People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research

University M'Hamed BOUGARA – Boumerdes

Institute of Electrical and Electronic Engineering
Department of Power and Control

Project Report Presented in Partial Fulfilment of

The Requirements of the Degree of

'MASTER'

In Electrical and Electronic Engineering

Option: Power Engineering

Title:

Implementation and simulation of PMSG driven by wind turbine and controlled by MPPT

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Abstract

Wind power is one of the fastest growing renewable energy technologies. It is very essential to extract the maximum available power from the wind by operating the wind turbine at its optimal operation condition, called maximum power point tracking (MPPT). Perturb and observe (P&O) is the simplest and mostly used algorithm for this purpose. However, this algorithm has its own disadvantages such as oscillation at maximum power point and wrong directionality under fast variation wind speed. In this project, a conventional P&O algorithm, a new algorithm based on Golden Section search principle and a Fuzzy logic MPPT algorithm for variable speed wind turbine using permanent magnet synchronous generator (PMSG) are tested and compared in the terms of complexity, speed responses and the ability to acquire the maximal energy output.

Acknowledgment

First we thank Allah, for helping us finish this modest work. And gave us strength and patience despite all obstacles we have been through.

This thesis has been submitted in partial fulfilment of the degree of Master in electrical and Electronic engineering. The work has been conducted under the supervision of Professor **KHELDOUN Aissa** at the institute of electrical and Electronic engineering, Department of power and control.

We would like to express our huge gratitude to the best supervisor

Dr. A.Abdelkarim for his help and support throughout the study and realization of this project.

Mr .dahmani seifeddine for his big help.

We extend our thanks to our dear parents who helped us during our studies

Dedication

I have great pleasure to dedicate this modest work:

- ❖ my beloved parents
- ❖ To all our teachers and especially **Dr Ammar.Abdelkarim** and **dr khaldoun**
- ❖ To all my friends and those who have supported us and helped us especially **benhoua seif eddin , khelifa ayoub**, and **boutheina berkane**

Mohamed

Dedication

In the memory of my Grandma,

I dedicate my thesis to my family and many friends. A special feeling of gratitude to my loving parents "Aissa and Zahia" and my second parents "Hassina and Mahdi" whose words of encouragement and push for tenacity ring in my ears. My sisters Dadi, Amira and Imen. My brothers Ahmed, Doudou, Cherif and Himoun and My babies Rama, Loulou and Malek for being always by my side.

I also dedicate my work to all my friends who have supported me throughout the process. Especially Dounia-Zed who never left my side, Seifou who helped me in the thesis, Mustafa Alrawy and Mohamed Almoutarjem for the encouragement and Mrs. potato head for the leadership.

I also give a special thanks to my husband Charger and his best friend abu-Inara for being there for me throughout the entire master program. Both of you have been my best cheerleaders.

Iatidel

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Abbreviations

MPPT	Maximum power point tracking
P&O	Perturb and Observe
FLC	Fuzzy Logic Controller
PMSG	Permanent Magnet Synchronous Generator
WECS	Wind Energy Conversion system
WT	Wind turbine
WF	Wind farm
BC	Before century
HAWT	horizontal axis wind turbines
VAWT	vertical axis wind turbine
DFIG	doubly fed induction generator
RPM	Round per minute
SG	synchronous generator
WRSG	wounded rotor synchronous generators
PLL	phase locked loop
BTB	back-to-back connected converter
MSC	Machine side converter
GSC	Grid side converter
RC	Resistor-Capacitor
RLC	Resistor-Inductor-Capacitor
WTG	Wind turbine generator
MPP	Maximum power point
HCS	hill-climb searching
VOC	Voltage Oriented Control
VSC	Voltage Source Control
CSC	Current Source Control

General Introduction

General Introduction

The energy is a vital input for the social and economic development of any nation. With increasing agricultural and industrial activities in the country, the demand for energy is also increasing. In recent years, the use of renewable energy resources is more and more increased due to the increasing need for energy and the shortage of traditional energy sources in the near future [1].

Wind power is used to produce electricity or mechanical power and supplies it to homes, business, schools, etc. Wind turbine converts kinetic energy into mechanical energy and then the generator in the wind turbine converts this mechanical energy into electrical power. Wind turbine consists of rotor, generator, tower that supports rotor, gear box, electrical cables, etc. It is classified into two major types; Horizontal Axis wind turbine and Vertical Axis wind turbine. A Permanent Magnet Synchronous Generator (PMSG) is a generator contains the permanent magnet in the excitation field instead of coil. It is used to convert the mechanical power into electrical power and supply it to the grid. It consists of stator and rotor where stator is the armature and rotor contains the magnet.

Maximum Power Point Tracking (MPPT) is a technique which is used to track the maximum power from various devices especially photovoltaic systems. The capacity and higher value of current and voltage in the solar panel can make higher power. MPPT contains different algorithms such as Perturb and Observe, Golden Section and Fuzzy Logic Method. In wind turbine, the rotor speed continuously changes with changing the wind speed to get Maximum power. Therefore, the Maximum Power Point Tracking controller is presented in the wind energy conversion system to extract the maximum possible wind power [2].

In this work, a modeling and simulation study of a wind energy system consists of wind turbine, PMSG generator, ac/dc converter, dc/dc boost converter , an ac/dc inverter and a grid load was presented . Thus, an MPPT controller was developed to optimize the system energy efficiency by tracking the optimum operating point, using different MPPT algorithms that are analyzed and compared in order to optimize their performance on our system.

the first chapter will give a thorough literature back ground about wind turbines, different types and components, also is devoted to illustrate and present the mathematical modeling of different parts of our system such as the wind turbine, the generator and the power electronics, in addition to the grid connection and control system.

The second chapter will talk about the theoretical background of the maximum power point tracking and some of its techniques that are used in WECS. Also, it will describe the proposed techniques in this thesis.

Finally, the third chapter includes the simulation and the comparative study between the proposed techniques and the discussion of their results.

CHAPTER I

wind turbine conversion system with PMSG

1.1 Introduction

Over the past 35 years, the size of WTs has gradually increased and has currently reached a massive level of 10 megawatts (MWs). Due to the rapid integration of wind power into electric grid, many concerns have emerged on the stable and secure operation of existing electric power systems. Grid code requirements have been updated and enforced in many countries on the grid connection of large-scale WTs and wind farms (WFs). [3]

Power electronic converters have been used in commercial WTs since the beginning of grid connected operation; this technology has significantly evolved over the years.

In this chapter, the design of the wind power system have been explained. The system composed of PMSG driven by wind turbine, the generator is connected to power electronic converters and gird. But before that let's start with brief history about the wind power.

1.2 History of wind power [4]:

Wind energy was used in the first time to propel boats along the Nile River as early as 5000BC. By 200BC, simple wind powered water pumps were used in China, and wind-mills with woven-reed blades were grinding grain in Persia and Middle East.

By the 11th century in the Middle East, wind pumps and wind-mills were used for food producing. Merchants and the Crusaders brought wind technology to Europe. The Dutch developed large wind pumps to drain lakes and marshes in the Rhine River Delta. Immigrations from Europe eventually took wind energy technology to the Western Hemisphere.

In the late 1800s early 1900s, small wind electric generators (turbine) were used in America colonies.

Soon after electricity became commonplace in cities in the early of 20th century, wind-mills were used to provide power to rural farmhouses that were too far from the big cities to be connected to the power grid.

Today [5], in some smaller countries such as Denmark, wind energy supplies 20 to 40% of the electricity. Though that percentage is much lower in countries as large as USA, it shows that wind power has come a long way from powering single rural homes and can be depended on to provide electricity to large cities as well.

1.3 Wind kinetic energy to electric energy conversion:

As illustrated in **Fig.1.1,** WTs convert kinetic energy into electric energy by using various mechanical and electrical components.

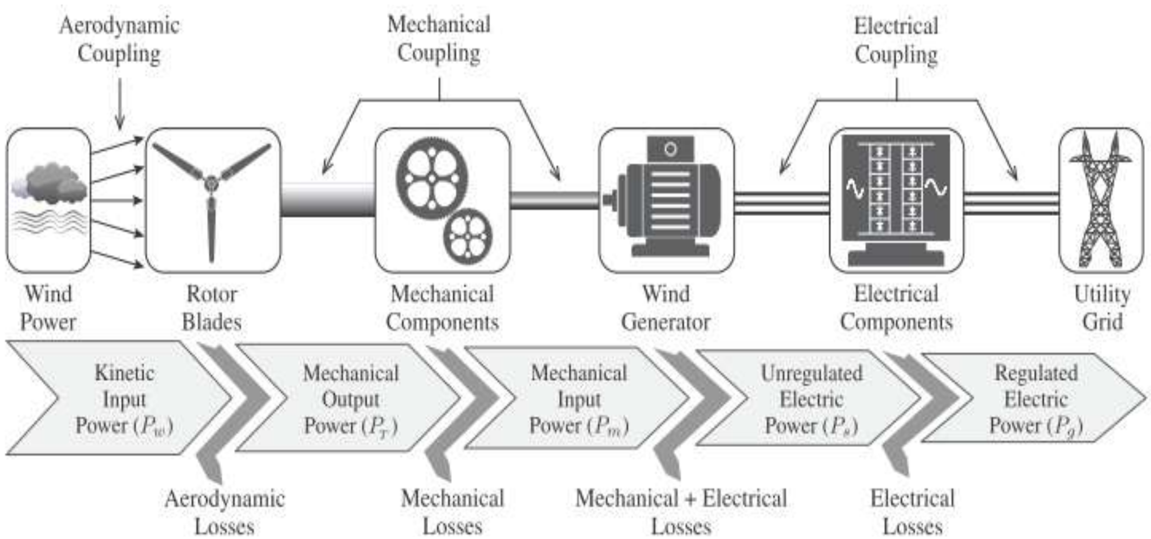

Figure 1.1: Block diagram of wind kinetic energy to electric energy conversion system [6]

Kinetic energy is first converted into mechanical energy by the rotor blade. According to well-known cub law equation1, the wind kinetic power Pw following through an imaginary area A_T at speed vw is:

$$P_w = \frac{1}{2} f A_T v_w^3; \qquad (1.1)$$

$$A_T = \pi r_T^2 \qquad (1.2)$$

Where: f is air density (kg/m3),

A_T is the rotor swept area (m2),

R_T is the blade radius (m),

And v_w is the wind speed (m/s).

A_{air} density is a function of altitude, temperature and humidity. At sea level and at 15°C, air has a typical density of 1.225 Kg/m^3.

According to the theory of German scientist Albert Betz, mechanical power P_T extracted from the wind kinetic power Pw is given by the following: [7]

$$P_T = P_w \times C_p = \frac{1}{2} f A_T v_w^3 C_p \qquad (1.3)$$

Where Cp represents the power coefficient of the rotor blades.

According to Betz, the theoretical or maximum value of Cp is 16/27 or 0.593. For the new generation of high power WTs, the Cp value ranges between 0.32 and 0.52.

The P_w and P_T curves of WT with respect to the wind speed v_w are plotted in **Fig.1.2**. P_T is always lower than P_w because of aerodynamic power losses. The typical cut-in, rated and cut-out wind speed values are in the range of 3.5 m/s, 10-15 m/s, and 25-30 m/s respectively. WTs produce negligible power when wind speed is below the cut-in value.

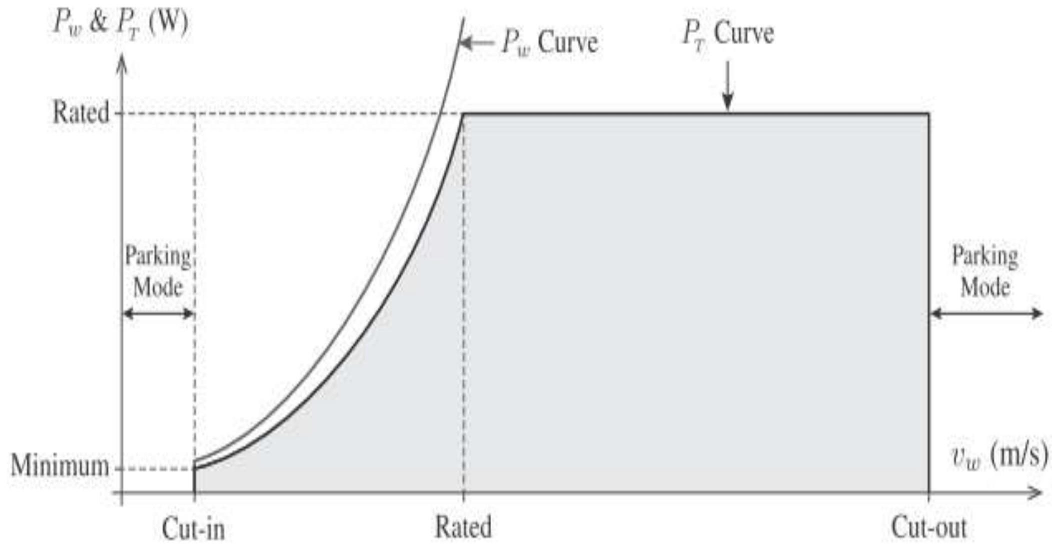

Figure 1.2: WT power characteristic curves with respect to wind speed. [6]

To ensure safety, the turbine is shut down and kept in parking mode when wind speed is above the cut-out value or during emergency conditions.

For wind speed values between cut-in and rated, the P_T curve maintains a cubic relationship with respect to v_w. When wind speed is between rated and cut-out value, the turbine output power P_T is regulated to its highest threshold (rated) value by the aerodynamic power control.

The slow rotating (5-20 rpm) turbine rotor is mechanically coupled to the fast rotating (1500-1800 rpm) wind generator through the main shaft and drivetrain. Losses in the mechanical component represent the difference between P_T and P_m. The mechanical input power P_m is converted into electric power P_s by the wind generator.

1.4 Wind energy conversion system (WECS):

Wind energy conversion systems (WECS) are designed to convert the energy of wind movement into mechanical power. With wind turbine generators, this mechanical energy is converted into electricity, and in windmills this energy is used to do work such as pumping water, mill grains, or drive machinery.

The WECS includes wind turbines, generators, control system and interconnection apparatus. **Fig.1.3** shows a model of wind energy conversion system.

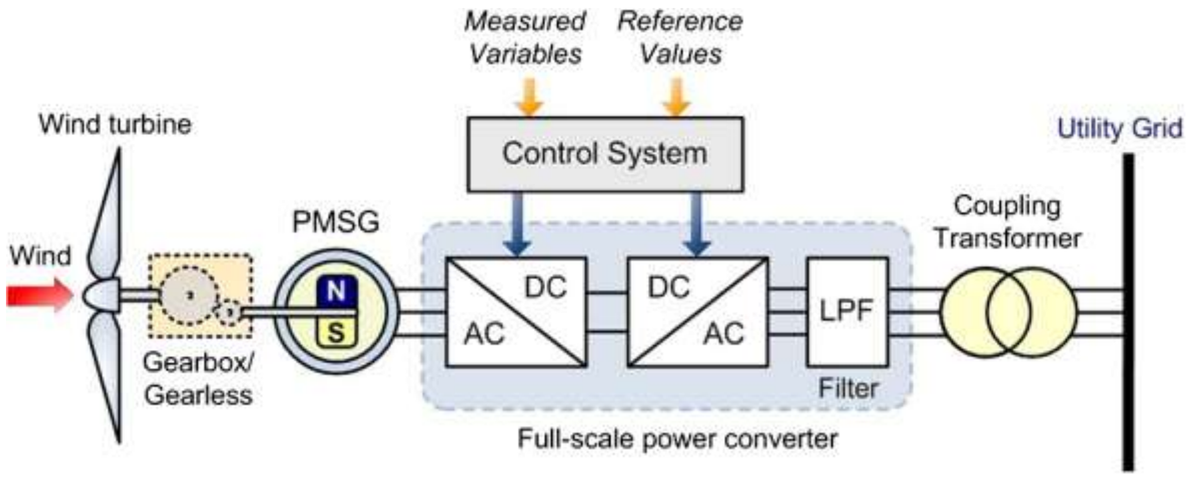

Figure 1.3: wind energy conversion system [7]

Wind turbines are mainly classified into horizontal axis wind turbines (HAWT) and vertical axis wind turbine (VAWT). Modern wind turbines use HAWT with two or three blades and operate either downwind or upwind configuration. This HAWT can be designed for a constant speed application or for the variable speed operation.

a. Horizontal axis:

Wind Horizontal axis wind turbine are the most common type used **(Fig.1.4).** All the components (blades, shaft, and generator) are on the top of a tall tower and the blade face into the wind. The shaft is horizontal to the ground. The wind hits the blades of the turbine that are connected to a shaft causing rotation. The shaft has a gear on the end which turns a generator. The generator produces electricity and send electricity into the power grid. [8]

Advantages:

- Blades are to the side of the turbine's center of gravity helping stability.
- Ability to wing warp, which gives the turbines blades the best angle to attack.
- Ability to pitch the rotor blades in a storm to minimize damage.
- Tall tower allows access to stronger wind in sites with wind shear.
- Tall tower allows placement on uneven land or in off shore locations.
- Can be sited in forest above tree-line.
- Most are self-starting.

Disadvantages:

- Difficulty operating in near ground winds.
- Difficult to transport (20% of equipment costs).
- Difficult to install (require tall cranes and skilled operators).
- Effect radar in proximity.
- Local opposition to aesthetics.
- Difficult maintenance.

b. Vertical axis:

In vertical axis turbines, the shaft and the blades are vertical to the ground. All of the main components are close to the ground. Also, the wind turbine itself is near the ground, unlike the horizontal where everything is on a tower. There are two types of vertical axis wind turbines: lift based and drag based. Lift based designs are generally much more efficient than drag, or "paddle" designs. [9].

Advantages:

- Easy to maintain.
- Lower construction and transportation costs.
- Not directional.
- Most effective at mesas, hilltops, ridgelines, and passes.

Disadvantages:

- Blades constantly spinning back into the wind causing drag.
- Less efficient.
- Operate in lower, more turbulent wind.

Low starting torque and many require energy to start turning.

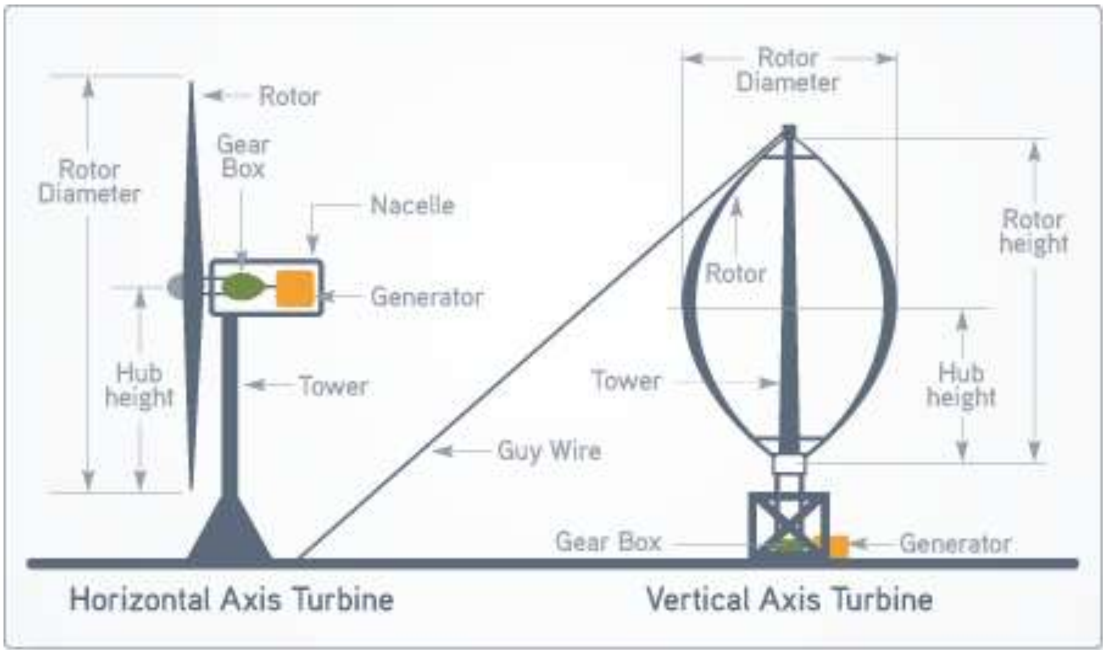

Figure 1.4: type of wind turbine horizontal and vertical axis [10]

Among this two types, variable speed wind turbine has high efficiency with reduced mechanical stress and less noise. Variable speed turbines produce more power than constant speed type, comparatively, but it needs sophisticated power converters, control equipment's to provide fixed frequency and constant power factor [11].

