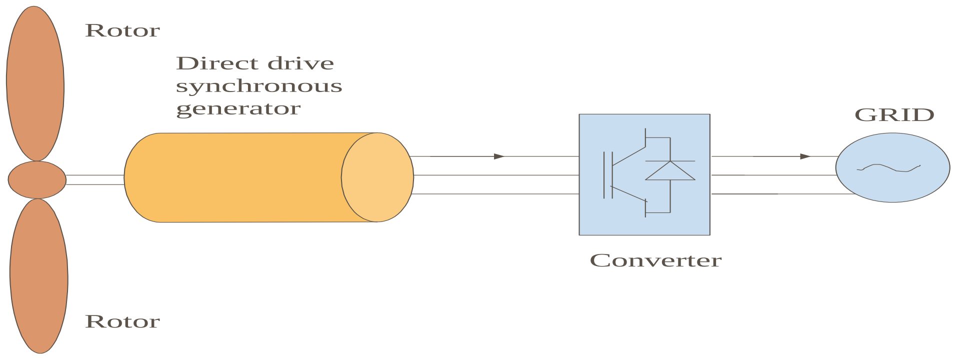


Figure 3.11 Direct drive synchronous generator systems

- The direct drive generator is excited using an excitation winding or permanent magnets. But directly grid coupled synchronous generators are not used in wind turbines due to unfavorable dynamic characteristics. When used in combination with a fluctuating prime movers cause high structural loads and a risk of instability during wind gusts which is also a problem.

3.5 CONTROL STRATERGY

In power systems, large power generation plants located at adequate geographical places produce most of the power, which is then transferred towards large consumption centers over long distance transmission lines. The system control centers monitor and control the power system continuously to ensure the quality of the power, namely the frequency and voltage. Since, the maximum power is the cubic function of generator speed for a given tip speed ratio, the continuous information of generator position and speed is essentially required. For this purpose, generally shaft-mounted speed sensors are used, resulting in additional cost and complexity of the system. To alleviate the need of these sensors, several speed-estimating algorithms are introduced. However, the precise estimation of rotor position and speed is very difficult as most of these suffer because of simplified computations based on several assumptions. For the linear systems PID controllers are used which are efficient for linear systems only and hence not effective for non-linear systems. Hence for non-linear systems Neuro fuzzy Logic System (FLS) is used, it has the disadvantage of non adaptiveness.

Neuro and Neuro- Neuro fuzzy (NF) system based position and speed estimator of DFIG has been proposed for wide range of speed operation during variable speed condition. The NF architecture has well-known advantages of modeling a highly non-linear system, as it combines the capability of Neuro fuzzy reasoning in handling uncertainties and capability of Artificial Neural Network (ANN) in learning from process. Neuro fuzzy Logic allows making definite decisions based on ambiguous data. ANN tries to incorporate human thinking process to solve problems without mathematically modeling. Both of these methods can be used to solve nonlinear problems. In contrast to Neuro fuzzy logic, ANN tries to apply the thinking process in the human brain to solve problems. Hybrid intelligent systems developed using these two methods called Neuro fuzzy Neural Network (FNN) or Neuro-Neuro fuzzy System (NFS)) the disadvantages found in both methods can be avoided and thus an efficient output can be obtained.

3.5.1 Power Converter Control System

A device that converts dc power into ac power at desired output voltage and frequency is called an Inverter. Voltage Source Inverter is one in which the dc source has small or negligible impedance. In other words, a voltage source inverter has a stiff voltage source at its input terminals. AC loads may require constant or adjustable voltage at their input terminals. When such loads are fed by inverters, it is essential that output voltage of the inverters is so controlled as to fulfill the requirements of the ac loads. PWM control is a method to control the output voltage that is widely in application. In this method, a fixed dc input voltage is given to the inverter and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components. The advantages possessed by PWM technique are as under,

i. The output voltage control with this method can be obtained without any additional components.

ii. With this method, lower order harmonics can be eliminated or minimized along with its output voltage control.

As the higher order harmonics can be filtered easily, the filtering requirements are minimized. The Insulated Gate Bipolar Transistor (IGBT) is a three-terminal power semiconductor device, noted for high efficiency and fast switching. Since it is designed to rapidly turn on and off, amplifiers that use it often synthesize complex waveforms with pulse width modulation and low pass filters.

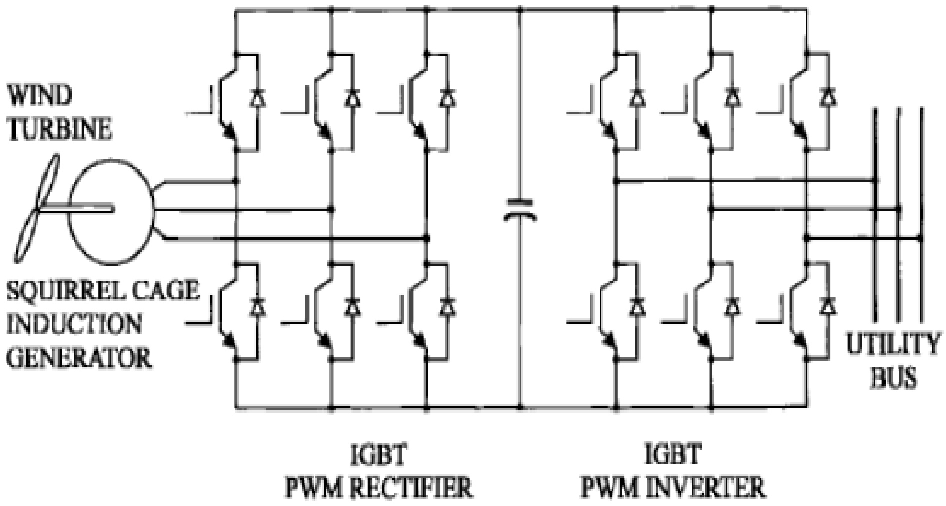


Figure 3.12 IGBT based rectifier and inverter

The voltage-fed converter scheme used in this system is shown in figure 3.12. A vertical (or horizontal) wind turbine is coupled to the shaft of a squirrel cage induction generator through a speedup gear ratio. The variable frequency variable voltage power from the generator is rectified by a PWM IGBT (Insulated Gate Bipolar Transistor) rectifier. The rectifier also supplies the excitation need of the machine. The inverter topology is identical to that of the rectifier, and it supplies the generated power at 60 Hz to the utility grid.

Back-to-back voltage source convertor is used in doubly fed induction generator which controls the grid and rotor currents. By controlling the rotor currents by the converter it is possible to adjust the active and reactive power fed to the grid from the stator independently of the generators turning speed. Rotor circuit is controlled by a power electronics converter, the induction generator is able to both import and export reactive power.

A salient advantage of the converter system includes the following:

- Line side power factor is unity with no harmonic current injection (satisfies IEEE 519).
- The cage type induction machine is extremely rugged, reliable, economical, and universally popular.
- Machine current is sinusoidal—no harmonic copper loss.
- Rectifier can generate programmable excitation for the machine.
- Continuous power generation from zero to highest turbine speed is possible.
- Power can flow in either direction permitting the generator to run as a motor for start-up (required for vertical turbine). Similarly, regenerative braking can quickly stop the turbine.
- Autonomous operation of the system is possible with either a start-up capacitor or with a battery on the dc link.
- Extremely fast transient response is possible.
- Multiple generators or multiple systems can be operated in parallel.
- The inverter can be operated as a VAR/harmonic compensator when spare capacity is available.

Considering all the above advantages, and with the present trend of decreasing converter and control cost, this type of conversion system has the potential to be universally accepted in the future. Of course, in recent years, soft-switched resonant link and resonant pole topologies have been proposed, but additional research and development are needed to bring them to the marketplace.

The back to back PWM converter has two converters, one is connected to rotor side and another is connected to grid side.

3.5.1.1 Grid side converter control system

The Grid side converter is used to regulate the voltage of the DC bus capacitor and it is shown in figure 3.13. For the grid-side controller the d-axis of the rotating reference frame used for d-q transformation is aligned with the positive sequence of grid voltage. This controller consists of

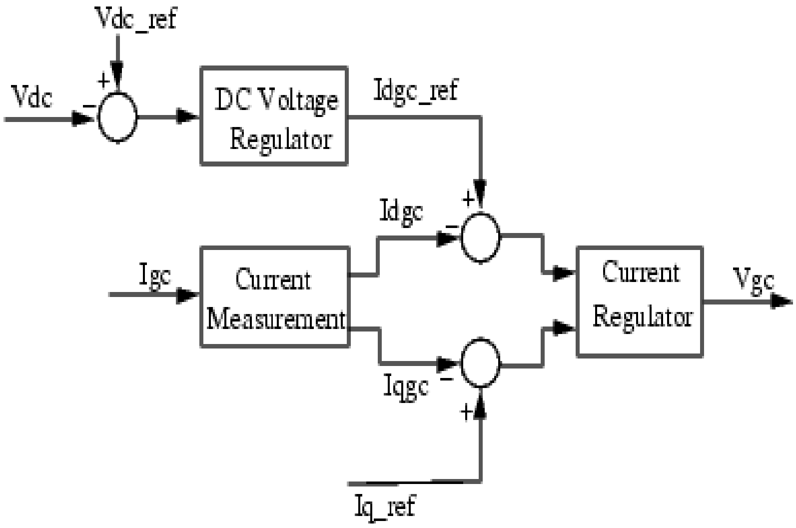


Figure 3.13 Grid side converter control

1. A measurement system measuring the d and q components of AC currents to be controlled as well as the DC voltage Vdc.
2. An outer regulation loop consisting of a DC voltage Regulator.
3. An inner current regulation loop consisting of a current Regulator.

The current regulator controls the magnitude and phase of the voltage generated by converter Cgrid (Vgc) from the Idgc _ ref produced by the DC voltage regulator and specified Iq_ref reference. The current regulator is assisted by feed forward terms which predict the Cgrid output voltage.

3.5.1.2 Pitch angle control system

The pitch angle is kept constant at zero degree until the speed reaches point D speed of the tracking characteristic. Beyond point D the pitch angle is proportional to the speed deviation from point D speed. For electromagnetic transients in power systems the pitch angle control is of less interest. The wind speed should be selected such that the rotational speed is less than the speed at point D.