The generators used for the wind energy conversion system mostly of either doubly fed induction generator (DFIG) or permanent magnet synchronous generator (PMSG) type. DFIG have windings on both stationary and rotating parts, where both windings transfer significant power between shaft and grid. In DFIG, the converters have to process only about 25-30 percent of total generated power (rotor power connected to grid through converter) and the rest being fed to grid directly from stator. Whereas, converter used in PMSG has to process 100 percent power generated, where 100 percent refers to the standard WECS equipment with three stage gear box in DFIG. Majority of wind turbine manufactures utilize DFIG for their WECS due to the advantage in terms of cost, weight and size. But the reliability associated with gearbox, the slip rings and brushes in DFIG is unsuitable for certain applications.

To achieve high efficient energy conversion on these drives, different control strategies can be implemented like perturb & observe technique, Golden section technique and Fuzzy logic technique.

1.5 Wind energy conversion system modeling:

1.5.1 Wind turbine:

Wind energy is transformed into mechanical power through wind turbine and hence it is converted into electrical power. The mechanical power is calculated by using the following equation: [12]

$$P_m = 0.5\rho A C_p(\lambda, \beta) v_{wind} \qquad (1.4)$$

Where ρ is the air density which normally takes the value in the range 1.22 -1.3 Kg/m3, A is the area swept out by turbine blades (m2), vwind is the wind speed (m/s), Cp(λ,β) is the power coefficient [12] which depends on two factors: β, the blade pitch angle and the tip speed ratio λ which defined as:

$$\lambda = \Omega . R / v_{wind} \tag{1.5}$$

Where, Ω is the angular speed (m/s) and R is the blade radius (m).

The power coefficient Cp is defined as:

$$C_p(\lambda, \beta) = C_1 \left(\frac{C_2}{\lambda_i} - C_3\beta - C_4 \right) \exp\left(\frac{-C_5}{\lambda_i} \right) + C_6\lambda \tag{1.6}$$

Where:

$$\frac{1}{\lambda_i} = \left(\frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \right) \tag{1.7}$$

And the coefficients C_1=0.5176, C_2=116, C_3=0.4, C_4=5, C_5=21 and C_6=0.0068.

The power coefficient is nonlinear, and it depends upon turbine blade aerodynamics and it can be represented as a function of tips speed ration λ. The optimum value of λ corresponds to maximum of Cp from the power coefficient-tip speed ratio curve.

Fig.1.5 shows Power Coefficient characteristic plotted in function of the Tip Speed Ratio (lambda) and parameterized with the pitch angle (beta). It is observed that the maximum power coefficient value $C_{p\text{-}max}$ (λ,β)=0.51.

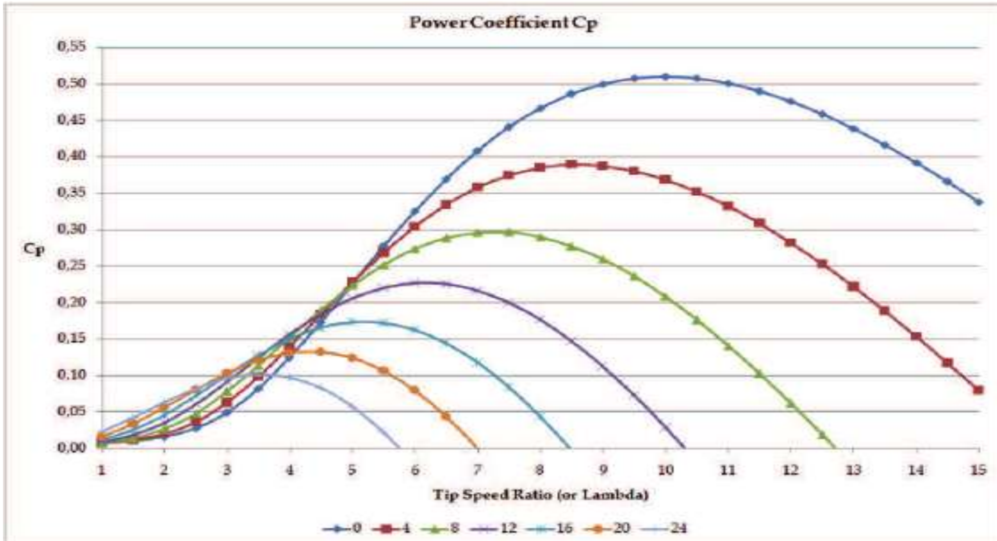

Figure 1.5 Power Coefficient characteristics [13]

As the power transmitted is assumed to be the product of rotational speed with mechanical torque, the rotational torque is obtained as:

$$T_m = \frac{P_m}{\Omega} \qquad (1.8)$$

Thus the optimal angular speed is achieved through the relation:

$$\Omega_{opt} = \frac{\lambda_{opt} v_{wind}}{R} \qquad (1.9)$$

And the maximum mechanical power is:

$$P_{m-max} = 0.5 \rho A C_{p-max} v_{wind}^3 \qquad (1.10)$$

Fig.1.6 shows the wind turbine power characteristics obtained for various values of the wind tangent speed, the figure was taken from our simulation For λ=12 and for β=0^o. This particular value of λ_{opt} results in optimal efficiency point where maximum power is captured from wind by the turbine. Here it can be observed that maximum power (active) is achieved through optimal wind speeds and not at high wind velocity. The wind turbine does not operate when the wind speed is less than the minimum speed because the captured wind energy is not enough to compensate the losses and operation cost.

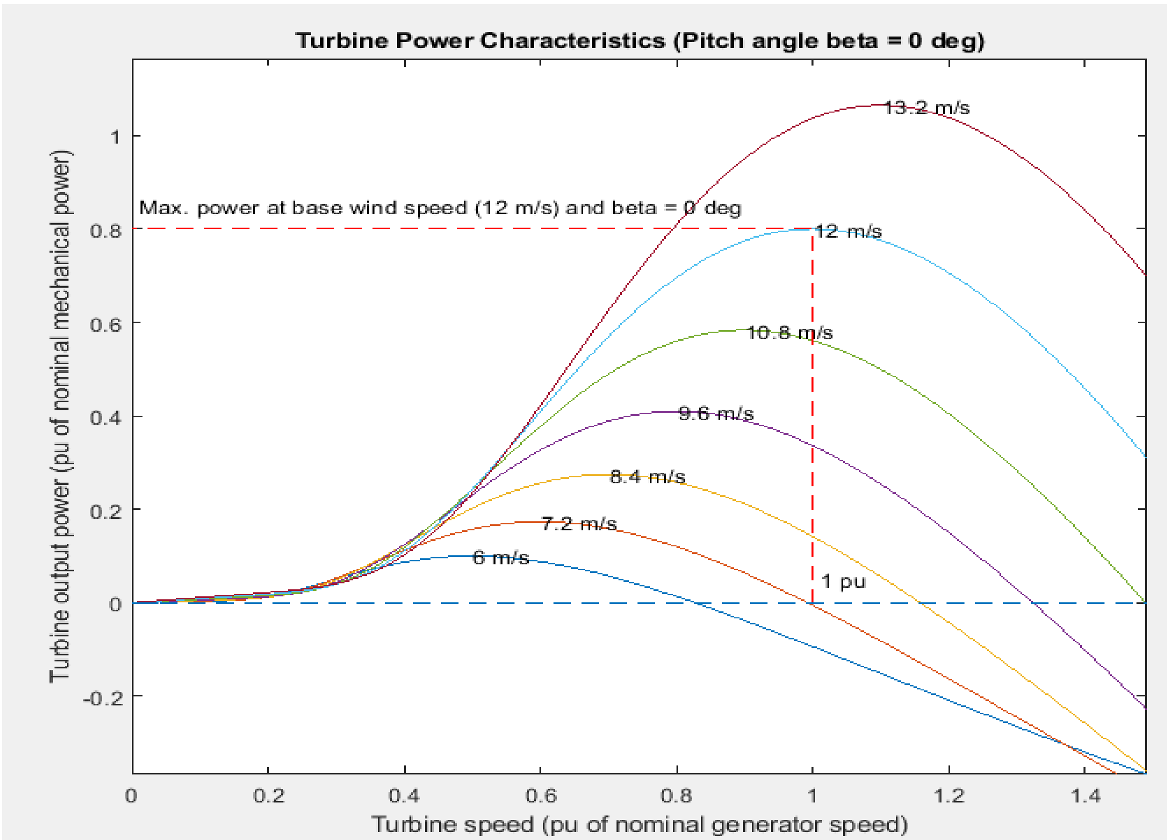

Figure 1.6: wind turbine characteristics

1.5.2 Wind generator:

Permanent magnet synchronous generator is a generator where the excitation field is provided by a permanent magnet instead of a coil. They are known as synchronous generators because f, the frequency of the induced voltage in the stator (armature conductors) conventionally measured in hertz, is directly proportional to RPM (round per minute), the rotation rate of the rotor usually given in revolutions per minute (or angular speed). The constant of proportionality is $\frac{P}{120}$, where P is the number of magnetic rotor poles and the factor of 120 comes from 60 seconds per minute and two poles in single magnet. This leads to: [14]

$$f(Hz) = RPM\,\frac{P}{120} \tag{1.11}$$

1.5.2.1 The advantages of PMSG:

The synchronous machines have many advantages over induction machines. One of them is a higher efficiency. It is because the magnetizing current is not a part of the stator current.

In variable speed wind systems, usually the synchronous generators are connected to the grid via a power electronic converter. The amount of deliverable active power from synchronous generator (SG) depends on rating of the converter in volt-amperes and the power factor of SG. Thus, for the same rating of the converter, the closer the power factor gets to unity, the more active power can be delivered.

The other advantage is that they can have longer air gap compared to induction machines. In induction machines, the air gap length is kept small to limit the magnetization current and to improve the power factor. In synchronous machines, on the other hand, it is desirable to have a longer air gap as it helps to reduce armature reaction and the synchronous reactance which in turn improves the stability.

Another advantage is that dynamic disturbances of the grid and the wind turbine are isolated from each other and SG is not at risk of losing synchronism.

Self-excitation brings about various benefits. One is the elimination of the rotor copper losses. Hence PMSGs are more efficient compared to wounded rotor synchronous generators (WRSG). Unlike WRSG, no external power supply is needed. The maintenance is eliminated since brushes and slip rings as well as the rotor windings are removed.

The commons issue with WRSG is the relation between the frequency induced and the mechanical speed of the rotor. When the wind speed changes, the rotor speed and the frequency of the inducted voltage changes. However, in variable speed application with PMSG this is usually not of concern since the generator is connected to the grid through a converter that will adapt the frequency of the induced voltage to the grid frequency. On the other consideration is that unlike WRSG, the field provided by magnets is not controllable. Thus, it is not possible to regulate the voltage and the reactive power. In variable speed wind systems, this is usually not an issue since the grid-side-converter regulates the output voltage and the power factor is determined by the grid. Lower maintenance requirements and thus lower cost are the main reasons why PMSGs are proposed with variable speed wind systems.

Furthermore, a PMSG with a high number of poles can be connected directly to a wind turbine without the use of a gearbox, which significantly reduces the construction, operation, and maintenance costs of the WECSs [15]

1.5.2.2 Permanent magnet synchronous generator model:

The dynamic model of the PMSG is derived from the two phase synchronous reference frame, which the q-axis is 90° ahead of the d-axis with respect to the direction of rotation. The synchronization between the d-q rotating reference frame and the abc-three phase frame is maintained by utilizing a phase locked loop (PLL). **Fig.1.7** shows the d-q reference frame used in a salient-pole synchronous machine (which is the same reference as the one used in a PMSG.

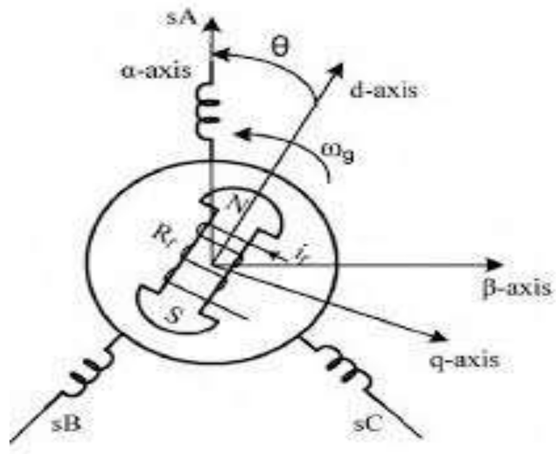

Figure 1.7: the dynamic model of PMSG [16]

Where θ is the mechanical angle, which is the angle between the rotor d-axis and the stator axis. The mathematical model of the PMSG for power system and converter system analysis is usually based on the following assumptions. The stator windings are positioned sinusoidal along the air-gap as far as the mutual effect with the rotor is concerned; the stator slots cause no appreciable variations of the rotor inductances with rotor position; magnetic hysteresis and saturation effects are negligible; the stator winding is symmetrical; damping windings are not considered; the capacitance of all the windings can be neglected and the resistances are constant (this means that power losses are considered constant).The modeling of PMSG type electrical equipment is made through the following equations, represented by d-q reference frame [17]:

$$V_d = R_s i_d + L_d \frac{di_d}{dt} - w_e L_q i_q \tag{1.12}$$

$$V_q = R_s i_q + L_q \frac{di_q}{dt} - w_e L_d i_d + w_e Q_m \tag{1.13}$$

Where Vd and Vq are d and q components of stator voltages (V), id and iq are d and q components of stator currents (A), Rs is stator resistance (Ω), Ld and Lq are machine inductances (H), We is the electrical speed (rad/s) and Qm is the magnetic flux (wb). The electrical torque is obtained through the following equations:

$$T_e = \frac{3}{2} p\{((Q_m i_q + (L_d - L_q) i_d i_q))\} \qquad (1.14)$$

Where P is the pair of poles. The rotor dynamics of the machine is given by:

$$T_m - T_e = B w_r + J \frac{dw_r}{dt} \qquad (1.15)$$

Where B is the rotor friction (Kgm^2/s), J is the rotor inertia (kgm^2), w_r is rotor speed (rad/s) and Tm is the mechanical torque produced by wind (Nm). The machine dynamics can be simplified by assuming (Ld=Lq=0) and the d-reference current is zero (id*=0) and hence the product term (Ld-Lq)idiq is negligible.

Equivalent circuits of the PMSG based on (1.12) and (1.13) equations are illustrated in **Fig.1.8** where λ_m is same as Q_m.

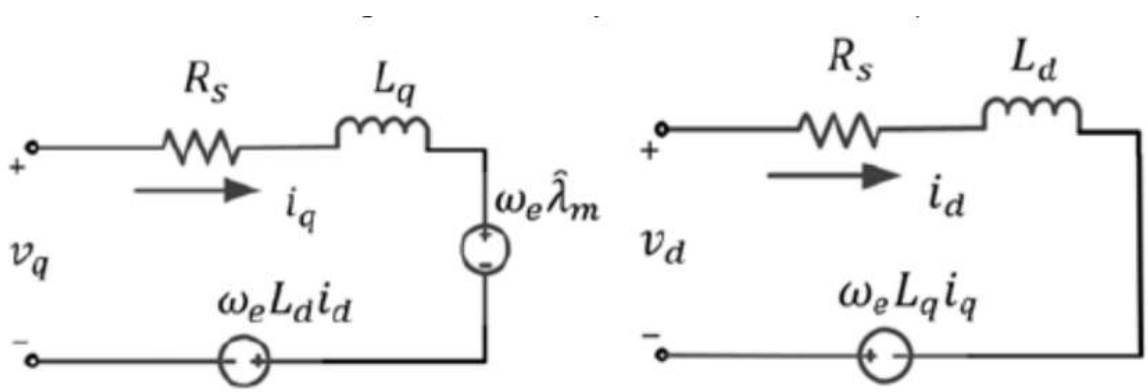

Figure 1.8: PMSG equivalent circuit in D-axis and Q-axis [18]

1.5.3 Machine side converter :

Wind generator output voltage and frequency changes with respect to the rotational speed (wind speed). In order to control the resulting power, the generator output terminals will be directly interfaced through a power electronic converter. The power electronic converter changes the generator AC output voltage to DC voltage by a rectifier (AC/DC converter) and then back to AC with a fixed voltage magnitude and frequency by an inverter (DC/AC converter). In most WTs, the configuration of both AC/DC and DC/AC converters is the same and is known as back-to-back (BTB) connected converter.

Switching harmonics are inevitable when using power converters. To solve this issue, harmonic filters are used in wind machine (generator) side converters (MSCs) and grid side converters (GSCs). The harmonic filter in the MSC helps reduce the harmonic distortion of the generator currents and voltages. This process leads to a reduction in harmonic losses incurred in the magnetic core and winding of the generator. The harmonic filter in the GSC helps meet the strict harmonic requirements specified by the grid code [19].

1.5.3.1 Rectifier model:

A three phase diode bridge rectifier converter the AC generated output voltage of PMSG, which will be varying in magnitude and also in frequency into DC. For a three-phase system it consists of six diodes as shown in **Fig.1.9** and its voltage waveforms are shown in **Fig1.10**

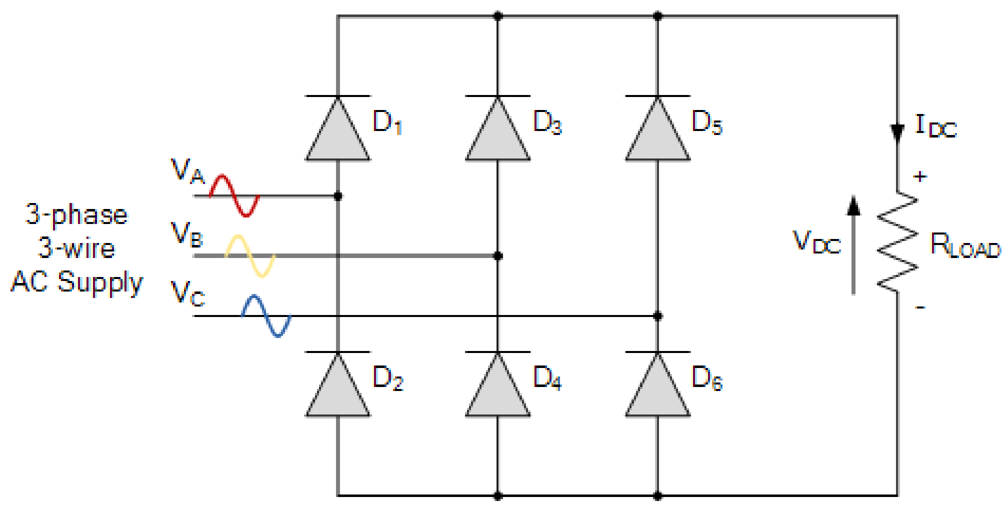

Figure 1.9: three phase diode bridge rectifier [20]

The phase voltages va, vb, and vc are equal to:

$$va = Vm \sin(\omega t) \tag{1.16}$$

$$vb = Vm \sin(\omega t - 120°) \tag{1.17}$$

$$vc = Vm \sin(\omega t - 240°) \tag{1.18}$$

Where Vm is the peak value.

The line to line voltages vab, vbc, and vca are equal to:

$$vab = \sqrt{3}Vm \sin(\omega t + 30) \tag{1.19}$$

$$vbc = \sqrt{3}Vm \sin(\omega t - 90) \tag{1.20}$$

$$vca = \sqrt{3}Vm \sin(\omega t - 210) \tag{1.21}$$

The average output voltage is given by the formula:

$$V_{dc} = \frac{6}{2\pi} \int_{\pi/3}^{2\pi/3} \sqrt{3}\, Vm \sin(wt)\, dwt = \frac{3\sqrt{3}}{\pi} Vm \tag{1.22}$$

The rms output voltage is equal to:

$$Vrms = [\frac{9}{\pi} \int_{\pi/3}^{2\pi/3} (Vm \sin(wt))^2\, dwt]^{1/2} = [\frac{3}{2} + \frac{9\sqrt{3}}{4\pi}]^{1/2}\, 1.6554Vm \tag{1.23}$$

If we consider that the load is purl resistive, so the rms value of the diode current is equal to:

$$Ir = [\frac{4}{2\pi} \int_{0}^{\pi/6} Im^2 \cos wt^2\, dwt]^{1/2} = Im[\frac{1}{\pi}(\frac{\pi}{6} + \frac{1}{2}\sin\frac{2\pi}{6})]^{1/2} \tag{1.24}$$

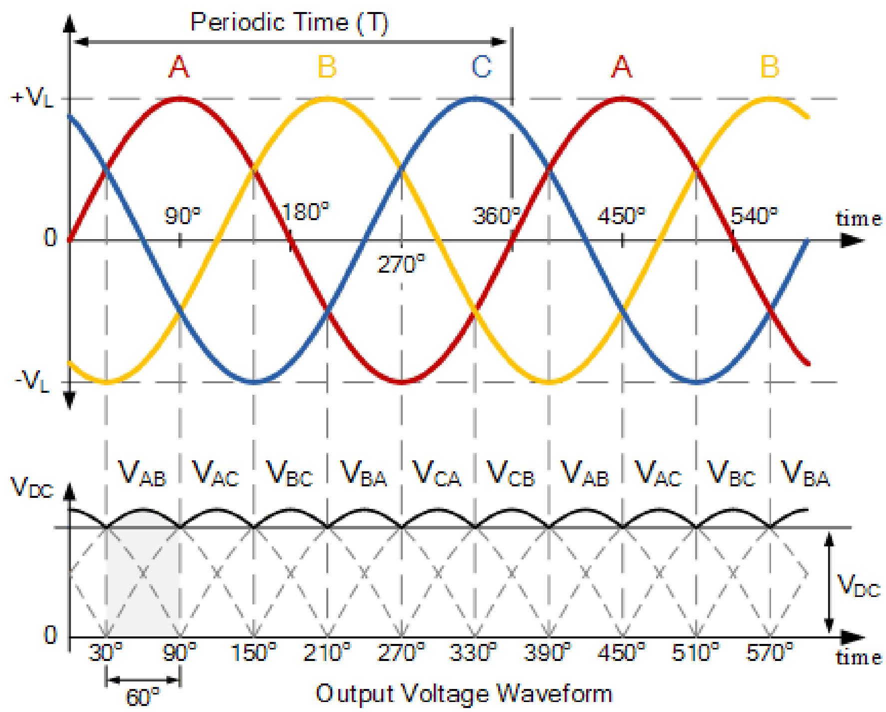

Figure 1.10: Three-phase Rectifier Conduction Waveform [20]

1.5.3.2 DC to DC boost chopper model:

A boost converter is a switched-mode power supply that uses two switches (usually a diode and a transistor), an inductor, and a capacitor to convert direct current voltage from a lower to a higher level. When the switch is turned off, the inductor current goes through the diode, the load, and the capacitor. When the switch is turned on, the inductor current increases and doesn't pass through the diode. A filter capacitor is added to smooth out the output voltage. A simple boost converter circuit is shown is **Fig 1.11**

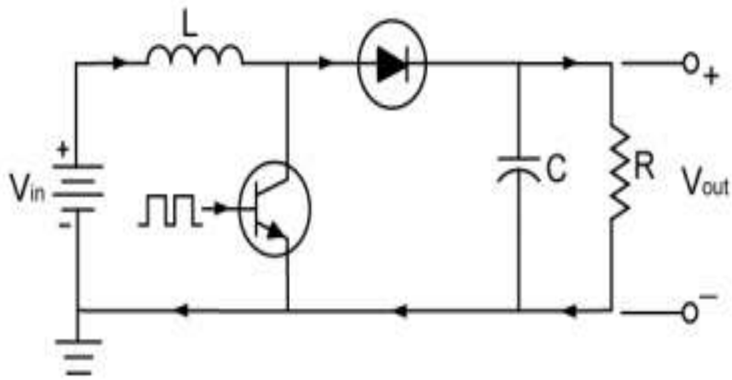

Figure 1.11: simple DC/DC boost converter circuit [21]

The relation between the input and output voltage and currents of the boost converter for a given period T and duty ration D is expressed by the following equations:

$$V_{dc1}DT = (V_{dc1} - V_{dc2})(1 - D)T \quad (1.25)$$

$$V_{dc2} = \frac{1}{(1-D)}V_{dc1} \quad (1.26)$$

$$I_{dc2} = (1 - D)I_{dc1} \quad (1.27)$$

Where Vdc1 and Idc1 are the input voltage and current. Vdc2 and Idc2 are the output voltage and current.

It is possible that boost chopper circuit and load resistance R are considered a kind of variable resistance changed by duty ratio from the viewpoint of the DC voltage source. This variable resistance Rdc1 is defined as:

$$R_{dc1} = \frac{V_{dc1}}{I_{dc1}} \quad (1.28)$$

The output current I_{dc2} is expressed by output voltage V_{dc2} and load resistance$R$:

$$I_{dc2} = \frac{V_{dc2}}{R} \quad (1.29)$$

By dividing (1.25) by (1.27) we obtain:

$$\frac{V_{dc1}}{I_{dc1}} = \frac{V_{dc2}}{I_{dc2}} \times \frac{1}{(1-D)^2} \quad (1.30)$$

By dividing (1.28) by (1.29) we obtain:

$$R_{dc1} = (1-D)^2 R \quad (1.31)$$

From equation (1.31), it was confirmed that the boost chopper from the viewpoint of the DC voltage source could be expressed in the function of the duty ratio.

Once the switching frequency is confirmed, the inductance of L determines the operating mode of the circuit, as given by:

$$L_c = \frac{(1-D)^2 DR}{2f} \quad (1.32)$$

Where L_c is the critical value of the inductance and f is the switching frequency.

1.5.4 Grid side converter:

The grid side inverter is used to regulate dc-link voltage so that the power balance can be maintained under both fluctuating wind and grid disturbances. The **Fig.1.12** represents o the grid side converter connected to the grid by means of a passive filter and a transformer**.**

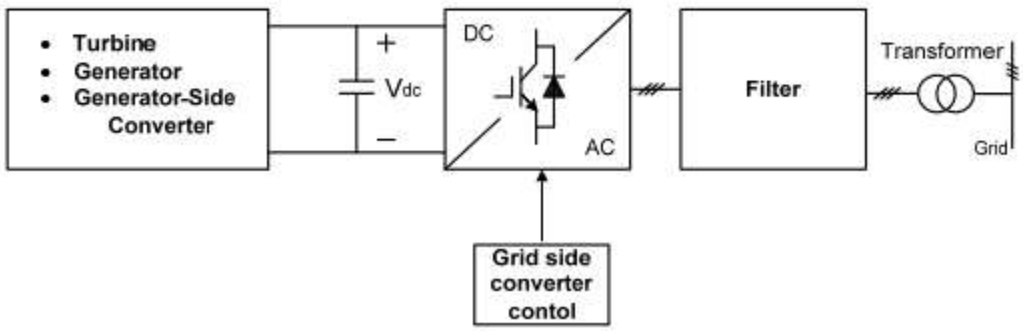

Figure 1.12: The grid side converter [22]

The converter is composed of two part: the DC to AC inverter that will be controlled using some techniques. In this chapter, it will be discussed about the inverter, the filter and the gird. And about the grid side converter control, it will be discussed in the next chapter.

1.5.4.1 DC to AC inverter model:

A power inverter, or inverter, is an electronic device or circuitry that changes direct current (DC) to alternating current (AC).The input voltage, output voltage and frequency, and overall power handling depend on the design of the specific device or circuitry. The inverter does not produce any power; the power is provided by the DC source [23].

A three phase inverters are used to provide industrial applications by adjustable frequency power. Three phase inverters are more common than single phase inverters. DC supply for three phase inverters is taken from a battery or usually from a rectifier. A six steps bridge is used for three phase inverter by using six switches, two switches for each phase. Each step is defined as a change in the time operation for each transistor to the next transistor in proper sequence. For one cycle 360°, each step would be of 60° interval for a six step inverter. **Fig.1.13** shows the power circuit diagram of a three phase bridge inverter using six IGBTs. Large capacitors are connected at the input terminal to make the DC input constant and also suppress the harmonics fed back to the source.

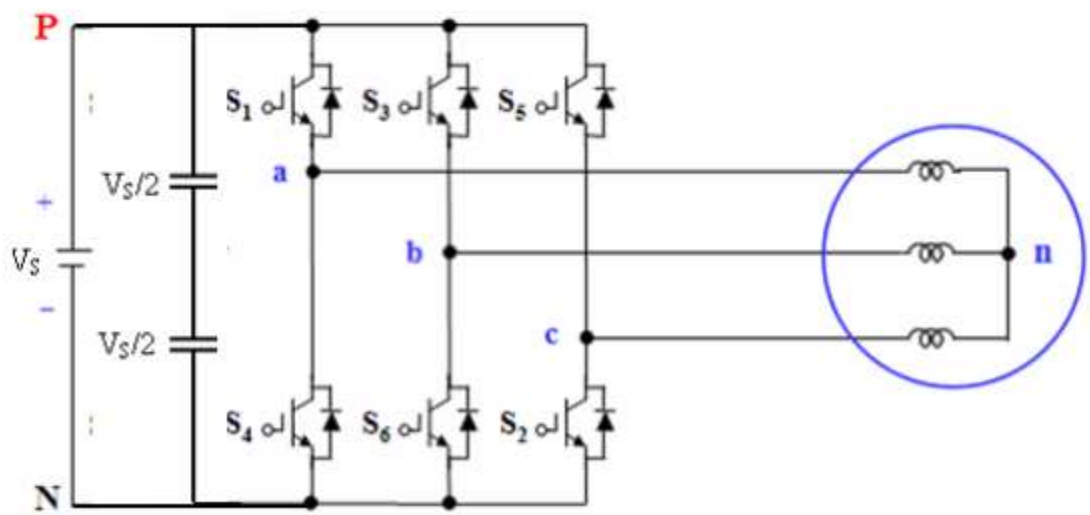

Figure 1.13: The power circuit diagram of a three phase bridge inverter [24]

. **Fig.1.13** illustrates a common topology of inverter, which consists of an upper bridge (S1, S3, S5) and a lower bridge (S4, S6, S2) there each switch is no more than IGBT. Each of the IGBT pairs in the upper and lower bridges cannot be conducting at the same time, otherwise the power input will be shorted. Therefore the switching state of the upper bridge has to be opposite to that of the lower bridge. [25]

To focus on the upper bridge S1, S3 and S5, if logic ‘1’ indicates the switched on state, and ‘0’ represents switched off state, the three switches have eight state combinations as listed in Table 2-1. In order to reduce the switching times of the IGBT pair in the inverter and to reduce the effects of harmonics, the switching state of IGBT pairs are only changed once within a pulse period.

Table 1.1: The relationship between work mode and phase voltage

Vector	S5	S3	S1	Va	Vb	Vc
V0	0	0	0	0	0	0
V1	0	0	1	2Vdc/3	-Vdc/3	-Vdc/3
V2	0	1	1	Vdc/3	Vdc/3	-2Vdc/3
V3	0	1	0	-Vdc/3	2Vdc/3	-Vdc/3
V4	1	1	0	-2Vdc/3	Vdc/3	Vdc/3
V5	1	0	0	-Vdc/3	-Vdc/3	2Vdc/3
V6	1	0	1	Vdc/3	-2Vdc/3	Vdc/3
V7	1	1	1	0	0	0

Table1.1 illustrates that a 3-phase AC power can be synthesized by eight vectors, in which there are two zero vectors V0and V7. A period of the output voltage is divided into 6 patterns, the patterns show the switching state of the upper bridge IGBTs, where lower bridge are just opposite to the upper bridge.

1.5.4.2 Filter design:

A Filter is a circuit that can be designed to modify, reshape or reject all unwanted frequencies of an electrical signal and accept or pass only those signals wanted by the circuit's designer.

In other words they "filter-out" unwanted signals and an ideal filter will separate and pass sinusoidal input signals based upon their frequency. In low frequency applications (up to 100kHz), passive filters are generally constructed using simple RC (Resistor-Capacitor) networks, while higher frequency filters (above 100kHz) are usually made from RLC (Resistor-Inductor-Capacitor) components. Passive filters are made up of passive components such as resistors, capacitors and inductors and have no amplifying elements (transistors, op-amps, etc) so have no signal gain, therefore their output level is always less than the input.[26]

The **Fig.1.14** shows low pass filter circuit

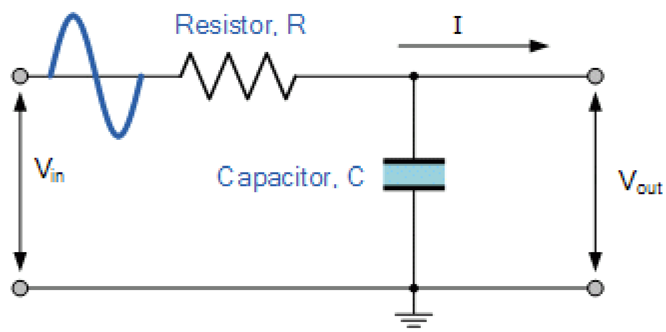

Figure 1.14: low pass filter circuit [26]

1.6 conclusion

In this chapter the wind energy conversion system from mechanical power to electrical power has been presented. All parts of it were discussed starting by the wind turbine and the generator used to produce electricity which is permanent magnet synchronous generator then the machine converter which transfer the current to DC current so that we can control it and finally the grid converter which turn the controlled DC current to the demanded AC current.

Since the power delivered from the wind is variable, a specific controlled techniques has been used to control the resulted power and turn it to a fixed power to transfer it to the grid. This techniques has been discussed in next chapter.

CHAPTER II
Control of Wind Turbine System

2.1 Introduction

To ensure high performance while minimizing costs, optimal solutions have been developed constantly. On the one side, wind turbines (WTs) have grown considerably in size over the last several years; on the other side, advanced control algorithms have been intensively studied. As shown in **Fig.2.1**, the general control scheme for modern wind turbine system includes typical three control units: wind turbine control strategy, power converter control strategy, and grid integration control strategy.

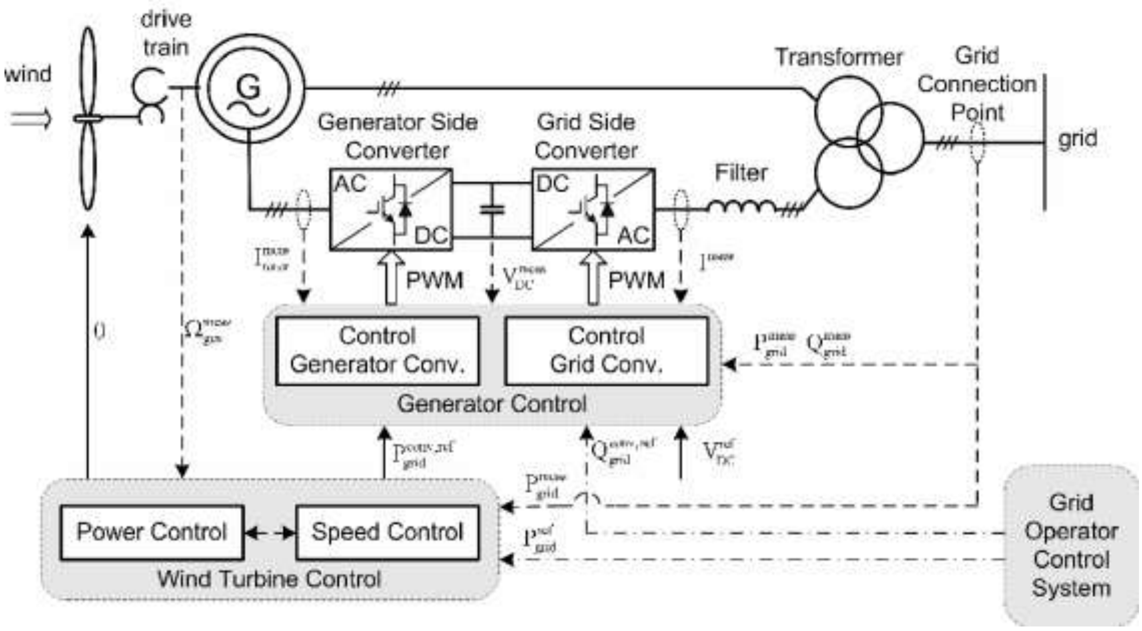

Figure 2.1: Control of wind turbine system [27]

2.2 Wind turbine control:

The common used method to control the wind turbine is blade pitch angle control. Pitch angle control is the most common means for adjusting the aerodynamic torque of the wind turbine when wind speed is above rated speed and various controlling variables may be chosen, such as wind speed, generator speed and generator power. The purpose of the pitch angle control might be expressed as follows [28-30]:

- Optimizing the power output of the wind turbine. Below rated wind speed, the pitch setting should be at its optimum value to give maximum power.
- Preventing input mechanical power to exceed the design limits. Above rated wind speed, pitch angle control provides a very effective means of regulating the aerodynamic power and loads produced by the rotor.
- Minimizing fatigue loads of the turbine mechanical component. It is clear that the action of the control system can have a major impact on the loads experienced by the turbine. The design of the controller must take into account the effect on loads, and the controller should ensure that excessive loads will not result from the control action. It is possible to go further than this, and explicitly design the controller with the reduction of certain fatigue loads as an additional objective.

2.3 Generator converter control:

To extract maximum energy from wind, an maximum power point tracking (MPPT) control is necessary to adjust the turbine rotor speed according to the variation of wind speeds so that the tip speed-ratio can be maintained at its optimal value.

Maximum Power Point Tracking, frequently referred to as MPPT, is an electronic control system that allows the Wind turbine to operate in a way that guarantees the production of the maximum power that can be converted. The concept of MPPT is not mechanical in such a way where it will move the turbine to make it aligned or facing the wind direction. MPPT is a totally electronic system that varies the electrical operating point of the WTG enabling it to deliver maximum available power. Maximum Power Point Tracking (MPPT) has been used for photovoltaic (solar system) energy for a long time. But it is still a new topic in the wind energy conversion system.

Many methods to find the MPP have been developed over the past decades. These techniques differ in many aspects such as required sensors, complexity, cost, range of effectiveness, convergence speed, required hardware, and correct tracking when wind speed changes.

Among these techniques: the Perturb and Observe, and the fuzzy logic algorithms, have the advantage of easy implementation but also have drawbacks. In this project we will compare them to deduce the most suitable one.