3.6 POWER QUALITY

Power quality is a concept used to characteristics an essential set of parameters that determine the impact of wind turbines on the voltage quality of an electric power network. It applies in principle both to transmission and distribution networks, but is far more essential for the medium voltage networks. The relevant parameters are active and reactive power, including maximum value, voltage fluctuations (flicker), number of switching operations (and resulting voltage variations), harmonic currents and related quantities.

3.7 IMPACTS

Impacts can be classified mainly into two types.

1. Local impacts
2. Systems impacts.

3.7.1 Local Impacts

Local impacts of wind power are impacts that occur in the (electrical) vicinity of a wind turbine or wind farm and can be attributed to a specific turbine or farm. Local impacts occur at each turbine are largely independent of the overall wind power penetration level in the system as a whole.

Local impacts are

1. Branch flows and node voltages.
2. Protection schemes, fault currents and switch gear ratings.
3. Harmonic distortion.
4. Flicker

3.7.1.1 Branch flows and node voltages

The way in which wind turbines locally affect the node voltages depends on speed of the turbine used .The squirrel cage induction generator in constant speed cannot affect node voltages by adopting the reactive power exchange with the grid. For this additional equipment for generating controllable amounts of reactive power would be necessary. On the other hand variable speed turbines have, at least theoretically, the capability of varying reactive power to affect their terminal voltage, but this depends on the rating of the controllers of the power electronic converter.

3.7.1.2 Protection schemes, faults currents and switch gear ratings

Protection schemes and switchgear ratings must be checked when connecting new generation capacity. These are independent of the prime mover of the generator. The contribution of wind turbines to the fault currents also differs between the three main wind turbine types. Constant speed turbines are based on a directly grid coupled squirrel cage induction generator. They therefore contribute to the fault current and relay on conventional protection schemes. Turbines based on the doubly fed induction generator also contribute to the fault current.

However, the control system of power electronic converter that controls the rotor current measures faults currents very quickly. Due to the sensitivity of power electronics to over currents, this wind turbine type is currently quickly disconnected when a fault is detected. Wind turbines with a direct drive generator hardly contribute to the fault current because the power electronic converter through which the generator is connected to the grid is not capable of supplying a fault current.

3.7.1.3 Harmonic distortion

It is mainly an issue in the case of variable speed turbines because this contains power electronic devices, which are sources of harmonics. Harmonics cause over heating of transformer and generators. This also cause increase in currents through shunt capacitors and thus leading to the failure of such capacitors.

A practical solution would be to provide shunt filters at the PCC of non-linear loads and reduce the harmonic currents flowing all over the network. This would result in lower voltage distortion. In the case of modern power electronic converters with their high switching frequencies and advanced algorithms and filtering techniques, harmonic distortion should not be a principal problem. Well-designed, directly coupled synchronous and asynchronous generators hardly emit harmonics.

3.7.1.4 Flicker

Flicker is a specific property of wind turbines. Wind is a quite rapidly fluctuating prime mover. In constant speed turbines, prime mover fluctuations are directly translated into output power fluctuation, because there is no buffer between mechanical input and electrical output. Depending on the strength of the grid connection, the resulting power fluctuations can result in grid voltage fluctuations, which can cause unwanted and annoying fluctuations in bulb brightness. This problem is referred to as flicker.

In general, no flicker problem occurs with variable speed turbines, because in these turbines wind speed fluctuations are not directly translated into output power fluctuations. The rotor inertia acts as an energy buffer.

3.7.1.5 Harmonic reduction

The proliferation of power electronics devices have resulted in distortion of the steady state ac current and voltage waveforms. Equipments realized through these devices pose as non-linear loads and draw reactive and harmonic currents in addition to the active load current. The reactive and harmonic currents lead to poor power factor, low efficiency, electromagnetic interference with neighboring electronic appliances and overheating of transformers. In most of the distribution systems, power is distributed through three-phase four-wire network. The non-linear loads, present in the system, result in excessive neutral current due to triple harmonics, which are potentially damaging to both neutral conductor and distribution transformer.

Hence the above problems are prevented effectively mainly the harmonics is reduced by the control scheme implemented.

3.7.2 System Impacts

System-impacts are the impacts that affect the behavior of the system as whole. They are an inherent consequence from the application of wind power but cannot be attributed to individual turbines or farms. They are strongly related to the wind power penetration level in the system that is the contribution of wind power to actual load.

System impacts are

1. Power system dynamics and stability
2. Reactive power and voltage control.
3. Frequency control and load dispatching of conventional unit.

3.7.2.1 Power system dynamics and stability

In order to investigate the impact of wind power on power system dynamics and stability, adequate wind turbine models are essential. Squirrel cage induction generator used with constant speed turbine can lead to voltage and rotor speed instability. During a fault, they accelerate due to the unbalance between mechanical power extracted from the wind and electrical power supplied to grid.

When the voltage restores, they consume much reactive power, impeding voltage restoration. When the voltage returns to normal value quickly, the wind turbines continue to accelerate and to consume large amounts of reactive power. This eventually leads to voltage and rotor speed instability. With variable speed turbines, the sensitivity of the power electronics to over currents caused by voltage drops can have serious consequences for the stability of power systems.

To prevent this, some grid companies and transmission system operators prescribe that wind turbines must able to withstand voltage drops of certain magnitudes and duration, in order to prevent the disconnection of a large amount of wind power during fault .In order to meet this requirements, manufactures of variables speed wind turbines are implementing solutions to reduce the sensitivity of variable speed wind turbines with grid voltage drops.

3.7.2.2 Reactive power and voltage control

The impact of wind power on reactive power generation and voltage control originates first from the fact that not all wind turbines are capable of varying their reactive power output.

First of all wind power cannot be very flexibly located when compared to conventional generation. Secondly wind turbines are relatively weakly coupled to the system because their output voltage is rather low and are often erected at the distinct locations. This further reduces their contribution towards voltage control. When wind turbines at remote locations on a large scale replace the output of conventional synchronous generator, the voltage control aspect must therefore be taken into account explicitly.

3.7.2.3 Frequency control and load dispatching of conventional units

The impact of wind power on frequency control and load dispatching is caused by the fact that the prime mover of wind power is uncontrollable. Therefore, wind power hardly ever contributes to primary frequency regulation. Further, the variability of the wind on the longer term tends to complicate the load dispatching with the conventional units that remain in the system, as the demand curve to be matched by these units is far less smooth than would be the case without wind power. This heavily affects the dispatch of power from the conventional generators.

Note that the aggregate short term output power fluctuations of a large number of wind turbines are very smooth and are generally not considered as problem. The impact of wind power on frequency control and load dispatching becomes more severe. The higher the wind power penetration level is. The higher the wind power penetration, the larger the impact of wind power on the demand curve faced by remaining conventional units. It is however, impossible to quantify the wind power penetration level at which system wide effects start to occur because of the differences in demand curve and network topology between various power systems.

The above impacts are solved to some extent. But there is no proper solution to the problems caused by high-speed winds. During high-speed winds, the turbine speed exceeds its limit. This will cause

1. Very high fluctuations in voltage
2. Very high fluctuations in frequencies
3. It may damage the rotor

These problems to some extent can be solved by

1. By using some governing mechanism to operate gear mechanism to control the speed of the rotor of the wind turbine.
2. By using computer techniques we may control the speed of the turbine or disconnecting the turbine from generator during high-speed winds.
3. By connecting parachutes to the rotor for blades emergency stopping of the rotor.

3.8 REQUIREMENTS OF GRID CONNECTION

Interconnection of the doubly fed induction generator to the grid is shown in figure 3.14. If wind farms would be installed solely to maximize energy output, they would have major limitations in terms of

1. Power Control and Frequency Range.
2. Power Factor and Voltage Control
3. Transient Fault Behavior, Voltage Operating Range

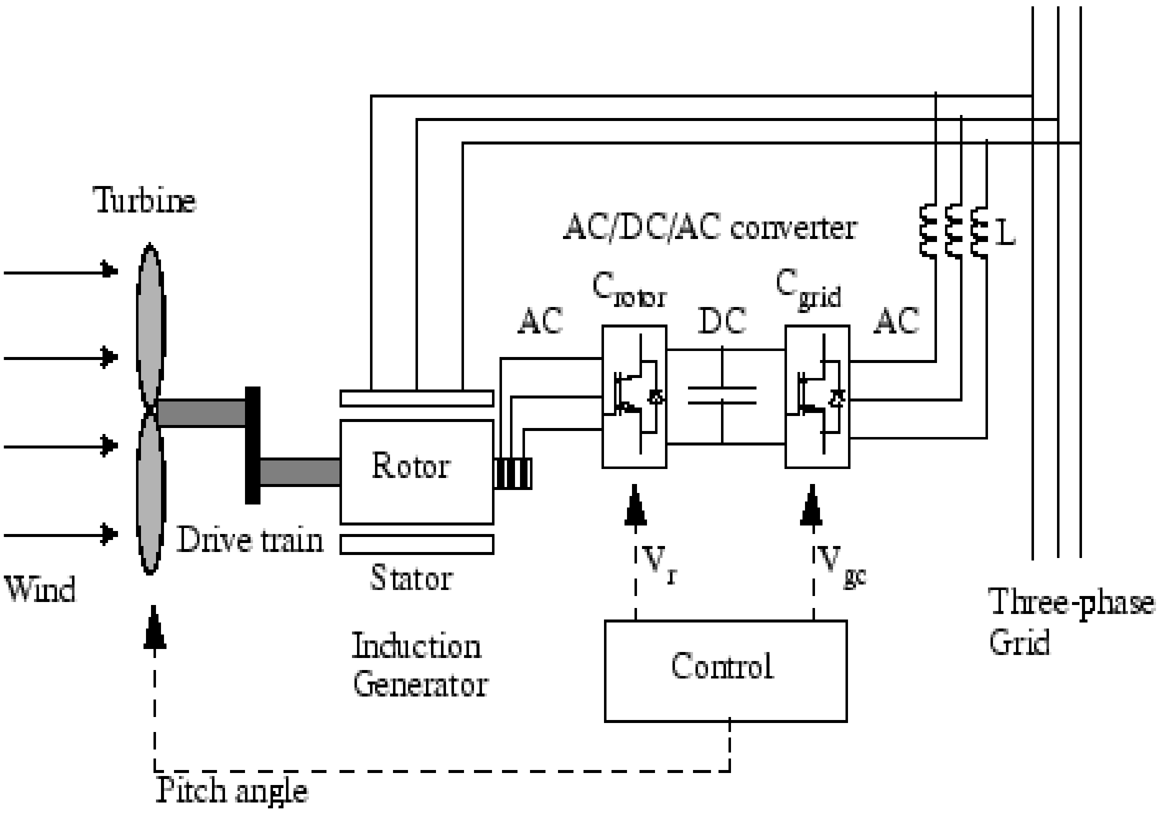


Figure 3.14 Interconnection of the doubly fed induction generator to the grid

These are the three main issues that new grid codes must address for wind farm connection. The most worrying problem that wind farms must face is a voltage dip in the grid. The effects of transient faults may propagate over very large geographical areas and the disconnection of wind farms under fault conditions could pose a serious threat to network security and security of supply because a great amount of wind power could be disconnected simultaneously.

3.8.1 Reactive Power Control

Voltage and current are typically measured 128 times per alternating current cycle, (i.e. 50 x 128 times per second or 60 x 128 times per second, depending on the electrical grid frequency). On this basis, a so called DSP processor calculates the stability of the grid frequency and the active 25 and reactive power of the turbine. (The reactive power component is basically a question of whether the voltage and the current are in phase or not). The term "power quality" refers to the voltage stability, frequency stability, and the absence of various forms of electrical noise (e.g. flicker or harmonic distortion) on the electrical grid. More broadly speaking, power companies (and their customers) prefer an alternating current with a nice sinusoidal shape.

3.8.2 Power Control and Frequency Range

It must be possible to limit the active power output from every operating point as a percentage of the nominal power. For power reduction a ramp rate of at least 10% of nominal power per minute must be possible. If power is ramped down, this must not imply disconnection of single turbines from the grid. In the wake of loss of grid voltage, power has to be ramped up with a gradient of not more than 10% of nominal power per minute. This ramp can be realized in steps (reconnection of single wind turbines), if the step size does not exceed 10% of nominal power per minute. The frequency range wind turbines have to tolerate is about 47.5-51.5 Hz. According to the requirements of German transmission grid operators, large wind farms have to be treated in the future like conventional power plants.

3.8.3 Power Factor and Voltage Control

It has to be possible to operate wind farms with nominal power of less than 100 MW with power factor between 0.95 lagging and 0.95 leading. The required power factor values are always applied at the grid connection point. Wind farms rated 100 MW or more have to be able to operate at power factor between 0.925 lagging and 0.95 leading. The power factor range is however limited depending on the grid voltage to avoid leading power.

3.8.4 Generating Alternating Current (AC) at Variable Frequency

Most wind turbines run at almost constant speed with direct grid connection. With indirect grid connection, however, the wind turbine generator runs in its own, separate mini AC-grid, as illustrated in the graphic. This grid is controlled electronically (using an inverter), so that the frequency of the alternating current in the stator of the generator may be varied. In this way it is possible to run the turbine at variable rotational speed. Thus the turbine will generate alternating current at exactly the variable frequency applied to the stator. The generator may be either a synchronous generator or an asynchronous generator, and the turbine may have a gearbox, as in the image above, or run without a gearbox if the generator has many poles.

3.8.5 Conversion to Direct Current (DC)

AC current with a variable frequency cannot be handled by the public electrical grid. We therefore start by rectifying it. The conversion from variable frequency AC to DC can be done using thyristors or large power transistors.

3.8.6 Conversion to Fixed Frequency AC

The (fluctuating) direct current is converted in to an alternating current (using an inverter) with exactly the same frequency as the public electrical grid. This conversion to AC in the inverter can also be done using either thyristors or transistors.

3.8.7 Filtering the AC

The rectangular shaped waves can be smoothed out, however, using appropriate inductances and capacitors, in a so-called AC filter mechanism.

The somewhat jagged appearance of the voltage does not disappear completely.

3.8.8 Advantages of Indirect Grid Connection

The advantage of indirect grid connection is that it is possible to run the wind turbine at variable speed. The primary advantage is that gusts of wind can be allowed to make the rotor turn faster, thus storing part of the excess energy as rotational energy until the gust is over. Obviously, this requires an intelligent control strategy, since we have to be able to differentiate between gusts and higher wind speed in general. Thus it is possible to reduce the peak torque (reducing wear on the gearbox and generator), and we may also reduce the fatigue loads on the tower and rotor blades. The secondary advantage is that with power electronics one may control reactive power (i.e. the phase shifting of current relative to voltage in the AC grid), so as to improve the power quality in the electrical grid. This may be useful, particularly if a turbine is running on a weak electrical grid. Theoretically, variable speed may also give a slight advantage in terms of annual production, since it is possible to run the machine at an optimal rotational speed, depending on the wind speed. From an economic point of view that advantage is so small, however, that it is hardly worth mentioning.

3.8.9 Disadvantages of Indirect Grid Connection

The basic disadvantage of indirect grid connection is cost. As we just learned, the turbine will need a rectifier and two inverters, one to control the stator current, and another to generate the output current. Presently, it seems that the cost of power electronics exceeds the gains to be made in building lighter turbines, but that may change as the cost of power electronics decreases. Looking at operating statistics from wind turbines using power electronics, it also seems that availability rates for these machines tend to be somewhat lower than conventional machines, due to failures in the power electronics. Other disadvantages are the energy lost in the AC-DC-AC conversion process, and the fact that power electronics may introduce harmonic distortion of the alternating current in the electrical grid, thus reducing power quality. Although the size and direction of the wind is stochastic and the output power of the wind turbine varies with the starting and ceasing of the system, the induction generator has many merits, such as low cost, high credibility and easy servicing. The modes of induction generator connected to grid are adopted in large wind farms. There're two types of wind turbine connected to grid. One is the direct grid-connection mode; the other is connected to grid though a power electronics

- Doubly fed induction generator with cascaded converter slip power recovery;
- Doubly fed induction generator with cycloconverter slip power recovery
- Synchronous generator with line-commutated and load commutated thyristor Converters

In addition to the above schemes, squirrel cage generators with shunt passive or active VAR (volt ampere reactive) generators have been proposed which generate constant voltage constant frequency power through a diode rectifier and line-commutated thyristor inverter. Recently, a variable reluctance machine and doubly stator-fed induction machine have also been proposed in wind generation systems. Very recently, a double sided pulse width modulated (PWM) converter system has been proposed to overcome some of the above problems. This describes a VSWT system with a squirrel cage induction generator and a double-sided PWM converter where Neuro fuzzy logic control has been used extensively to maximize the power output and enhance system performance.

3.9 EXISTING SYSTEM

This paper proposes a hybrid ac/dc micro grid to reduce the processes of multiple dc–ac–dc or ac–dc–ac conversions in an individual ac or dc grid. The hybrid grid consists of both ac and dc networks connected together by multi-bidirectional converters. AC sources and loads are connected to the ac network whereas dc sources and loads are tied to the dc network. Energy storage systems can be connected to dc or ac links. The proposed hybrid grid can operate in a grid-tied or autonomous mode. The coordination control algorithms are proposed for smooth power transfer between ac and dc links and for stable system operation under various generation and load conditions. Uncertainty and intermittent characteristics of wind speed, solar irradiation level, ambient temperature, and load are also considered in system control and operation. A small hybrid grid has been modeled and simulated using the Simulink in the MATLAB. The simulation results show that the system can maintain stable operation under the proposed coordination control schemes when the grid is switched from one operating condition to another.

3.9.1 CIRCUIT DIAGRAM

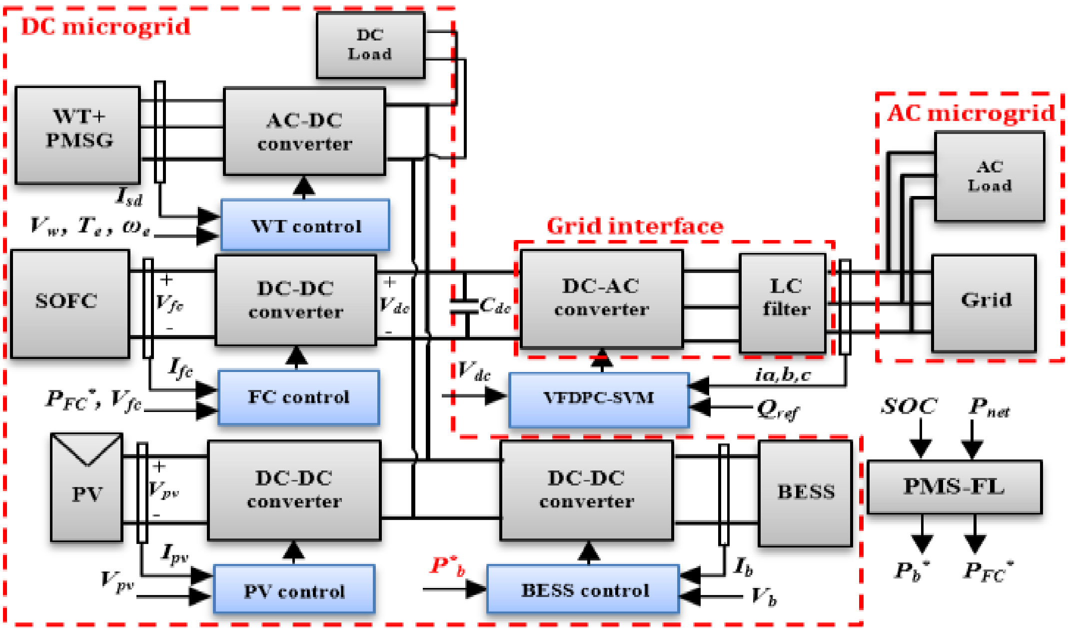


Fig 3.13 A hybrid ac/dc microgrid system.