2.3.1 Perturbation and observation (P&O) control technique [31]:

The perturbation and observation (P&O), or hill-climb searching (HCS) method is a mathematical optimization technique used to search for the local optimum point of a given function. It is widely used in wind energy systems to determine the optimal operating point that will maximize the extracted energy. This method is based on perturbing a control variable in small step-size and observing the resulting changes in the target function until the slope becomes zero. As shown in **Fig 2.2**, if the operating point is to the left of the peak point, the controller must move it to the right to be closer to the MPP, and vice versa if it is on the other side. In the available literature, some authors perturbed the rotational speed and observed the mechanical power, while others monitored the output power of the generator and perturbed the inverter input voltage or one of the converter variables, namely: duty cycle, d; output current, I in; or input voltage, Vin. In electrical power measurement, the mechanical sensors are not required, and thus they are more reliable and low-cost.

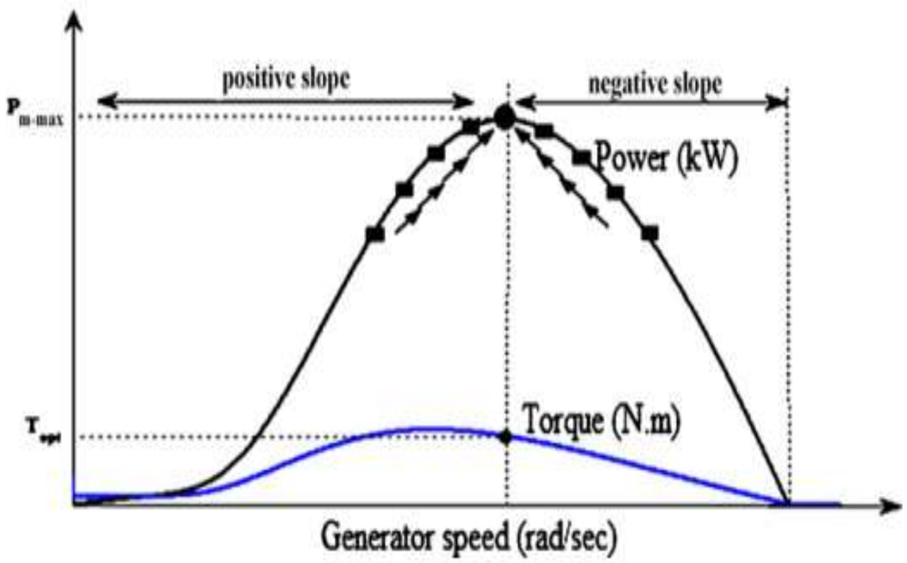

Figure2.2: Wind turbine output power and torque characteristics with MPP tracking [31]

Since the P&O method does not require prior knowledge of the wind turbine's characteristic curve, it is independent, simple, and flexible. However, it fails to reach the maximum power points under rapid wind variations if used for large and medium inertia wind turbines. Additionally, choosing an appropriate step size is not an easy task: though larger step-size means a faster response and more oscillations around the peak point, and hence, less efficiency, a smaller step-size improves efficiency but reduces the convergence speed as shown in **Fig. 2.3.** In addition, initialization of the parameters significantly affects the system's performance .The HCS method is also influenced by the value of the capacitance of the converter output capacitor, where a larger capacitance reduces the system's speed of response.

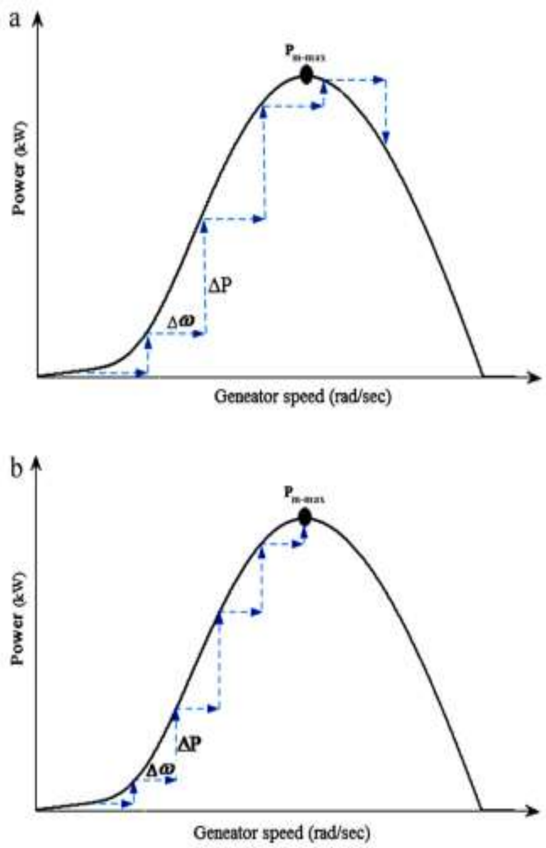

Figure2.3: Power vs Generator speed
[31]

To implement the algorithm, the next flowchart will be used.

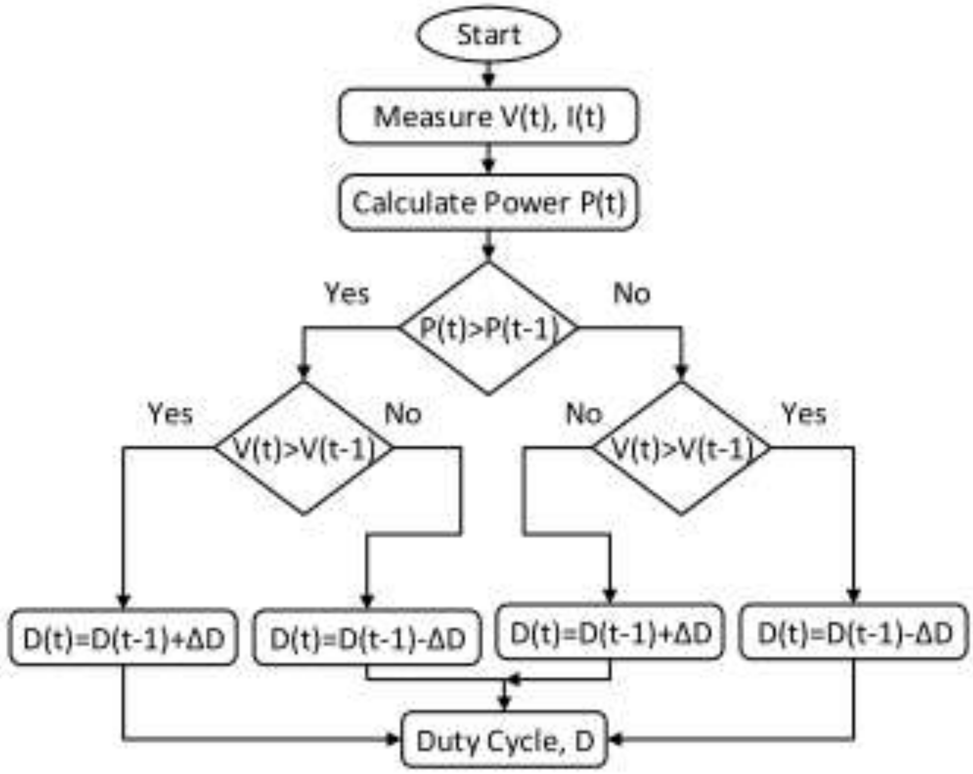

Figure 2.4: Flowchart of P&O algorithm [32]

2.3.2 Fuzzy Logic Controller FLC:

This MPPT controller method measures the current and voltage values of rectifier first followed by searching the maximum power point. Then the controller DC power is fed to the FLC controlled inverter system. **Fig.2.5** below shows the basic block diagram of a FLC [33]. There are two inputs in this Fuzzy algorithm. The Fuzzy controller has three main parts namely fuzzification, Fuzzy inference and defuzzification described below.

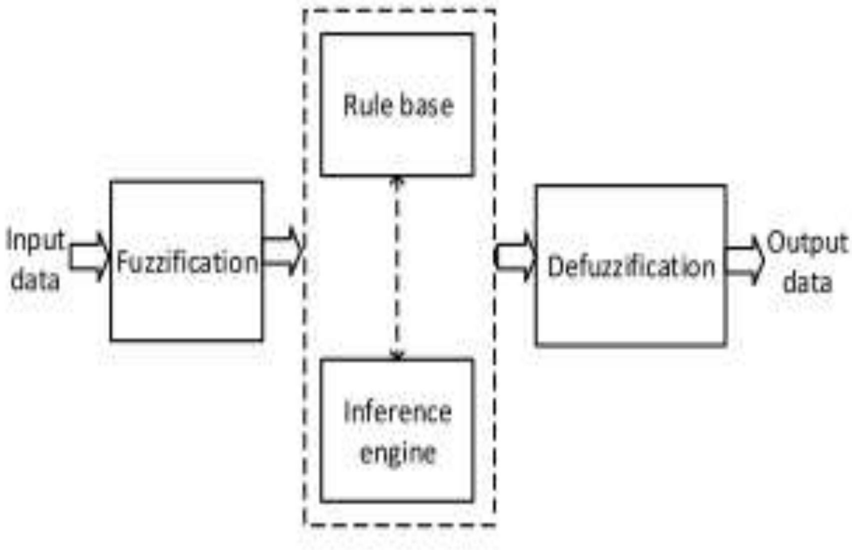

Figure 2.5: FLC basic block diagram [32].

The process of converting physical set known as crisp set as input data of Fuzzy controller to Fuzzy set starts first in fuzzification [34]. The Fuzzy inference engine processes rules to produce Fuzzy output sets according to the IF-THEN rule logic. The Fuzzy system combines all Fuzzy output sets into a single output Fuzzy thus producing a single crisp solution for the output variable [34]. Then, the defuzzification process is executed to convert Fuzzy set into classical set or crisp value. **Fig 2.6** presents the membership function editor of the proposed Fuzzy logic controller in Matlab/Simulink.

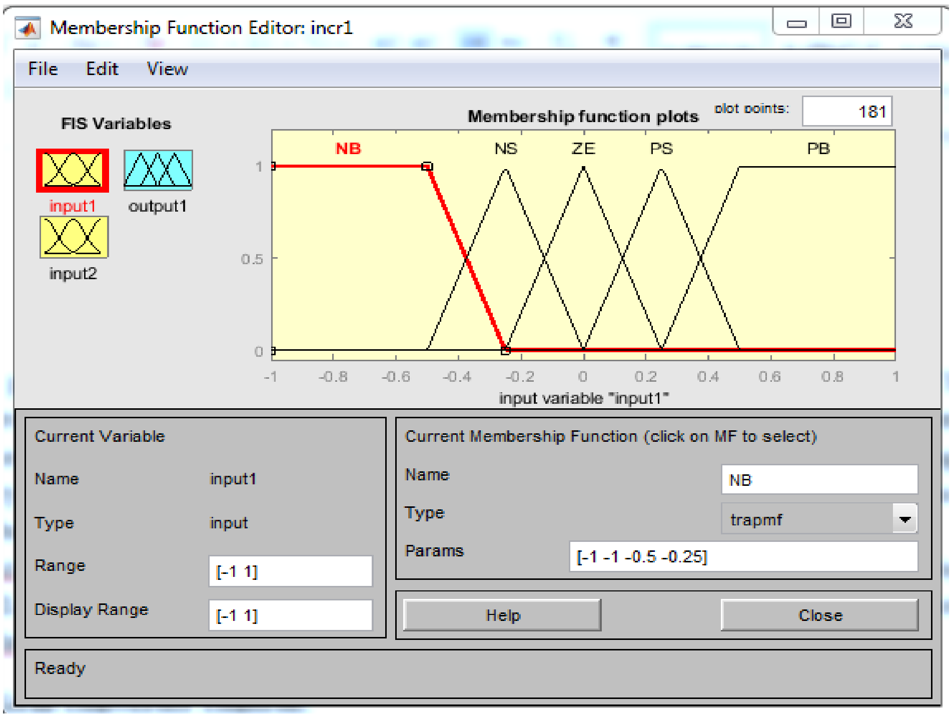

Figure 2.6: Membership function editor of fuzzy logic controller

For each input variable, there is a total of five membership functions. Since there are two inputs in this case, therefore there are twenty five fuzzy rules in total. The range of the membership functions has to be set so that each membership function might have its own range value. Based on these rules, a fuzzy rule table is constructed to simplify it so that it can be seen clearly.

Table 2.1: Fuzzy rules table

V I	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NS	ZE
NS	NB	NS	NS	ZE	PS
ZE	NS	NS	ZE	PS	PS
PS	NS	ZE	PS	PS	PB
PB	ZE	PS	PB	PB	PB

NB: Negative Big; NM: Negative Medium; NS: Negative Small; ZE: Zero; PS: Positive Big; PM: Positive Medium; PB: Positive Big

Based on **Table 2.1**, the rules created are responsible for the controller's decision to execute task. For example:

Rule 1: IF voltage is NB AND current is NB THEN the output duty cycle is NB

Rule 2: IF voltage is NB AND current is NS THEN the output duty cycle is NB

A clear understanding of Fuzzy rules setup might be obtained from the FLC rules editor in **Fig.2.7** and FLC rules viewer in **Fig.2.8**

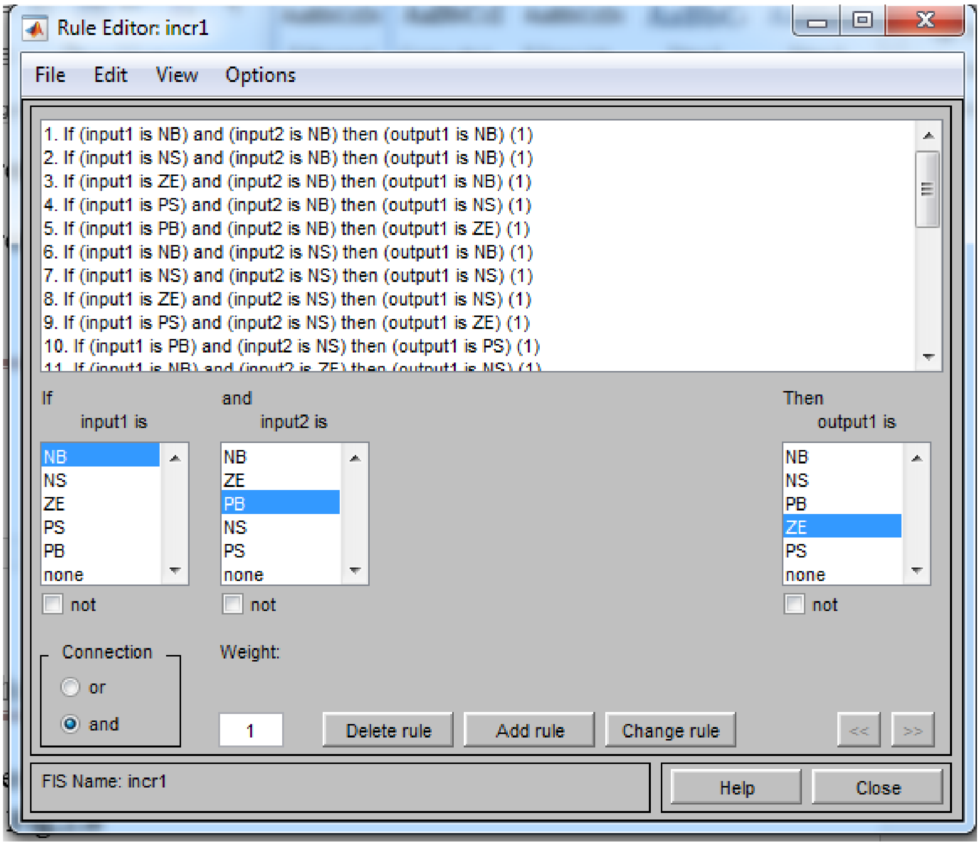

Figure 2.7: FLC rules editor

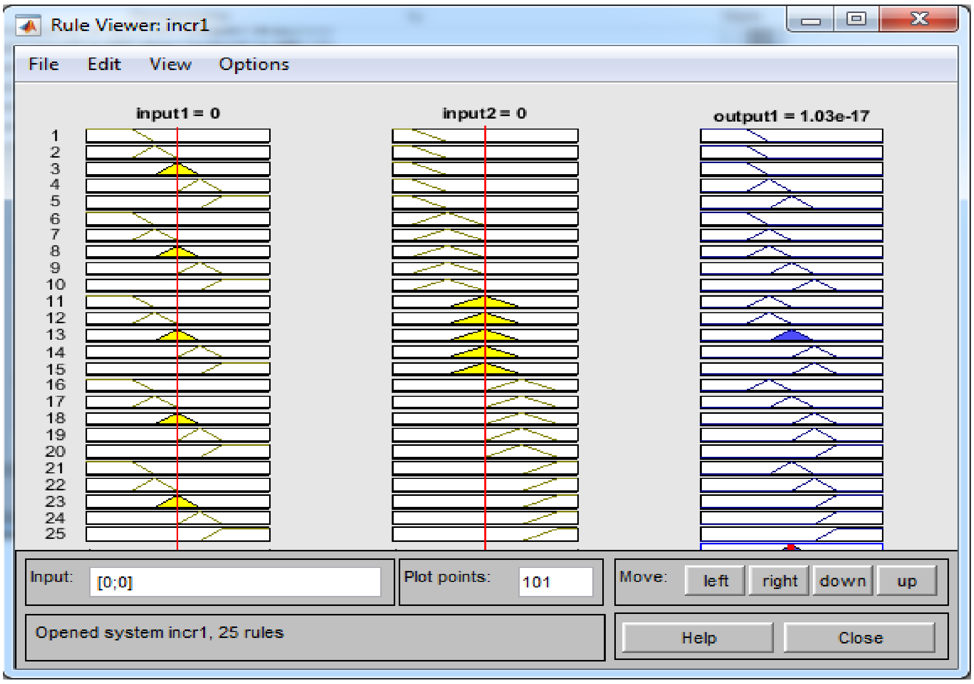

Figure 2.8: FLC rule viewer

2.4 Grid converter control:

One of the main concerns of the network operators is the power quality which depends on what kind of sources is connected to the grid. The wind energy has to be grid compatible, because in any power system the operator has to control the frequency and the voltage, the main purpose of the grid side converter (GSC) is to maintain the voltage level on the DC link capacitor by exchanging active power with the grid. It also has the ability to control terminal voltage or power factor by exchanging reactive power with the grid as we can see in. **Fig 2.9**

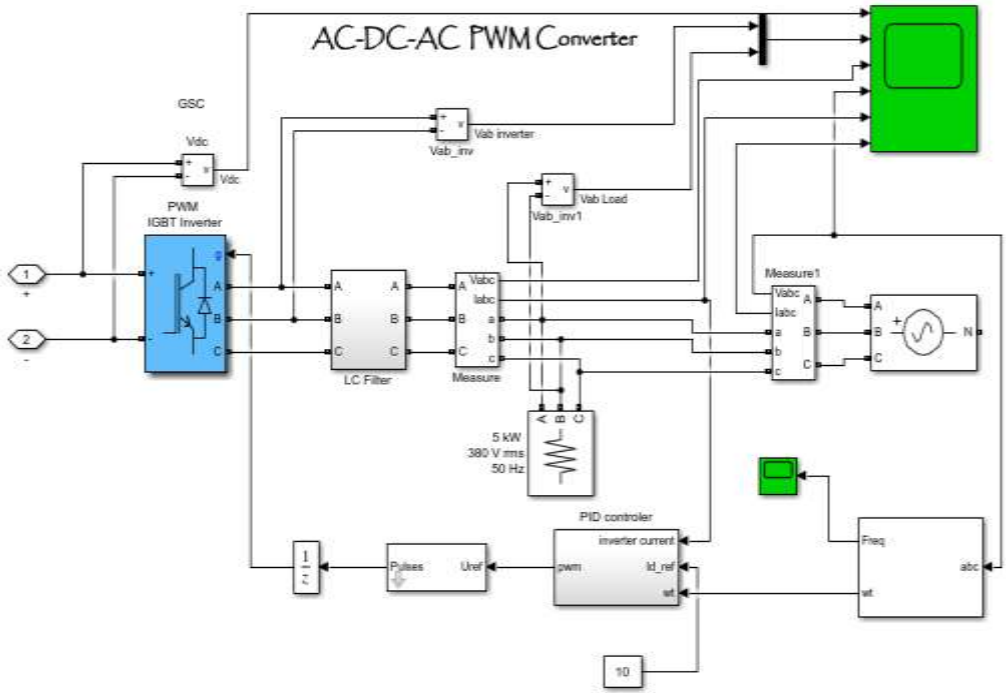

Figure 2.9: Grid converter control system

2.4.1 Voltage Oriented Control (VOC):

There are two types of grid side converter control systems, the Voltage Source Control (VSC) and the Current Source Control (CSC). VSC is the one applied in this project. The voltage oriented control is the main part of the grid side converter control. Its main purpose is to produce a synchronized voltage signal to the PWM generator which controls the DC/AC inverter. The produced signal purpose must have two specific features, one is to have the same phase and frequency as the grid voltage, and the second feature is to have a unity power factor, which means all the power transferred from the wind turbine system to the grid is the active power, while the reactive power is controlled to have a null value. This operation can be done in various ways based on which frame is used, synchronous (dq0), stationary (αβ0), and natural reference frame.