3.10 RESULTS

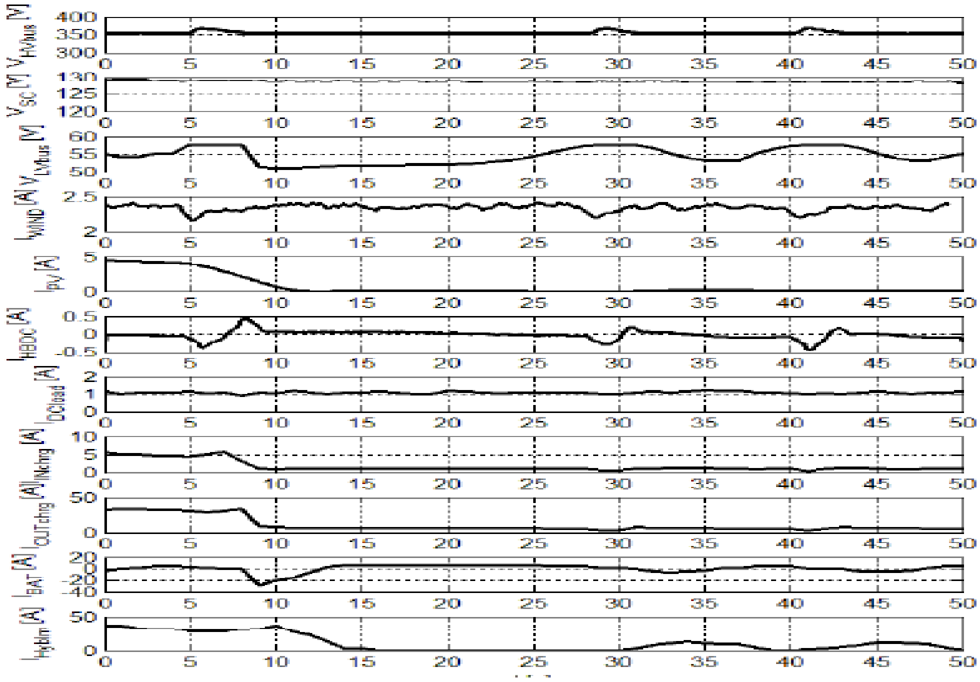


Fig 3.14 A hybrid ac/dc microgrid system outputs

CHAPTER-4

PROPOSED SYSTEM

4.1 INTRODUCTION

The concept of microgrid is considered as a collection of loads and micro sources 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 dispatch able 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 feeder losses, local voltages support, increased efficiency through use waste heat, voltage sag correction . 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. Microgrid considered as a ‘grid friendly entity” and does not give undesirable influences to the connecting distribution network i.e. operation policy of distribution grid does not have to be modified.

4.2 BLOCK DIAGRAM

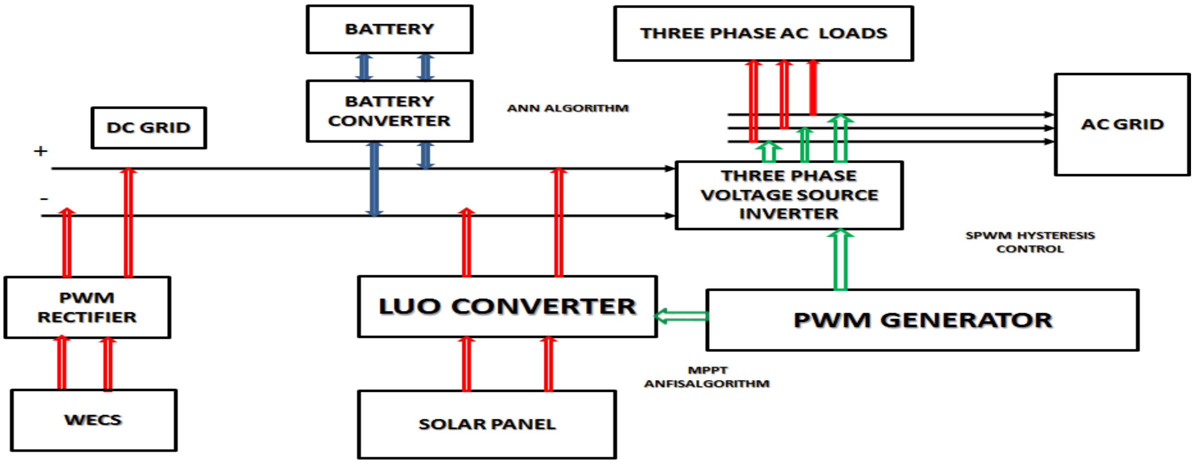


Fig 4.1. A hybrid AC/DC microgrid system

4.3 CIRCUIT DIAGRAM

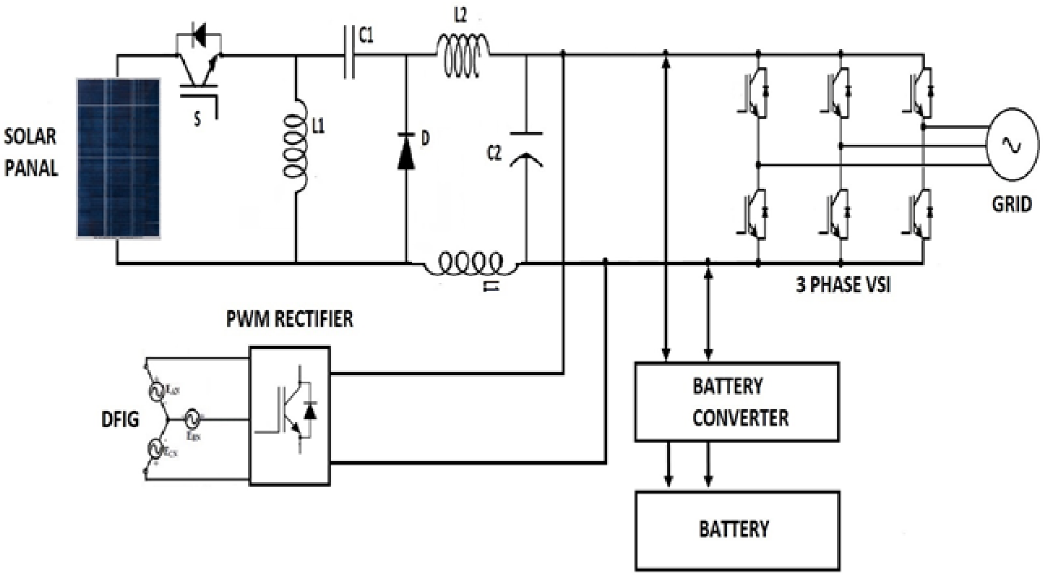


Fig 4.2. A hybrid AC/DC microgrid system Circuit diagram

The configuration of the hybrid system is shown in Figure 4.1 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. Figure 4.2 describes the hybrid system configuration which consists of AC and DC grid. The AC and DC grids have their corresponding sources, loads and energy storage elements, and are interconnected by a three phase converter. The AC bus is connected to the utility grid through a transformer and circuit breaker. In the proposed system, PV arrays are connected to the DC bus through boost converter to simulate DC sources. A PMSG 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. PV modules are connected in series and parallel. As solar radiation level and ambient temperature changes the output power of the solar panel alters. A capacitor C is added to the PV terminal in order to suppress high frequency ripples of the PV 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 (PMSG) 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 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.

4.4 OPERATION OF GRID

The hybrid grid performs its operation in two modes.

4.4.1. GRID TIED MODE

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.

4.4.2. AUTONOMOUS MODE

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.

4.4.3. MODELLING OF BOOST CONVERTER

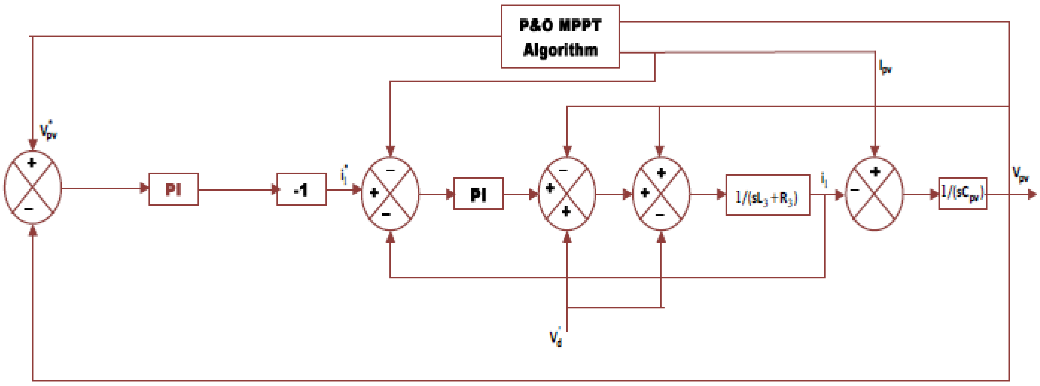


Fig 4.3. Control block diagram of converter

With the implementation of Neuro fuzzy logic algorithm a reference value is calculated which mainly depends upon solar irradiation and temperature of PV array. Here for the boost converter dual loop control is proposed. 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 and inner current loop help in improvisation of dynamic response.

4.4.4. MODELLING 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 iT- reference and the instantaneous reactive current in- reference is determined by reactive power compensation command.

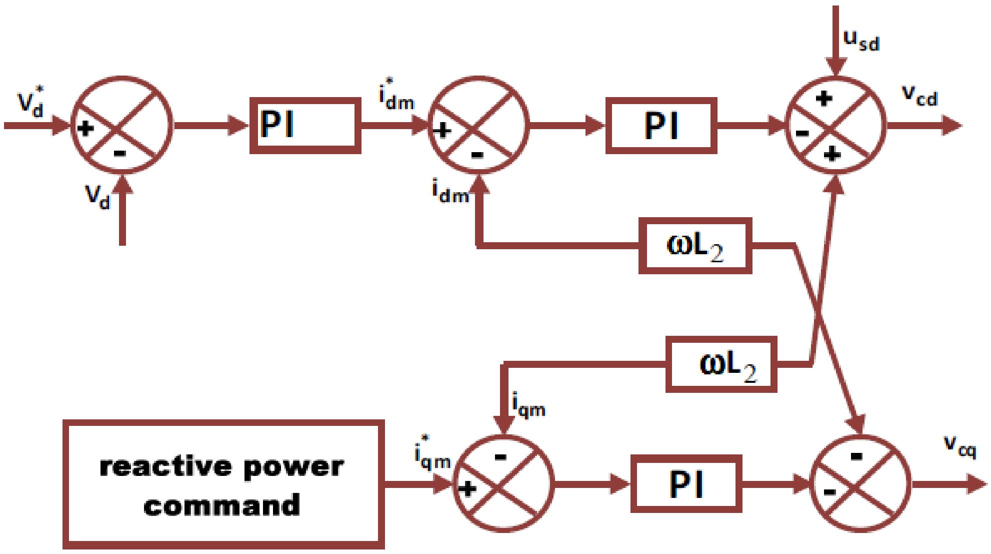


Fig 4.4. Control block diagram of main converter

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 CT leads to rising of DC-link voltage VT. The negative error caused by the increase of VT produces a higher active current reference iT through PI control. A higher positive reference iT will force active current reference iT- 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 VT 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 VT drop makes the magnitude of iT- increase through the PI control. Since iT- and iT are both negative, the magnitude of iT- is increased through the inner current control loop. Hence power is transferred from AC grid to the DC side.