The two common VOC schemes are based on the synchronous and stationary frames. The VOC chosen for this project is based on the dq0 components since they will be considered constant (step signal) due to the same rotation speed between the actual signals and the frame's axis, which will ease up the control scheme. The active and reactive power equations are given by:

$P=\frac{3}{2}V_d I_d$ (2.1)

$Q=\frac{3}{2}V_q I_q$ (2.2)

From the previous equations, it can be seen that the power components can be controlled via i_d and i_q, which are represented by the following equations:

$\frac{di_{d(t)}}{dt}$ -w $i_q(t) = \frac{1}{L}[-Ri_d(t) - (t) + p(t)v_{dc}(t)]$ (2.3)

$\frac{di_{q(t)}}{dt}$ - W $i_d(t) = \frac{1}{L}[-Ri_q(t) - e_q(t) + p_q(t)v_{dc}(t)]$ (2.4)

The i_d* can be controlled using V_{dc} as presented in **Fig 2.8**

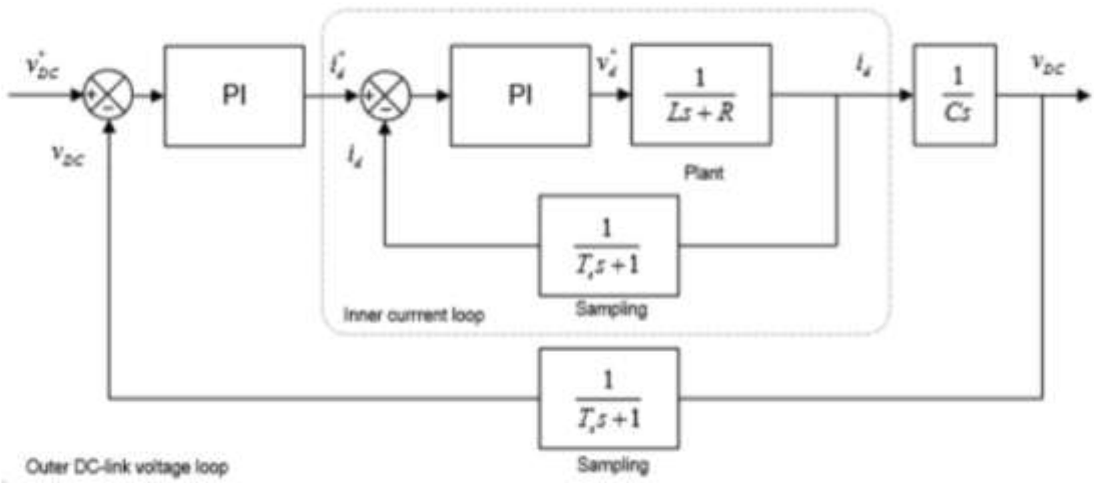

Figure 2.10: Id control loop [35].

I_q control has only one loop which is its control loop and it will have the same parameters as i_d loop. The results will be used to produce v_d* and v_q* using PIs and sums to decouple each component from the other, which in turn will be transferred to the abc voltage components that will be fed to the PWM inputs to generate the inverter control signal. The VOC scheme is shown in **Fig 2.9**:

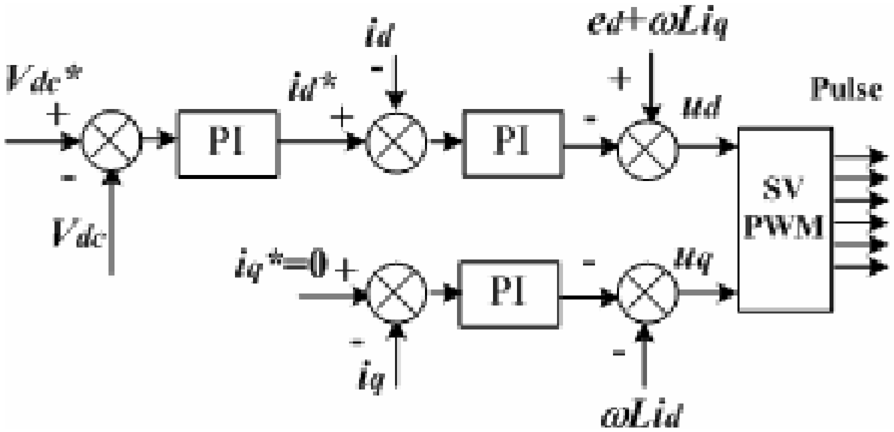

Figure 2.11: Voltage Oriented Control scheme [36]

2.5 Conclusion:

In this chapter we introduced the concept of the maximum power point tracking, what it means MPP, how to find it, and the factors responsible for changing it. We also explained the MPPT algorithms we used in this project which are the perturb and observe and the fuzzy logic methods by demonstrating the way they work and how to implement them in our WECS. We also introduced the concept of the grid converter control and how it is voltage oriented in our study.

The next chapter will be dedicated to the simulation results and the discussion of our system.

CHAPTER III

Simulation of PMSG driving by wind turbine

3.1 Introduction

Nowadays, simulation has become an important and powerful tool during development and to study the behavior of various systems. It allows gaining time and cost.

In order to investigate the performance and accuracy of the proposed MPPT method, simulations are performed for a model of turbine in MATLAB/SIMULINK facilities.

3.2 The system configuration

The overall system model of wind turbine conversion system with DC load is shown in **Fig3.1**:

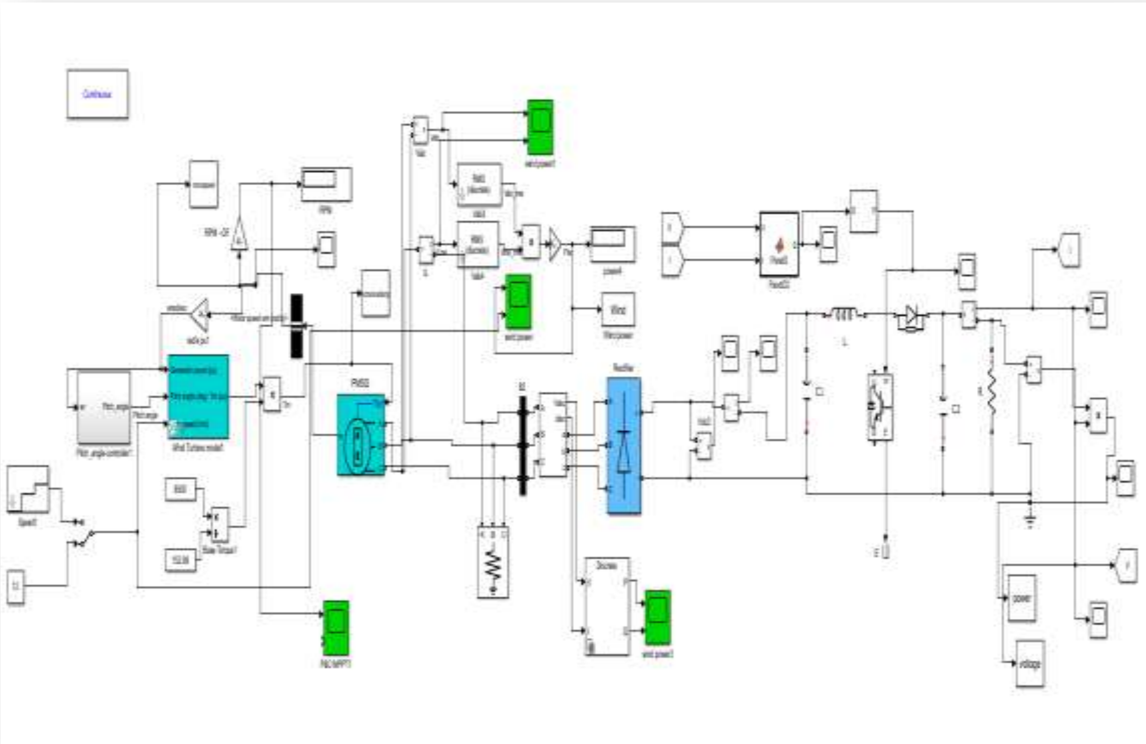

Figure 3.1: Wind turbine conversion system with DC load

The wind power conversion system consists of wind turbine module connected to a permanent magnet synchronous generator as shown in **Fig 3.2** and its parameter are shown in **table 3.1** and **table 3.2** respectively

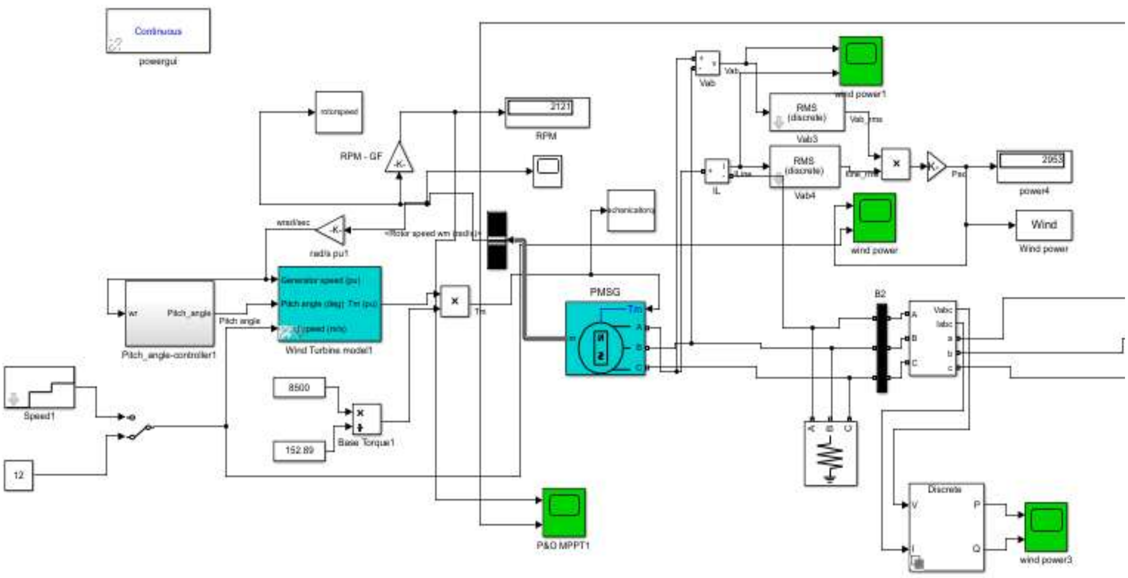

Figure 3.2: permanent magnet synchronous generator driven by wind turbine

Table 3.1: wind turbine parameters

Parameters	Value
Nominal mechanical output power	8.5 Kw
Base power of the electrical generator	6 Kw
Base wind speed	12
Maximum power at base wind speed	0.8
Base rotational speed	1
Pitch angle beta	0

Table 3.2: PMSG parameters

Parameters	Value
Rated Power	8.5 Kw
Rated torque	1.152 N.m
Rated current	12 A
Rated speed	153 rad/s
Number of pole pairs	4
Armature resistances	0.05 ohm
Stator dq axis inductance	0.000635 H
Magnetic flux linkage	0.192 Wb
Friction coefficient	0.001889N.m/s
Rotor inertia	0.011 $Kg.m^2$

The power-conditioning unit consists of two blocks, uncontrolled Rectifier (AC-DC) and DC-DC boost converter in addition to the control system, as illustrated in **Fig.3.3**

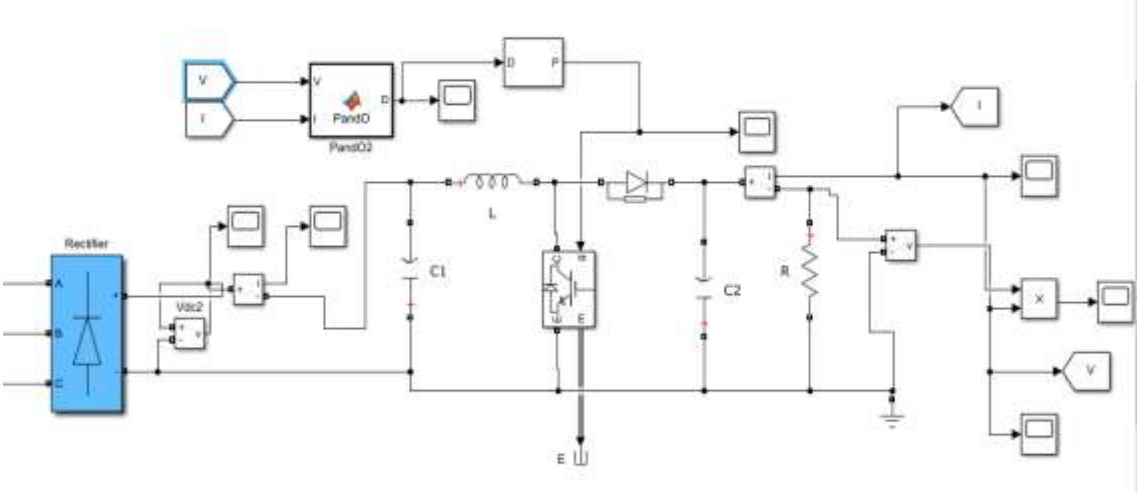

Figure 3.3: power conditioning units

The parameters of the boost are shown in the next table

Table 3.3: boost converter parameters

Parameters	Values
Input capacitor	0.3 mF
Inductance	1 H
Diode	Ideal in parallel with RC snubber circuit
Output capacitor	33.6 mF
DC load	40 ohms

3.3 Simulation and results for WEC with DC load:

The simulation will process first for fixed speed 12 m/s which chosen as nominal speed for the system without MPPT control, then with P&O technique and finally with Fuzzy Logic technique. Then after that it will done using variable speeds.

Before that it's necessary to show the codes of the two technique. The code of perturb and observe technique is shown in **Fig 3.4**

```
function D  = PandO(V, I)
Dinit = 0.42;  %Initial value for D output
Dmax = 0.8;   %Maximum value for D
Dmin = 0.08;   %Minimum value for D
deltaD = 0.000005; %Increment value used to increase/decrease the duty cycle D
persistent Vold Pold Dold;
dataType = 'double';
if isempty(Vold)
    Vold=0;
    Pold=0;
    Dold=Dinit;
end
P= V*I;
dV= V - Vold;
dP= P - Pold;
    if dP < 0
        if dV < 0
            D = Dold - deltaD;
        else
            D = Dold + deltaD;
        end
    else
        if dV < 0
            D = Dold + deltaD;
        else
            D = Dold - deltaD;
        end    end
if D >= Dmax | D<= Dmin
    D=Dold;
end
Dold=D;Vold=V;Pold=P;
```

Figure 3.4: P&O algorithm

The block of FLC contain the circuit that shown in **Fig.3.5** the rules and characteristics of the chosen FLC was shown in chapter 2 (the 2.3.2 part)

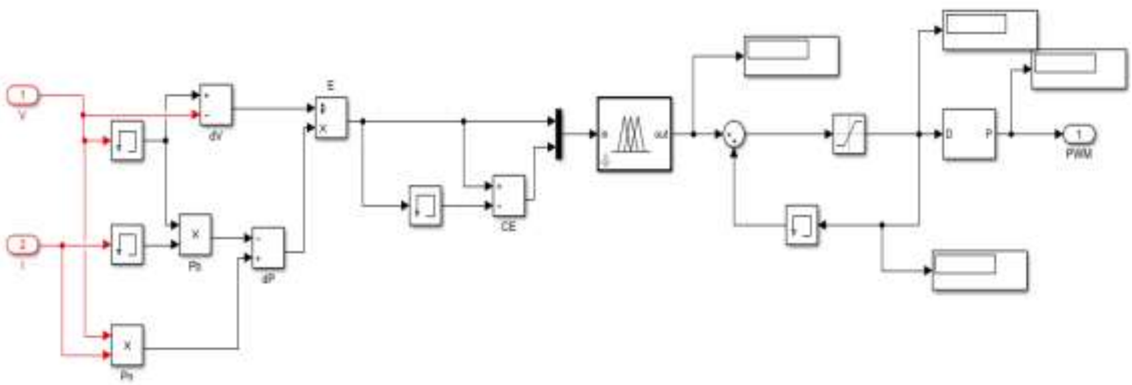

Figure 3.5: Fuzzy Logic Controller system

3.3.1 for fixed speed (12 m/s):

The results of each part will be shown in three ways; without MPPT, with P&O technique and with FLC technique respectively. The **Fig 3.6, Fig 3.7** and **Fig 3.8** show the RPM and the rotor speed of PMSG.