4.5 INTRODUCTION TO NFLC

Neuro fuzzy logic has rapidly become one of the most successful of today's technology for developing sophisticated control system. With it aid complex requirement so may be implemented in amazingly simple, easily minted and inexpensive controllers. The past few years have witnessed a rapid growth in number and variety of application of Neuro fuzzy logic. The application range from consumer products such as cameras ,camcorder ,washing machines and microwave ovens to industrial process control ,medical instrumentation ,and decision- support system .many decision-making and problem solving tasks are too complex to be understand quantitatively however ,people succeed by using knowledge that is imprecise rather than precise .

Neuro fuzzy logic is all about the relative importance of precision. Neuro fuzzy logic has two different meanings .in a narrow senses, Neuro fuzzy logic is a logical system which is an extension of multi valued logic .but in wider sense Neuro fuzzy logic is synonymous with the theory of Neuro fuzzy sets . Neuro fuzzy set theory is originally introduced by Lotfi Zadeh in the 1960, resembles approximate reasoning in it use of approximate information and uncertainty to generate decisions.

Several studies show, both in simulations and experimental results, that Neuro fuzzy Logic control yields superior results with respect to those obtained by conventional control algorithms thus, in industrial electronics the FLC control has become an attractive solution in controlling the electrical motor drives with large parameter variations like machine tools and robots. However, the FL Controllers design and tuning process is often complex because several quantities, such as membership functions, control rules, input and output gains, etc must be adjusted. The design process of a FLC can be simplified if some of the mentioned quantities are obtained from the parameters of a given Proportional-Integral controller (PIC) for the same application.

4.5.1 MOTIVATIONS FOR CHOOSING NEURO FUZZY LOGIC CONTROLLER

- Neuro fuzzy logic controller can model nonlinear system

  The design of conventional control system essential is normally based on the mathematical model of plant .if an accurate mathematical model is available with known parameters it can be analyzed., for example by bode plots or nyquist plot , and controller can be designed for specific performances .such procedure is time consuming.

- Neuro fuzzy logic controller has adaptive characteristics.

The adaptive characteristics can achieve robust performance to system with uncertainty parameters variation and load disturbances.

4.5.2 NEURO FUZZY LOGIC CONTROLLER

Neuro fuzzy logic expressed operational laws in linguistics terms instead of mathematical equations.

Many systems are too complex to model accurately, even with complex mathematical equations; therefore traditional methods become infeasible in these systems. However Neuro fuzzy logics linguistic terms provide a feasible method for defining the operational characteristics of such system.

Neuro fuzzy logic controller can be considered as a special class of symbolic controller. The configuration of Neuro fuzzy logic controller block diagram is shown in Fig.4.5

The Neuro fuzzy logic controller has three main components

- Fuzzification
- Neuro fuzzy inference
- Defuzzification

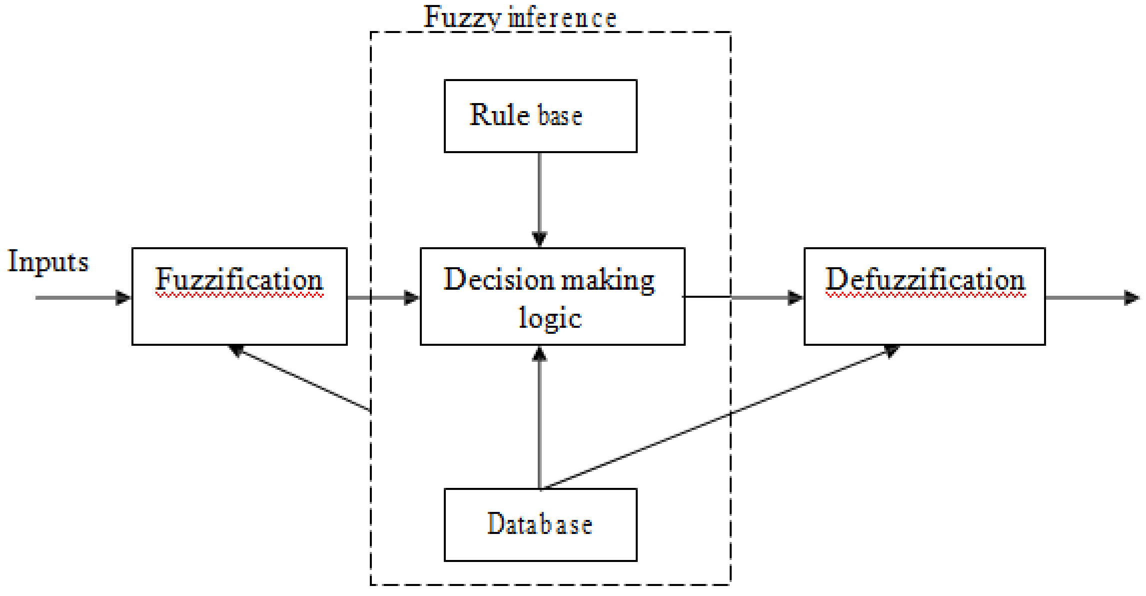


Fig 34.5 Block Diagram of Neuro fuzzy logic control

4.5.3 FUZZIFICATION

The following functions:

- Multiple measured crisp inputs first must be mapped into Neuro fuzzy membership function this process is called fuzzification.
- Performs a scale mapping that transfers the range of values of input variables into corresponding universes of discourse.
- Performs the function of fuzzification that converts input data into suitable linguistic values which may be viewed as labels of Neuro fuzzy sets.

Neuro fuzzy logic linguistic terms are often expressed in the form of logical implication, such as if- then rules. These rules define a range of values known as Neuro fuzzy membership functions.

Neuro fuzzy membership function may be in the form of a triangular, a trapezoidal, a bell or another appropriate form.

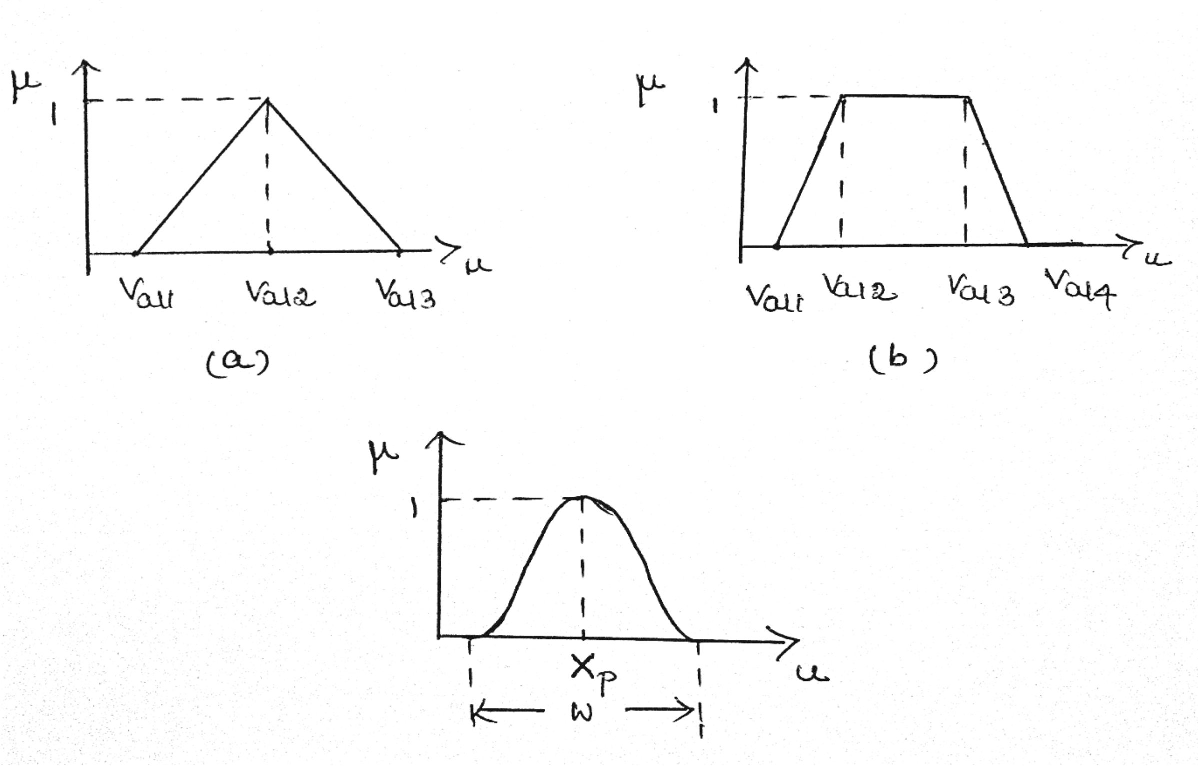


Fig 4.6 Membership function

The inputs of the Neuro fuzzy controller are expressed in several linguist levels. As shown in Fig. 4.7 these levels can be described as Positive big (PB), Positive medium (PM), Positive small (PS) Negative small (NS), Negative medium (NM), Negative big (NB) or in other levels. Each level is described by Neuro fuzzy set.