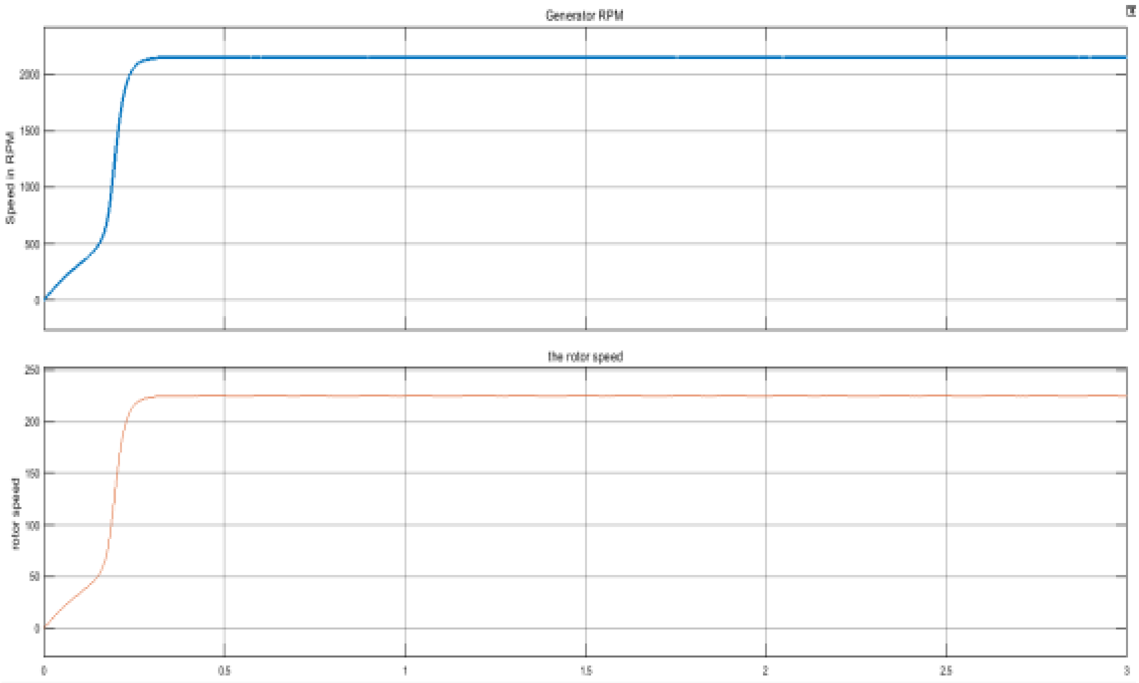

Figure 3.6: RPM and rotor speed with no MPPT

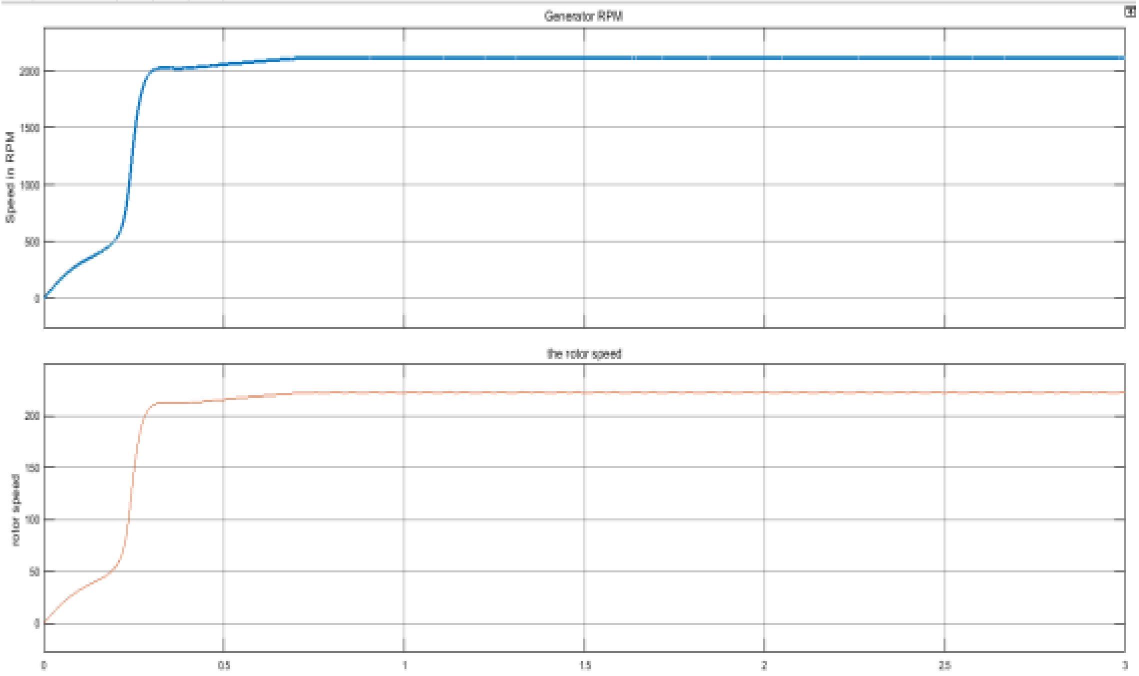

Figure 3.7: RPM and rotor speed with P&O technique

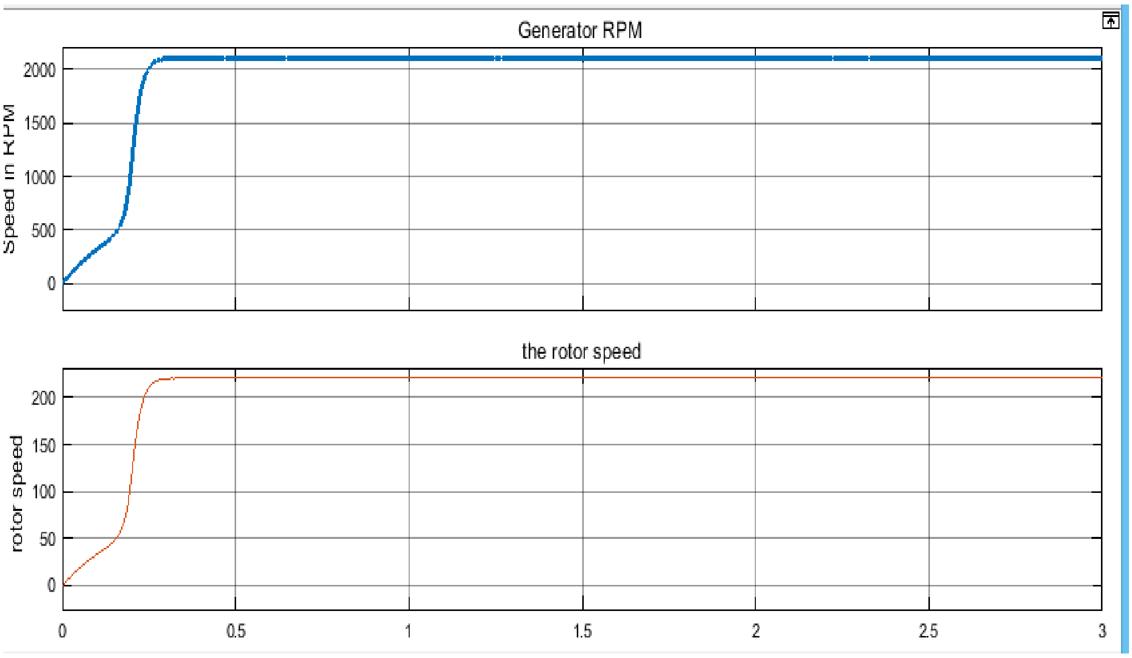

Figure 3.8: RPM and rotor speed with FLC technique

The **Fig 3.9, Fig 3.10** and **Fig 3.11** show the power produced by PMSG.

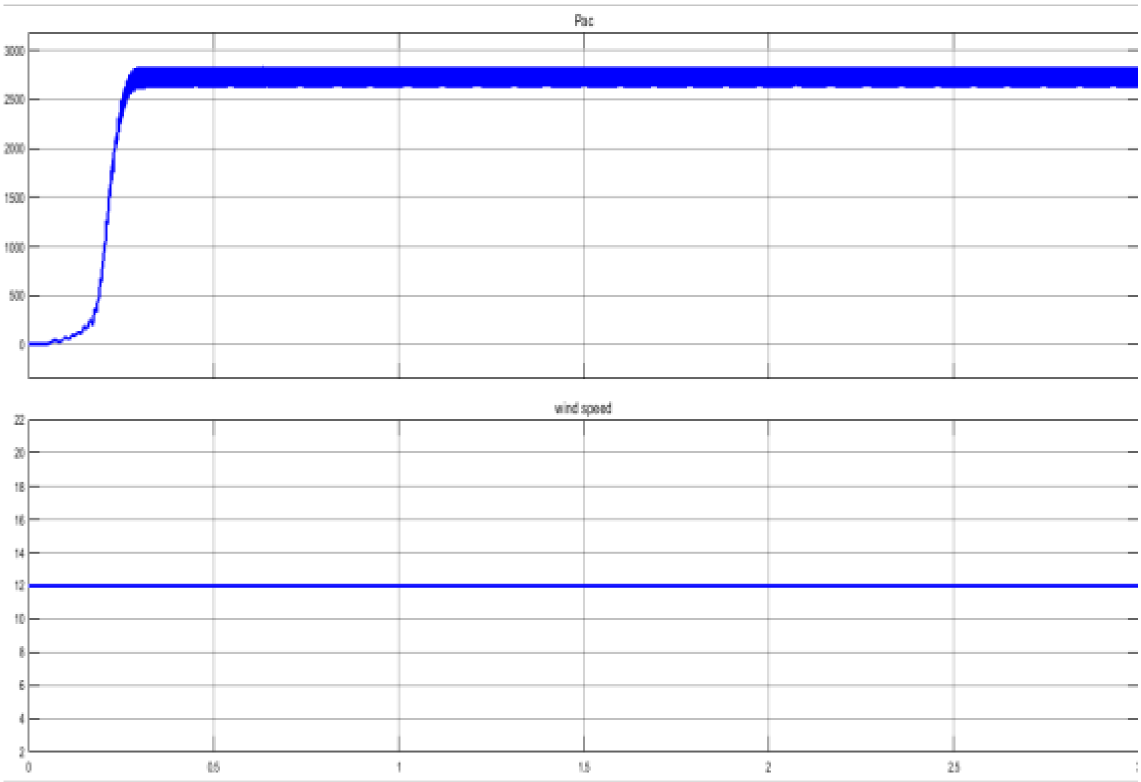

Figure 3.9: power produced by PMSG with no MPPT

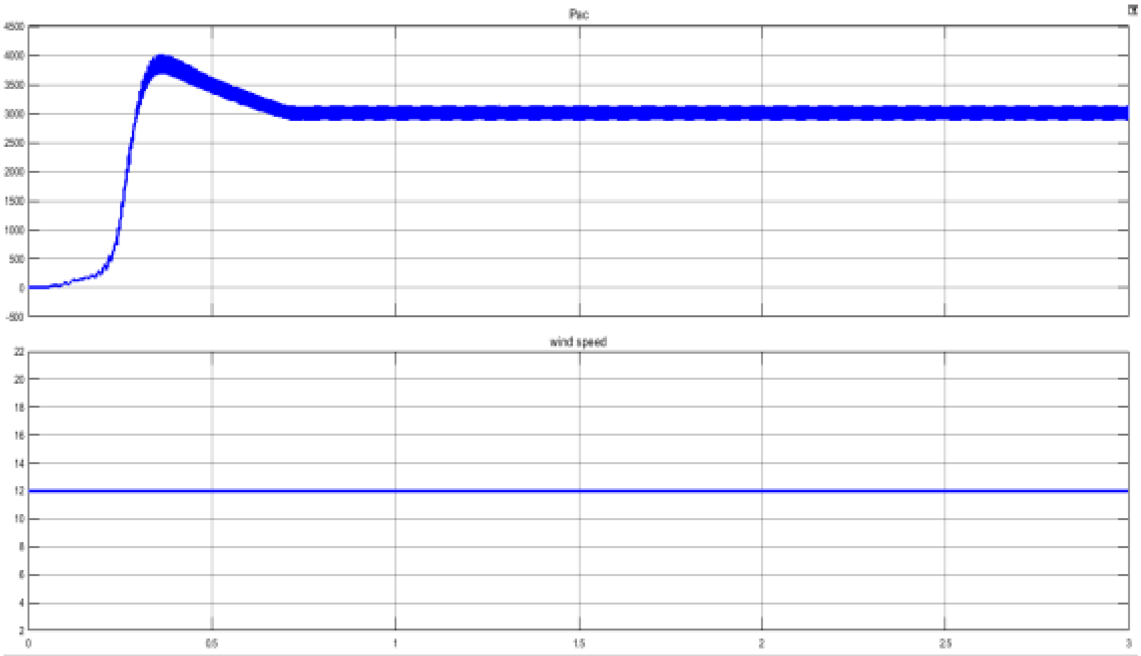

Figure 3.10: Power produced by PMSG with P&O technique

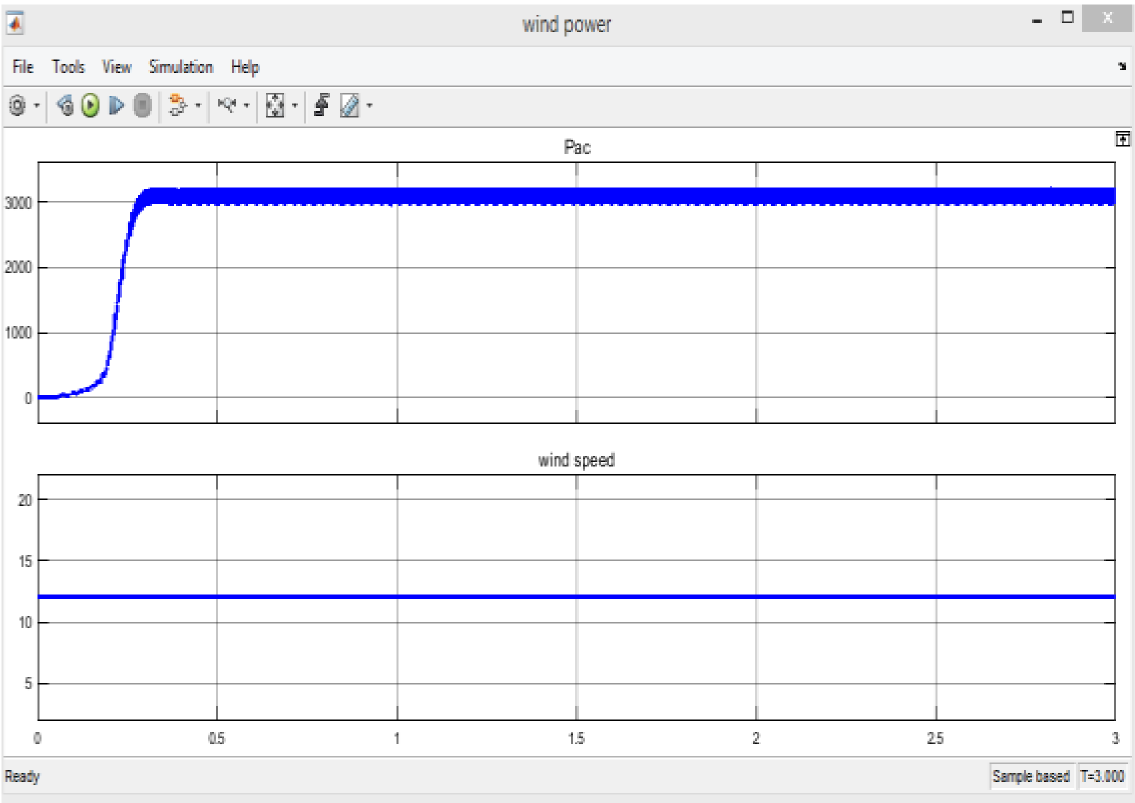

Figure 3.11: Power produced by PMSG with FLC technique

The **Fig 3.12, Fig 3.13** and **Fig 3.14** show the RMS voltage and current of PMSG.