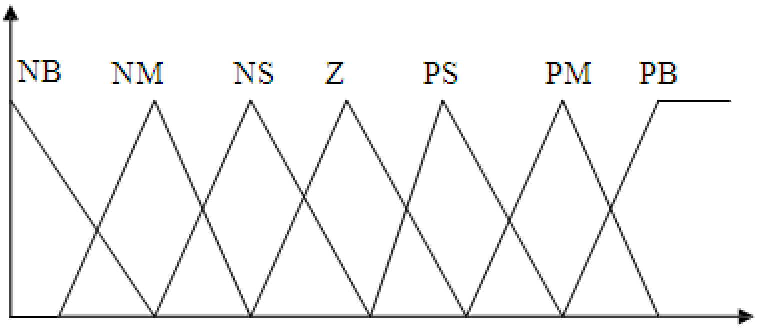


Fig 4.7 Seven levels of Neuro fuzzy Membership function

4.5.4 NEURO FUZZY INFERENCE

Neuro fuzzy inference is the process of formulating the mapping from a given input to an output using Neuro fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned. There are two types of Neuro fuzzy inference systems that can be implemented in the Neuro fuzzy Logic Toolbox: Mamdani-type and Sugeno-type. These two types of inference systems vary somewhat in the way outputs are determined.

Neuro fuzzy inference systems have been successfully applied in fields such as automatic control, data classification, decision analysis, expert systems, and computer vision. Because of its multidisciplinary nature, Neuro fuzzy inference systems are associated with a number of names, such as Neuro fuzzy-rule-based systems, Neuro fuzzy expert systems, Neuro fuzzy modeling, Neuro fuzzy associative memory, Neuro fuzzy logic controllers, and simply (and ambiguously) Neuro fuzzy.

Mamdani's Neuro fuzzy inference method is the most commonly seen Neuro fuzzy methodology. Mamdani's method was among the first control systems built using Neuro fuzzy set theory. It was proposed in 1975 by Ebrahim M amdani [Mam75] as an attempt to control a steam engine and boiler combination by synthesizing a set of linguistic control rules obtained from experienced human operators. Mamdani's effort was based on Lotfi Zadeh's 1973 paper on Neuro fuzzy algorithms for complex systems and decision processes [Zad73].

The second phase of the Neuro fuzzy logic controller is its Neuro fuzzy inference where the knowledge base and decision making logic reside .The rule base and data base from the knowledge base. The data base contains the description of the input and output variables. The decision making logic evaluates the control rules .the control-rule base can be developed to relate the output action of the controller to the obtained inputs.

4.5.5 DEFUZZIFICATION

The output of the inference mechanism is Neuro fuzzy output variables. The Neuro fuzzy logic controller must convert its internal Neuro fuzzy output variables into crisp values so that the actual system can use these variables. This conversion is called Defuzzification. One may perform this operation in several ways. The commonly used control Defuzzification strategies are

(a).The max criterion method (MAX)

The max criterion produces the point at which the membership function of Neuro fuzzy control action reaches a maximum value.

(b)The height method

The centroid of each membership function for each rule is first evaluated. The final output U_0 is then calculated as the average of the individual centroids, weighted by their heights as follows:

$$U_O = \frac{\sum_{i=1}^{n} u_i \mu(u_i)}{\sum_{i=1}^{n} \mu(u_i)}$$

(c) The centroid method or center of area method (COA)

The widely used centroid strategy generates the center of gravity of area bounded by the Membership function are

$$\bar{y} = \frac{\int \mu_Y(y).y\,dy}{\int \mu_Y(y)\,dy}$$

CHAPTER-5

SIMULATION RESULTS

A hybrid microgrid is simulated using MATLAB/SIMULINK environment. The operation is carried out for the grid connected mode. Along with the hybrid microgrid, the performance of the doubly fed induction generator, photovoltaic system is analyzed. The solar irradiation, cell temperature and wind speed are also taken into consideration for the study of hybrid microgrid. The performance analysis is done using simulated results which are found using MATLAB.