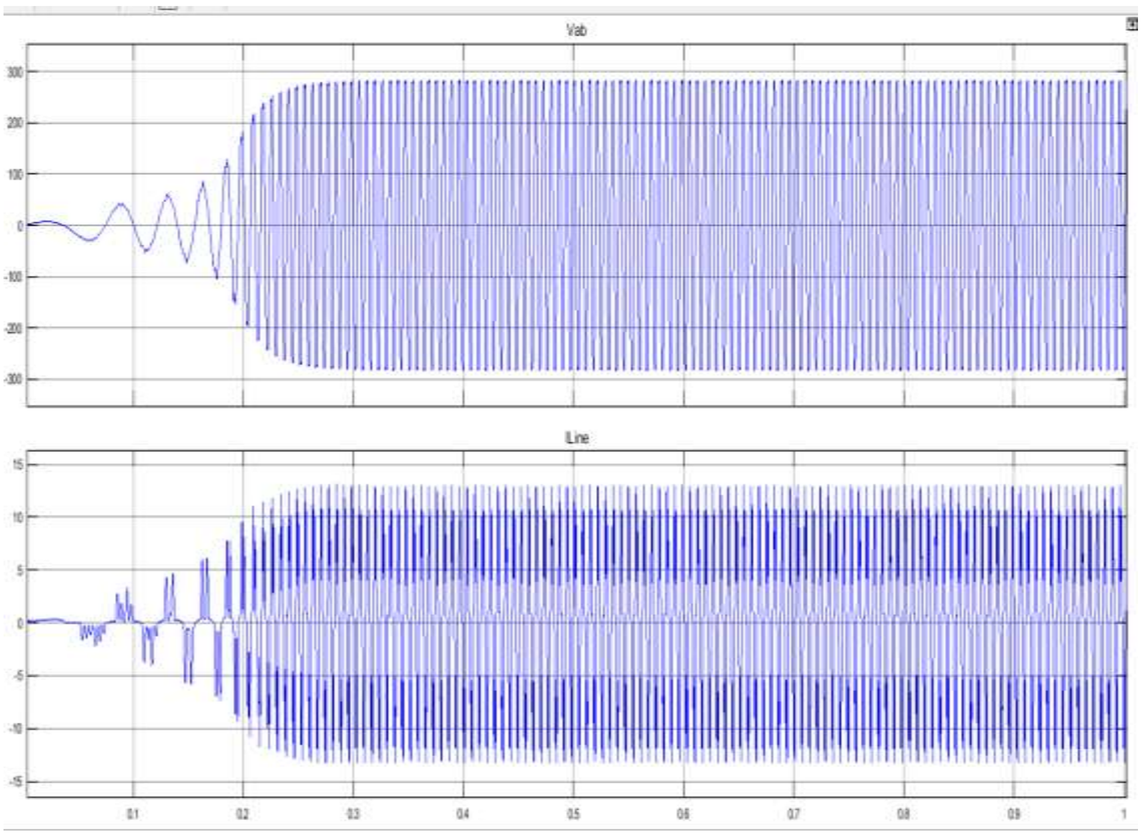

Figure 3.12: RMS voltage and current of PMSG with no MPPT

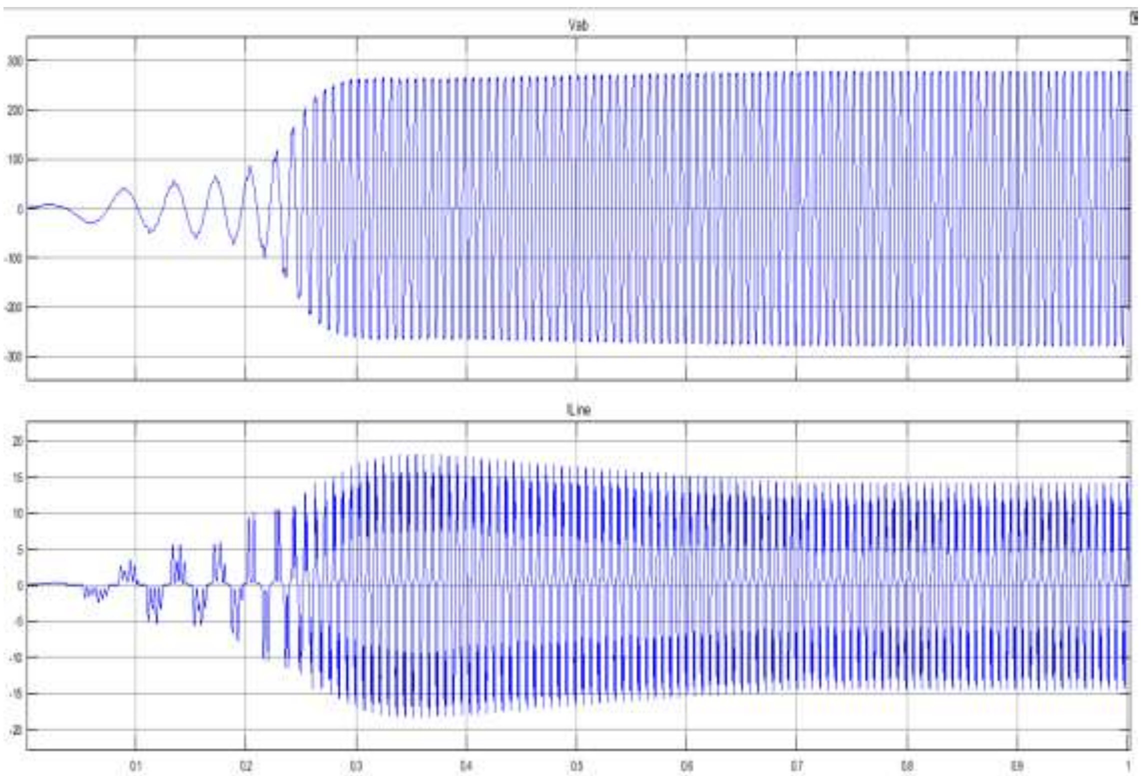

Figure 3.13: RMS voltage and current of PMSG with P&O technique

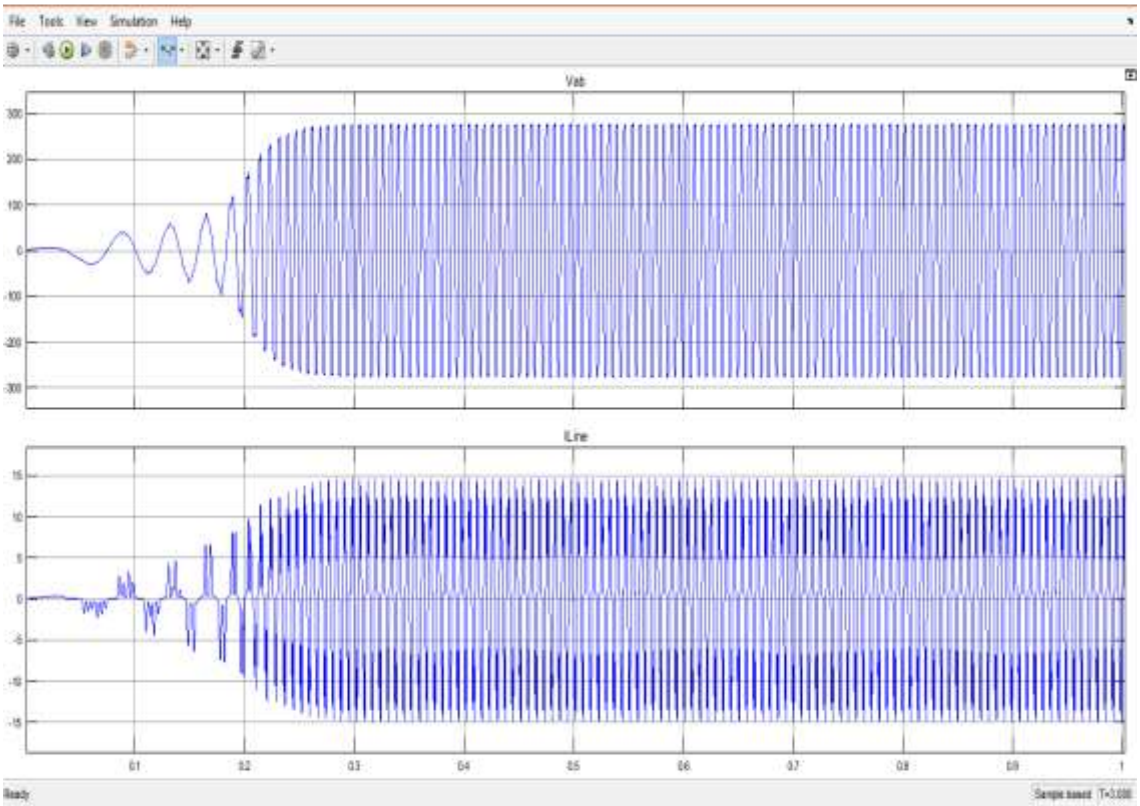

Figure 3.14: RMS voltage and current of PMSG with FLC technique

The **Fig 3.15, Fig 3.16** and **Fig 3.17** show the DC voltage and current of the load.

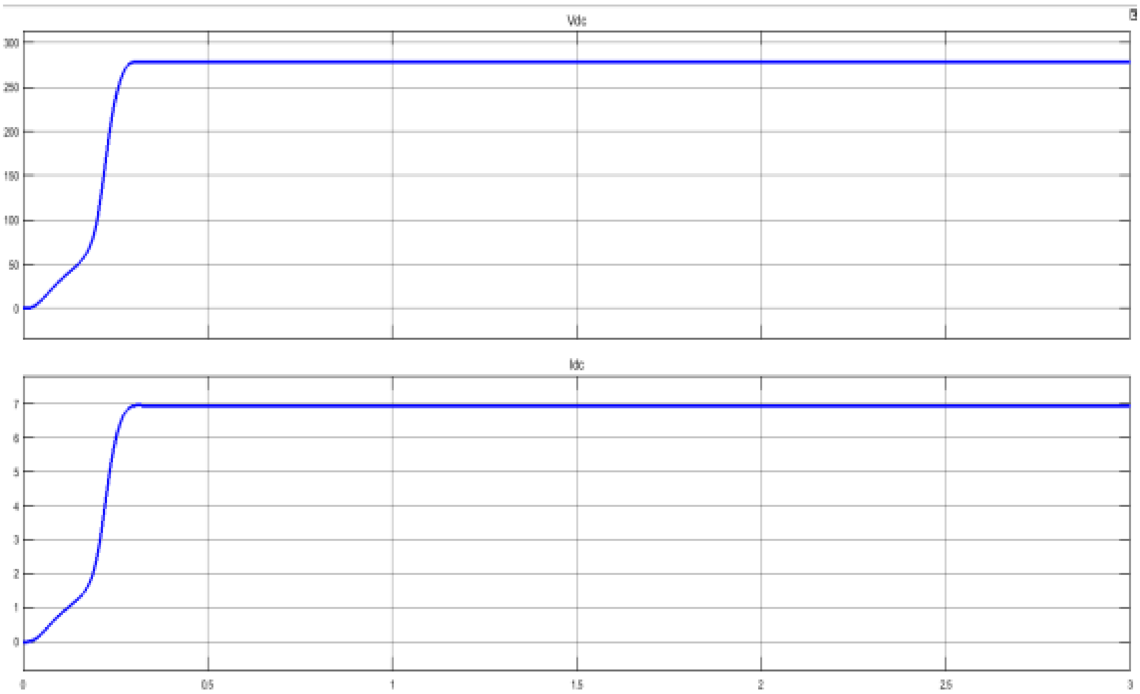

Figure 3.15: DC voltage and current with no MPPT

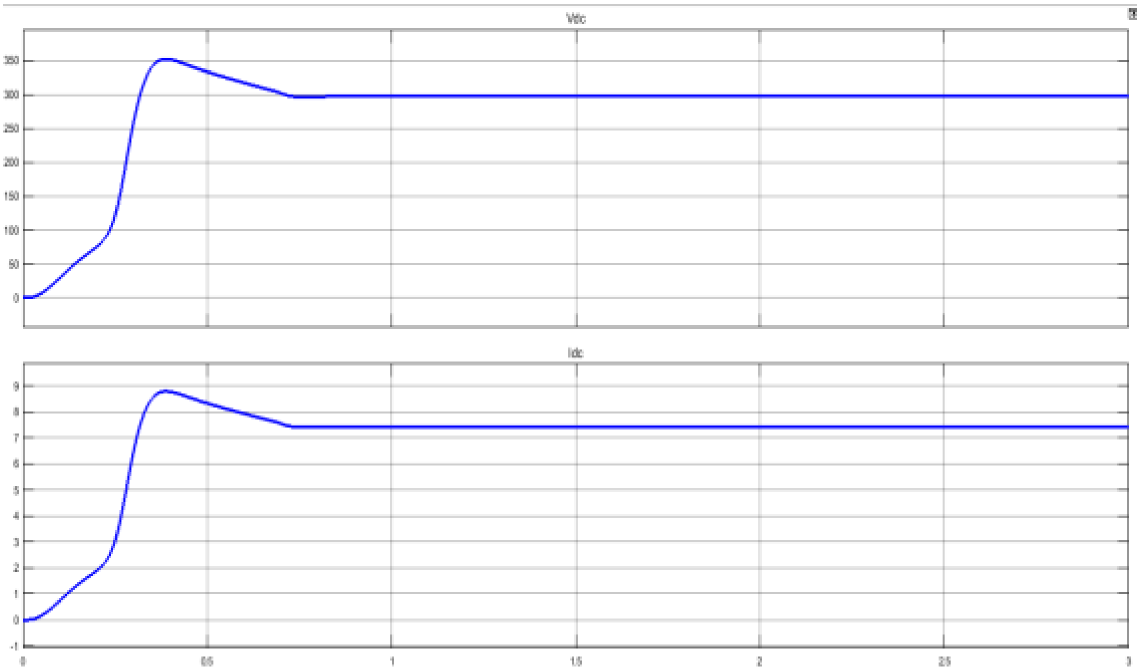

Figure 3.16: DC voltage and current with P&O technique

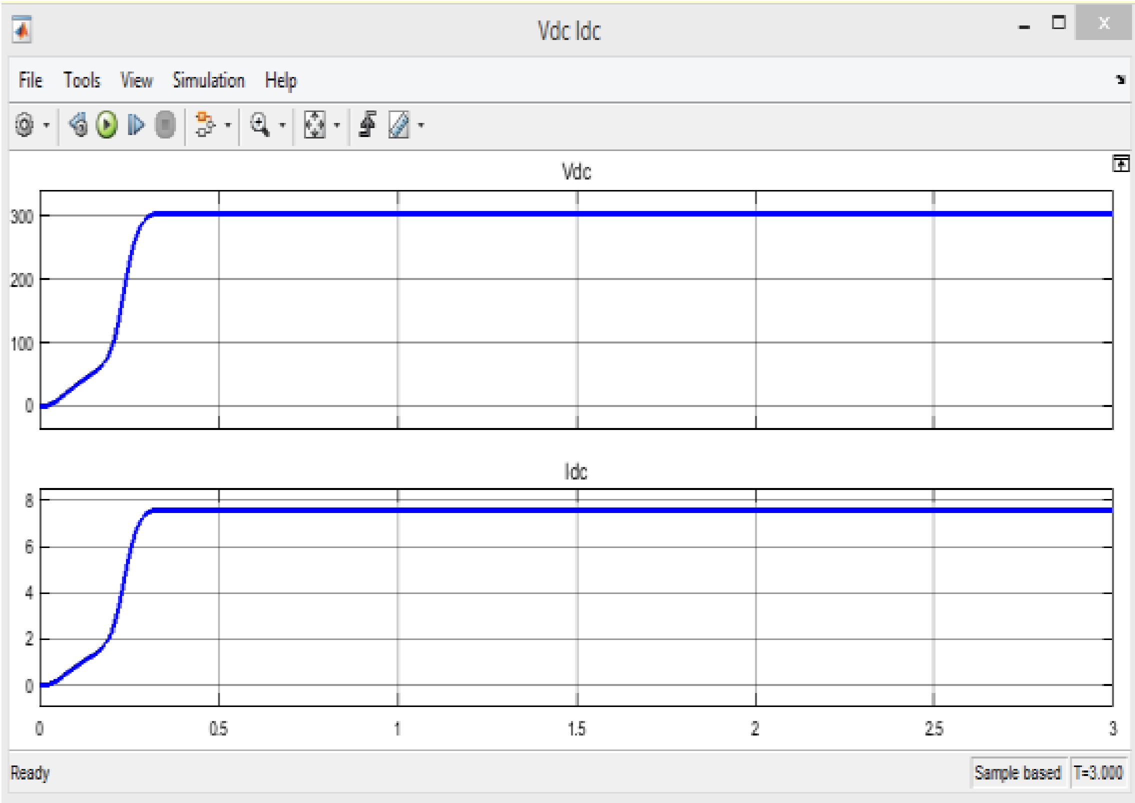

Figure 3.17: DC voltage and current with FLC technique

The **Fig 3.18, Fig 3.19** and **Fig 3.20** show the DC power delivered by the system.

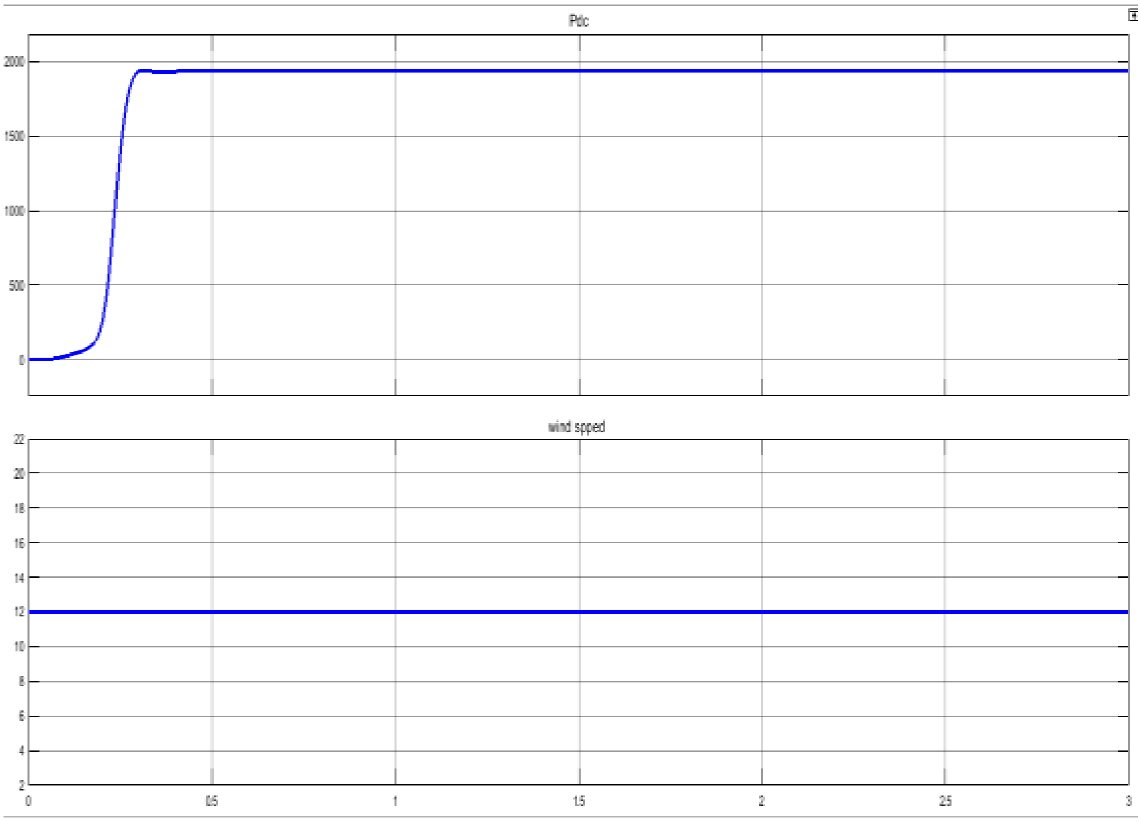

Figure 3.18: DC power delivered with no MPPT

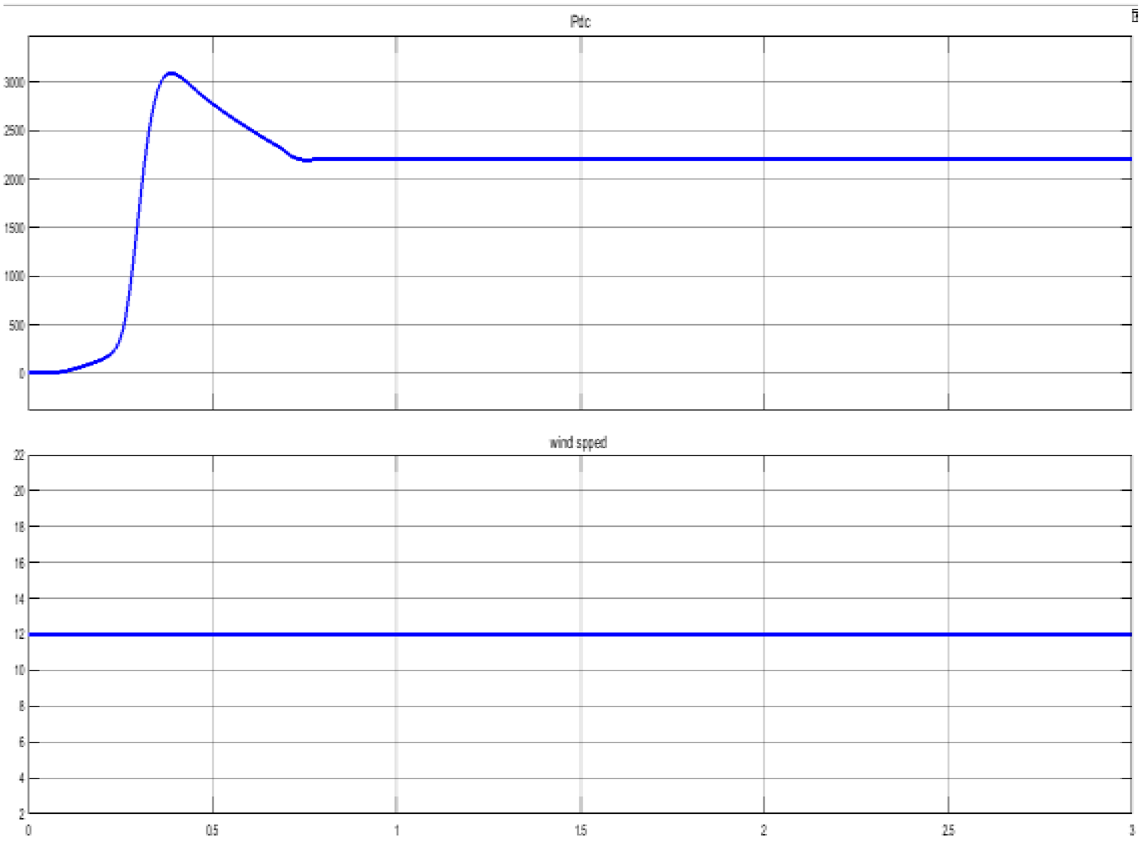

Figure 3.19: DC power delivered with P&O technique

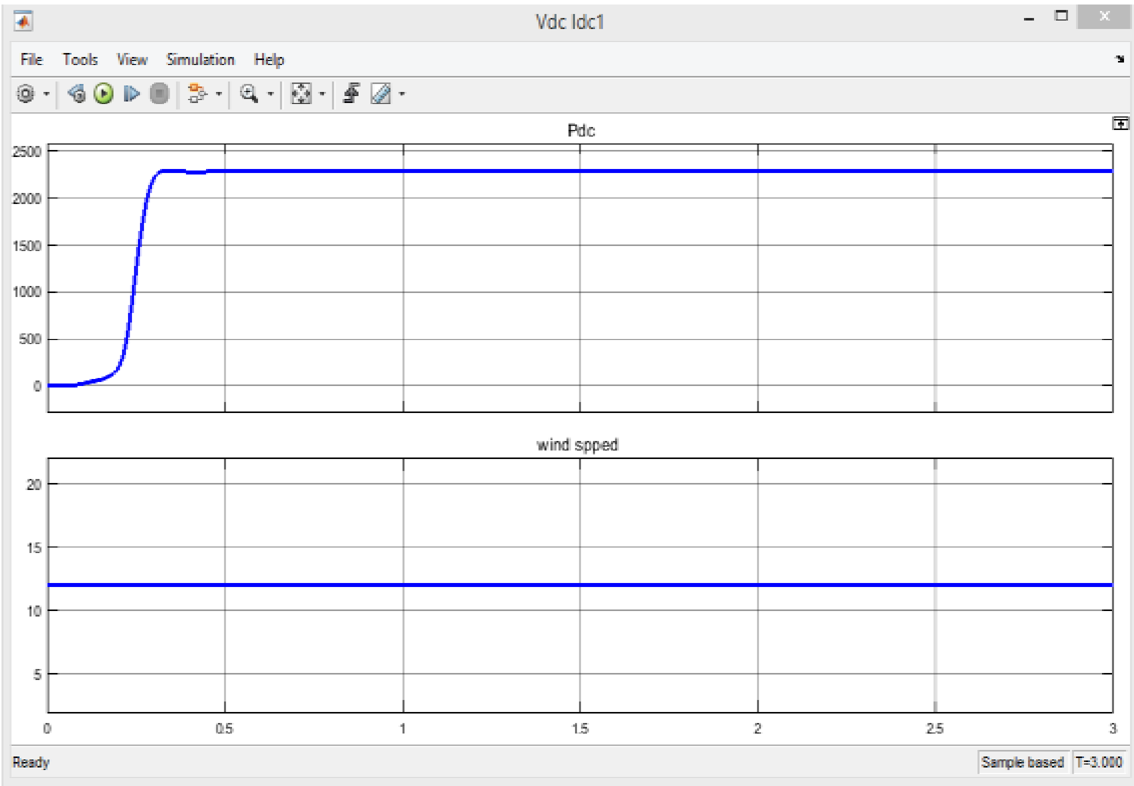

Figure 3.20: DC power delivered with FLC technique

3.3.2 for variable speed:

The wind speed data used in this development is 7, 9, 10, 8 and 11m/s respectively to test the tracking performance of the P&O and FLC MPPT as shown in **Fig.3.21.**

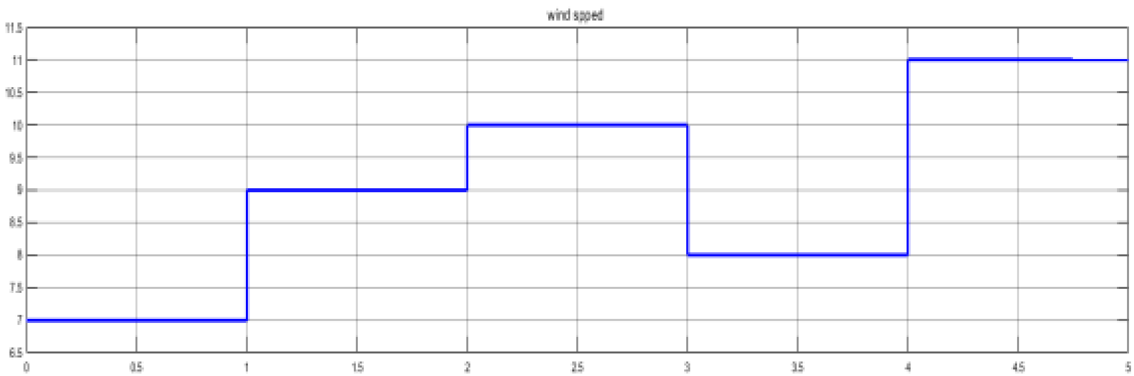

Figure 3.21: Wind speed data for the proposed WECS

As the previous part, the results of each part will be shown without MPPT, with P&O technique and with FLC technique respectively. The **Fig 3.22, Fig 3.23** and **Fig 3.24** show the RPM and the rotor speed of PMSG.