5.1 MATLAB SIMULINK

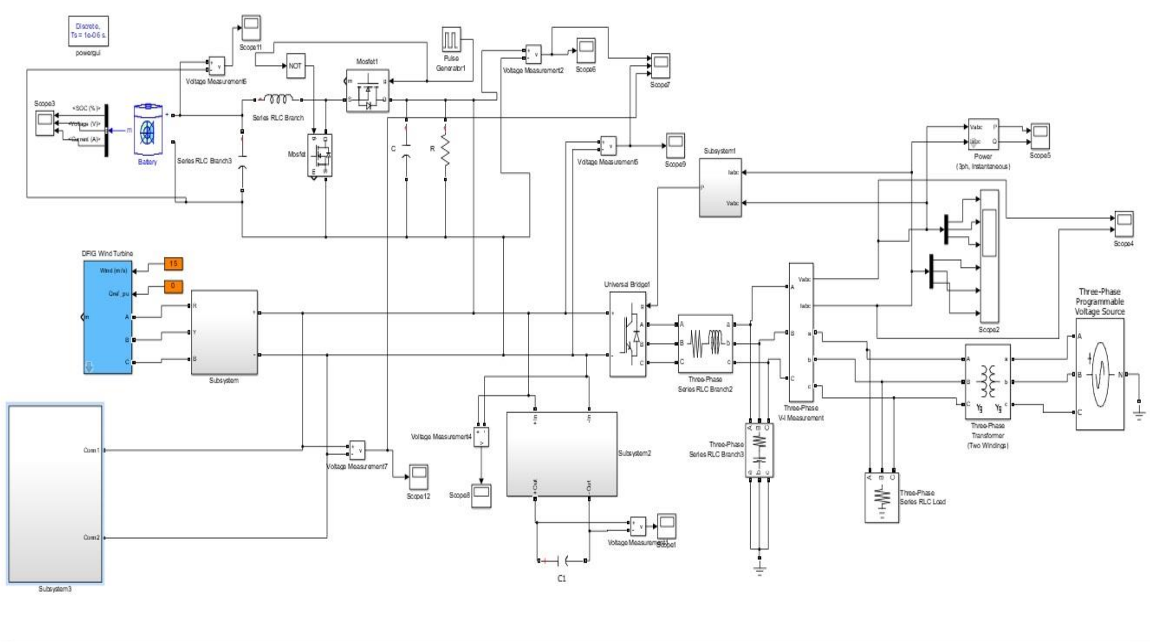


Fig 5.1 Proposed system simulation diagram

5.2 SOLAR PANEL OUTPUT WAVE FORM

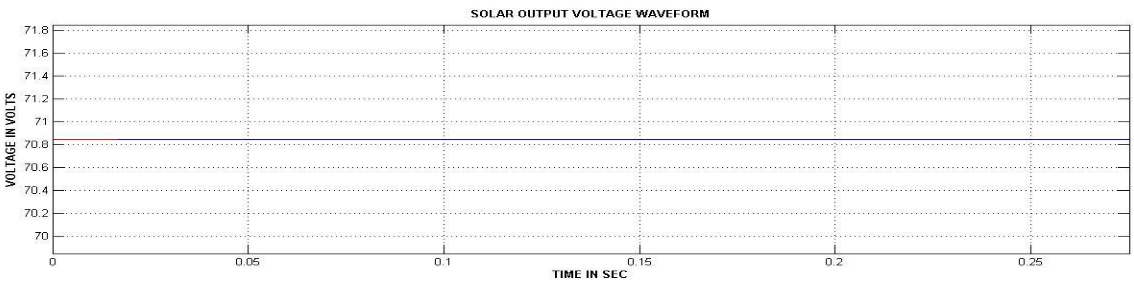


Fig 5.2 Solar panel output voltage waveform

5.3 LUO CONVERTER INPUT & OUTPUT WAVEFORM

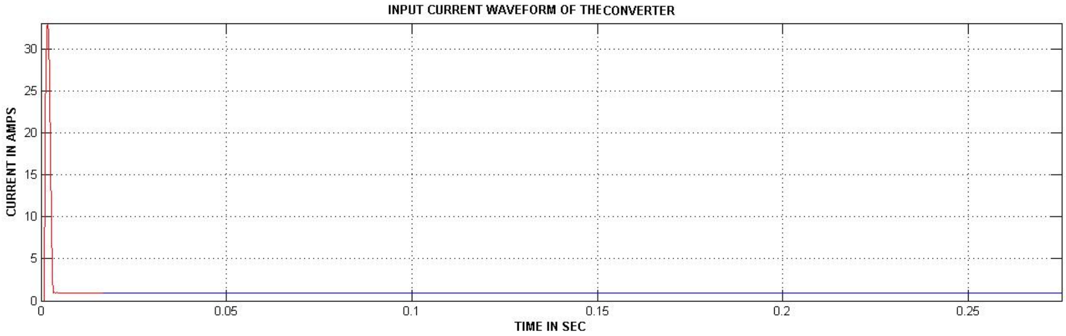


Fig 5.3 LUO converter input current waveform

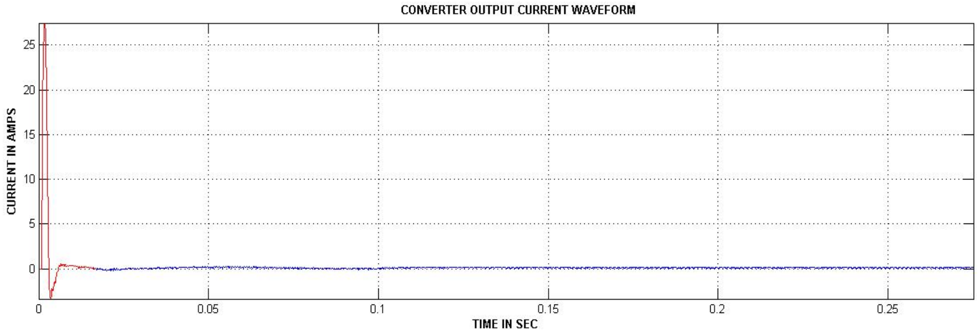


Fig 5.4 LUO converter output current waveform

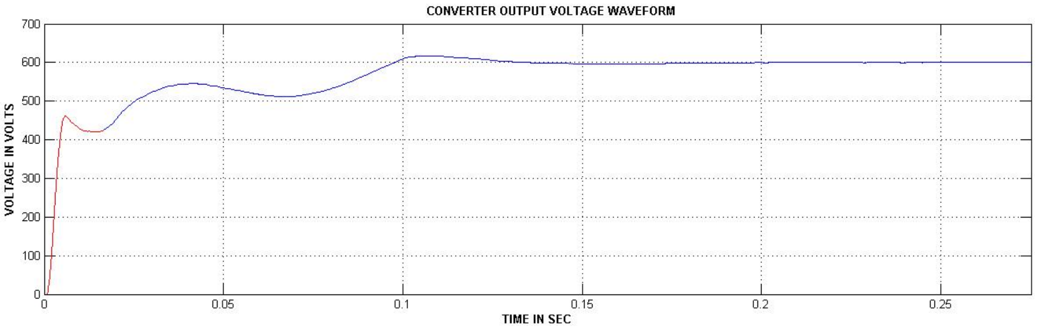


Fig 5.5 LUO converter input voltage waveform

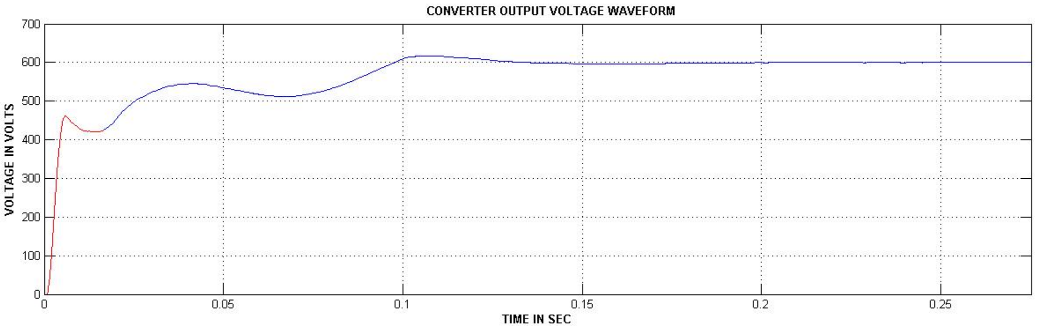


Fig 5.6 LUO converter output voltage waveform

5.4 WIND ENERGY OUTPUT WAVEFORM

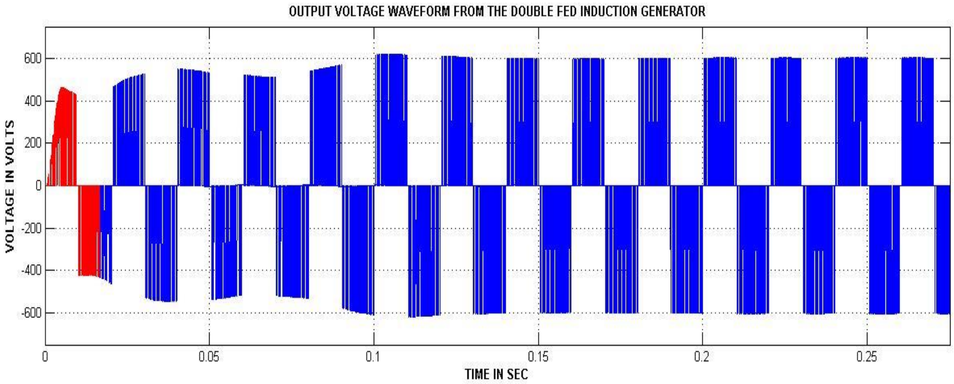


Fig 5.7 Wind system output AC voltage waveform

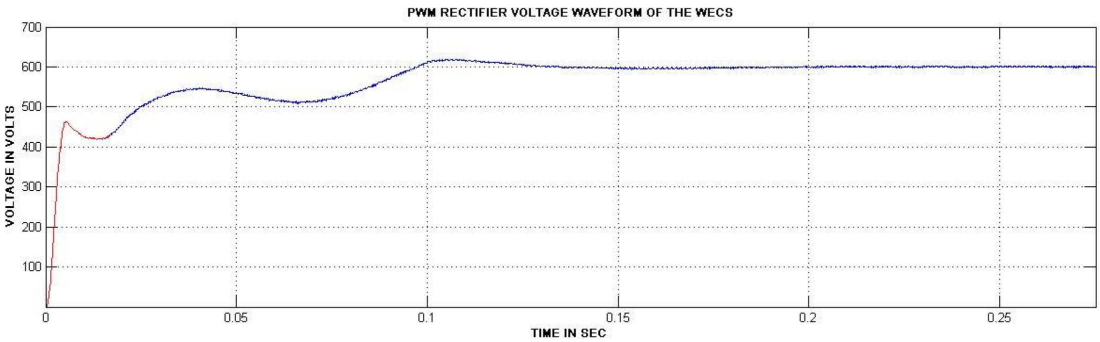
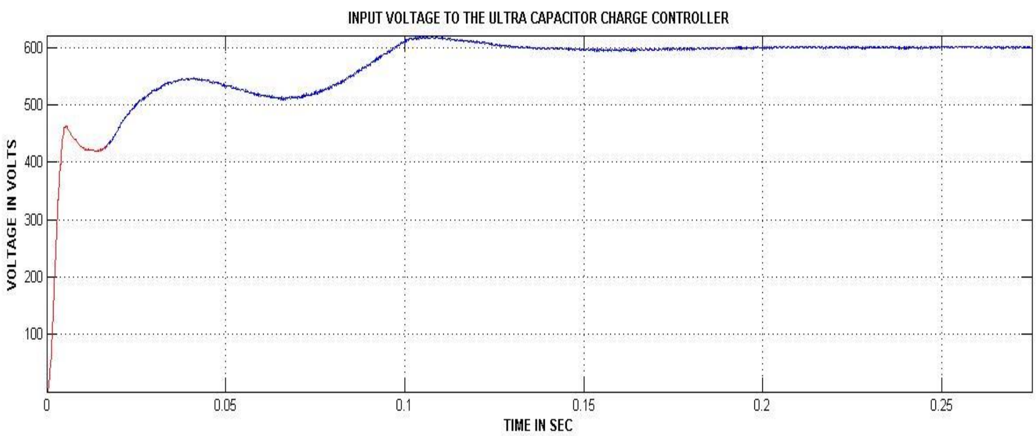


Fig 5.8 Wind system output DC voltage waveform

5.5 ULTRA CAPACITOR INPUT & OUTPUT WAVEFORM



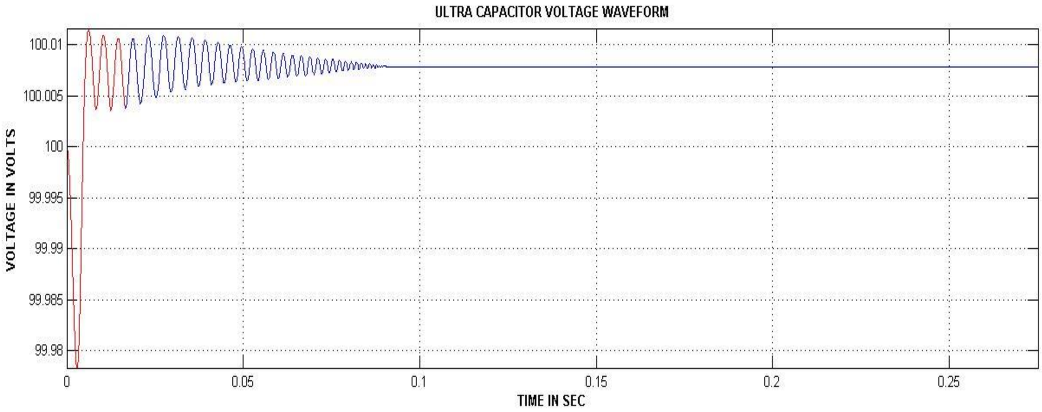


Fig 5.9 Capacitor input and output DC voltage waveform

5.6 BATTERY VOLTAGE WAVEFORM

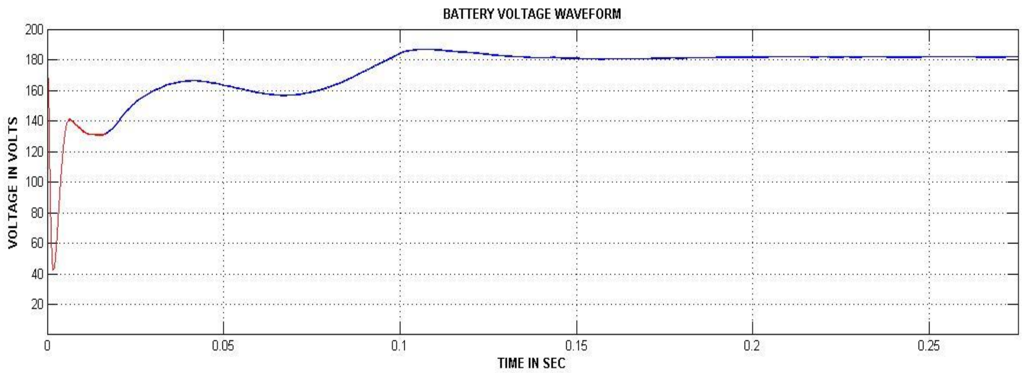
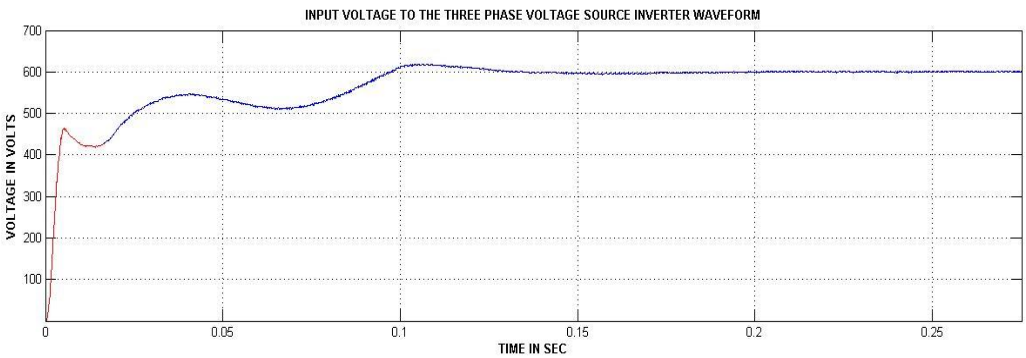
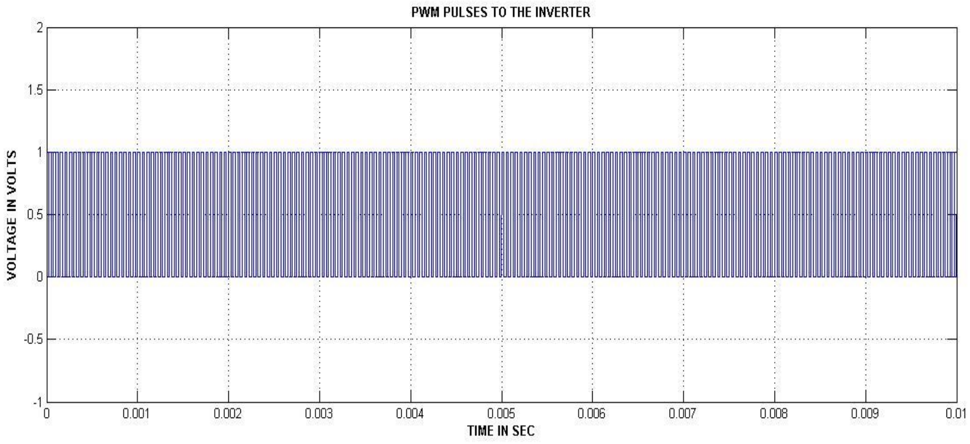


Fig 5.10 Battery output DC voltage waveform

5.7 THREE PHASE VOLTAGE SOURCE INVERTER INPUT AND OUTPUT WAVEFORM





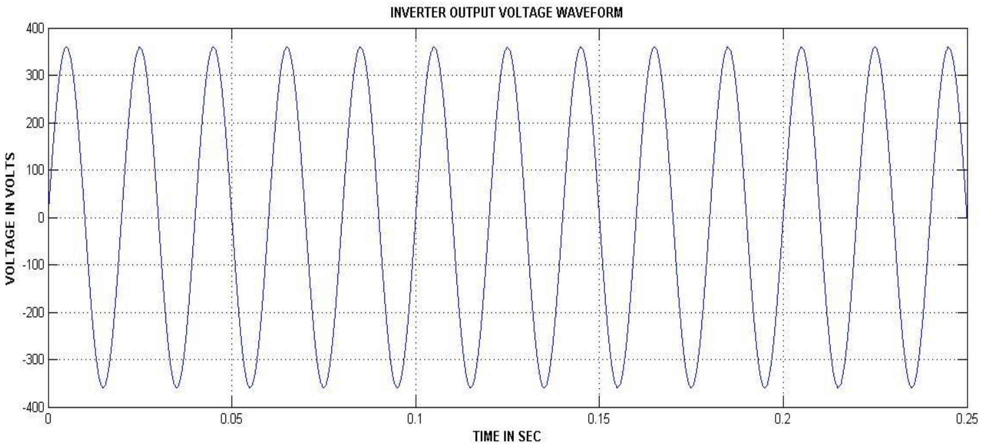
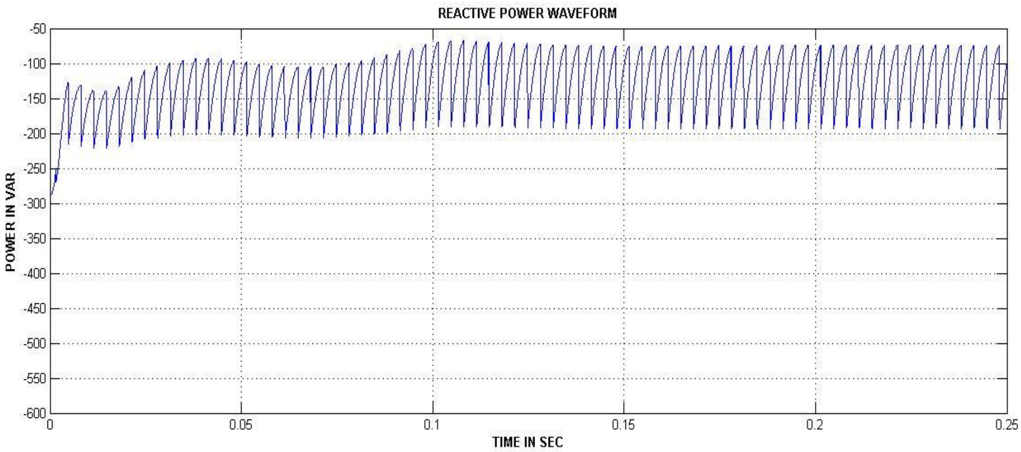


Fig 5.11 Inverter section waveforms

5.8 REAL AND REACTIVE POWER WAVEFORM



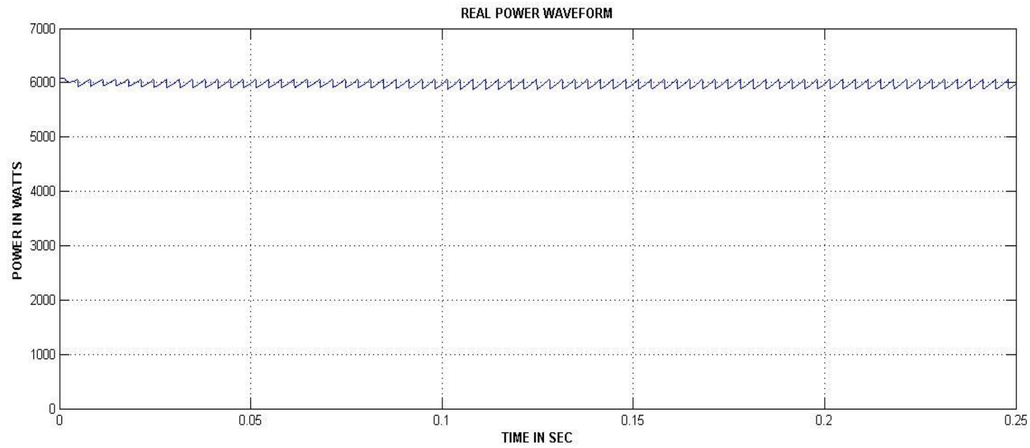


Fig 5.12 Power waveforms

5.9 FFT ANALYSIS FOR GRID CURRENT WAVEFORM

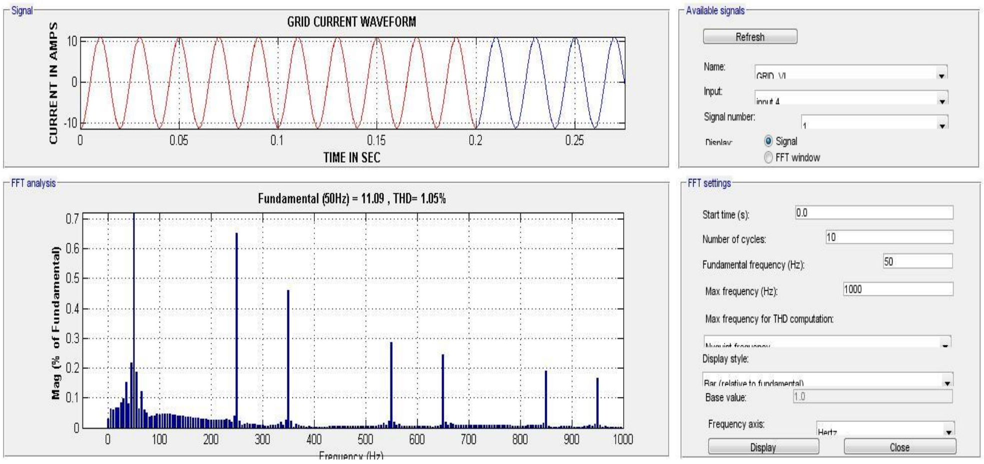


Fig 5.13 THD results using Fuzzy logic algorithm

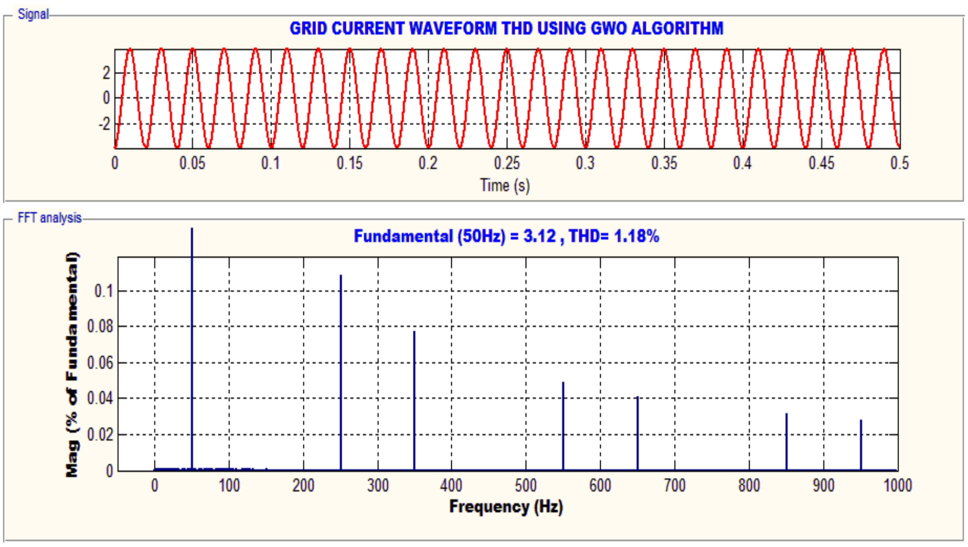


Fig 5.14 THD results using Neuro Fuzzy logic algorithm

TABLE 5.1 COMPARISON BETWEEN EXISTING AND PROPOSED WORK

SI NO	PARAMETERS	EXISTING LUO CONVERTER	MODIFIED LUO CONVERTER
1	THD	1.98	1.18
2	MPPT Efficiency	92%	96%

CHAPTER-6

CONCLUSION

6.1 CONCLUSION

The modelling of hybrid microgrid for power system configuration is done in MATLAB/SIMULINK environment. The present work mainly includes the grid tied mode of operation of hybrid grid. 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. MPPT Neuro fuzzy algorithm is used 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 PV systems and wind turbine generator as the major power supply.

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