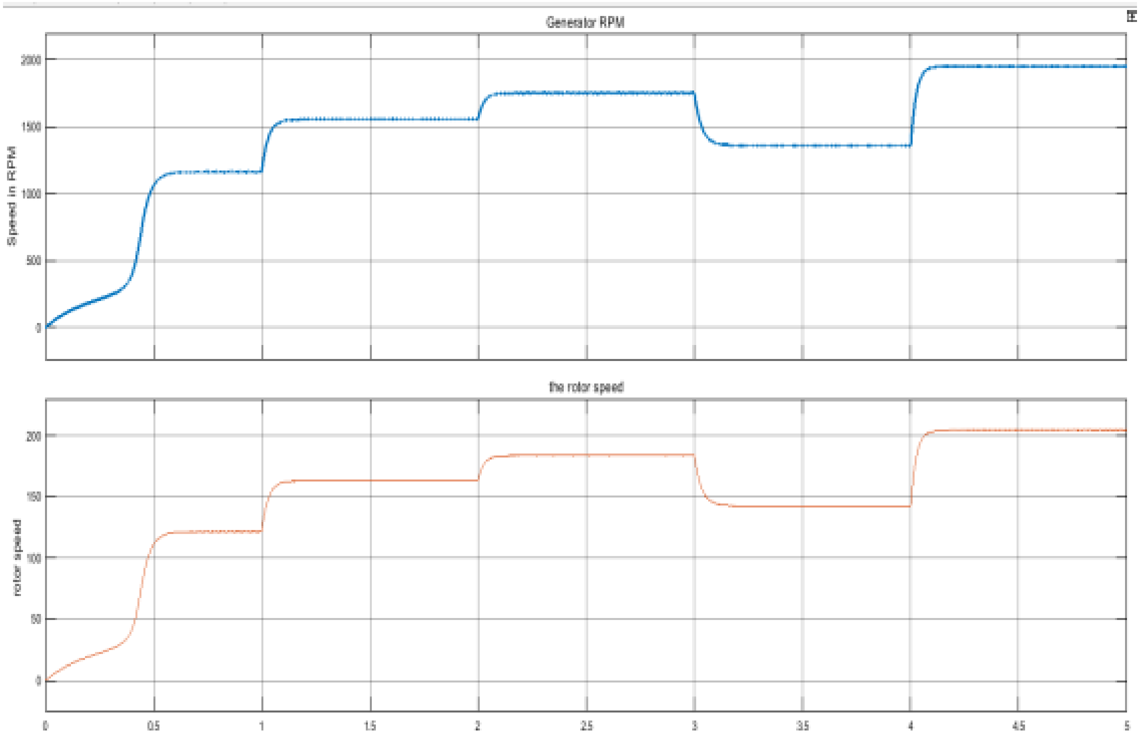

Figure 3.22: RPM and rotor speed without MPPT

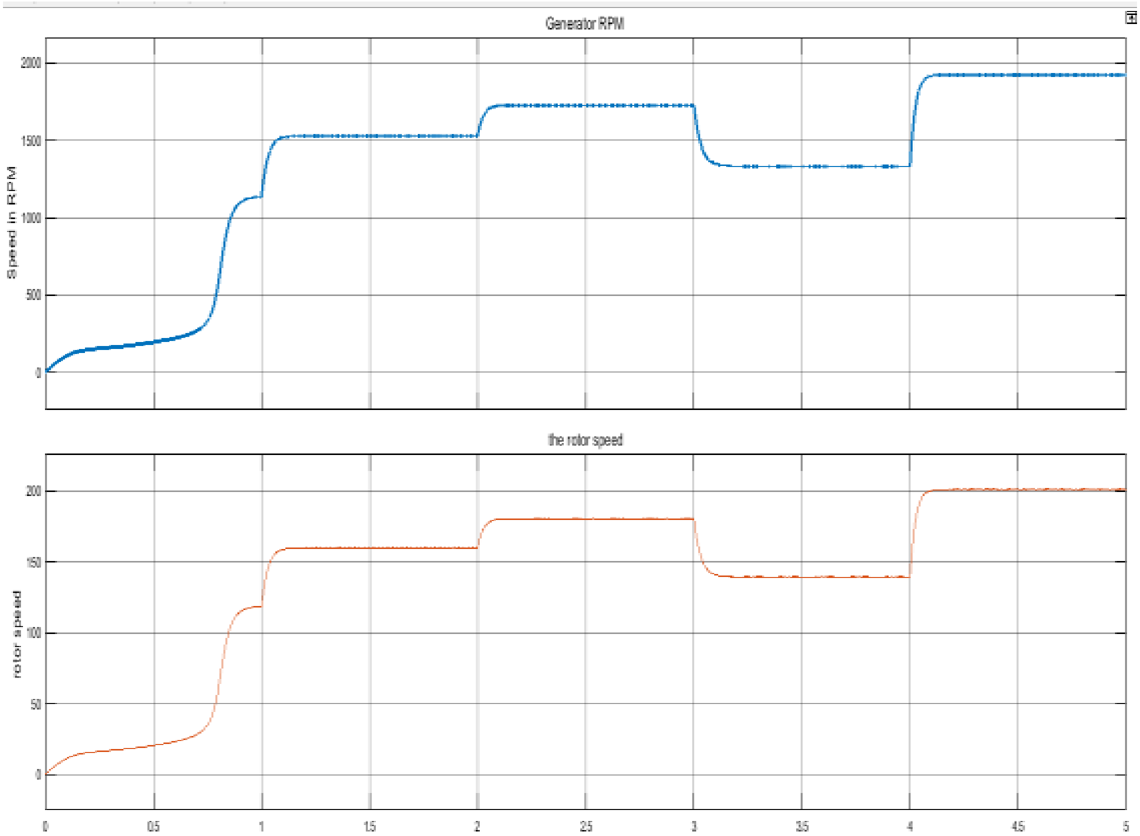

Figure 3.23: RPM and rotor speed with P&O technique

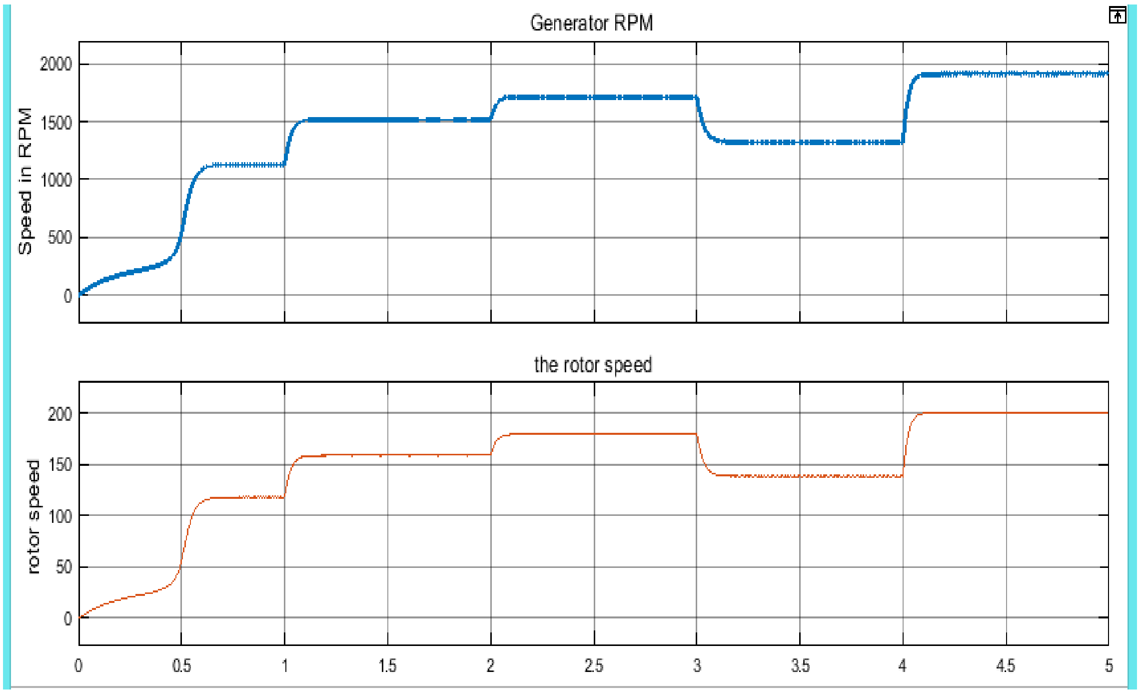

Figure 3.24: RPM and rotor speed with FLC technique

The **Fig 3.25, Fig 3.26** and **Fig 3.27** show the power produced by PMSG.

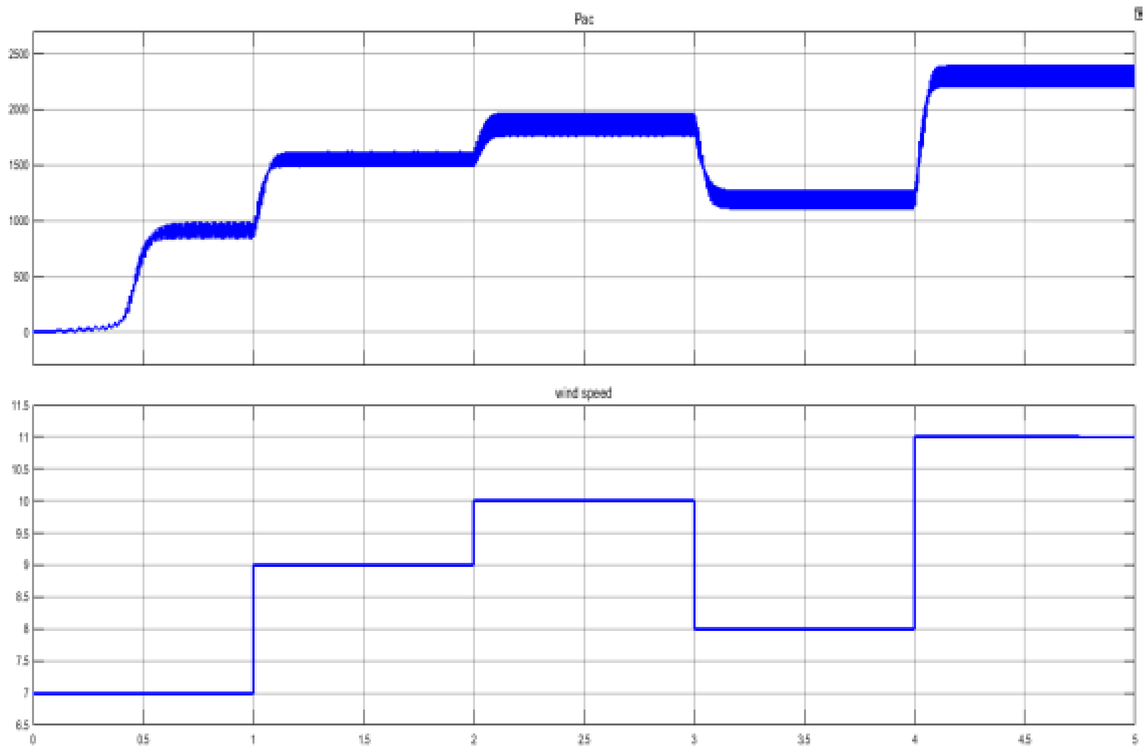

Figure 3.25: Power produced by PMSG without MPPT

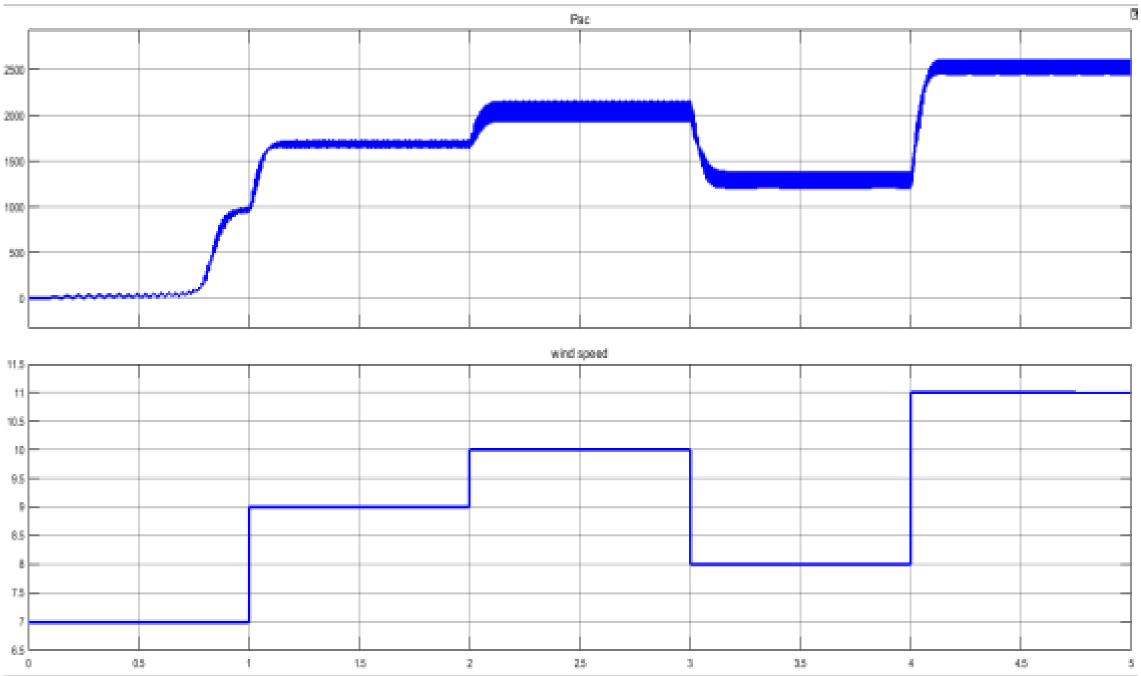

Figure 3.26: Power produced by PMSG with P&O technique

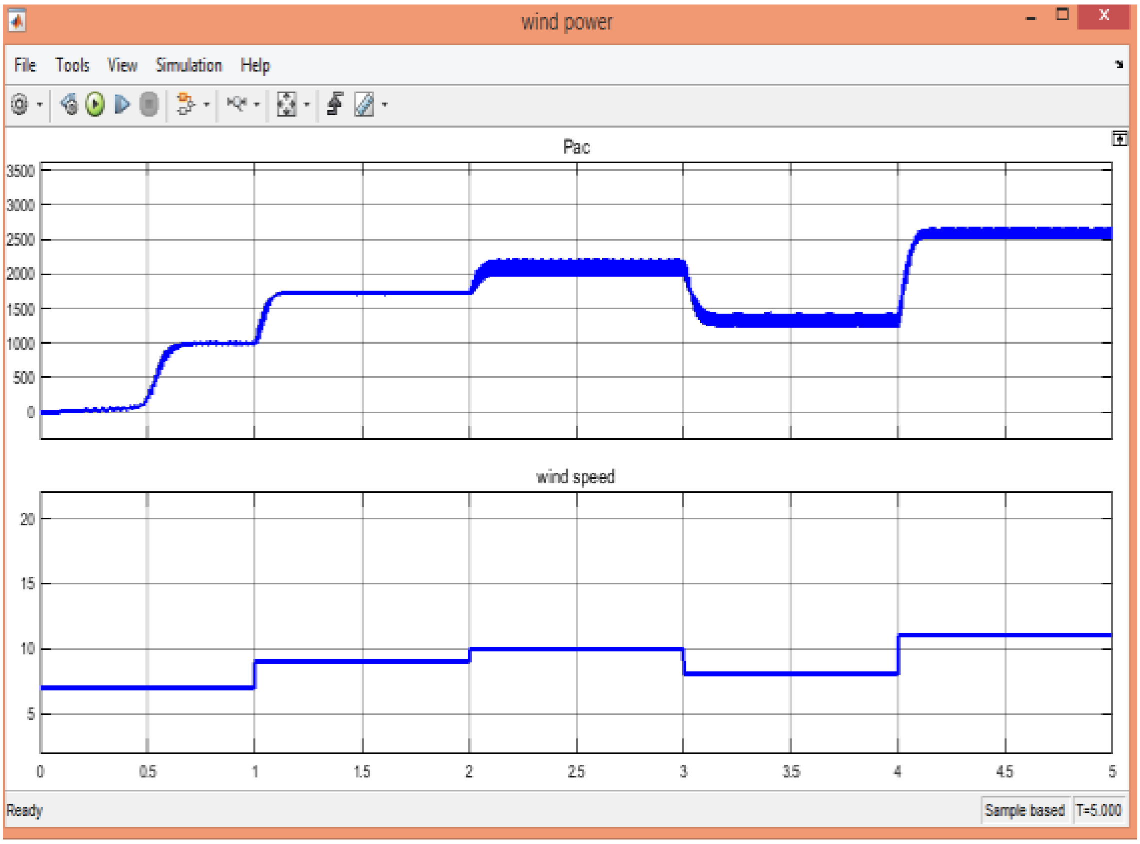

Figure 3.27: Power produced by PMSG with FLC technique

The **Fig 3.28, Fig 3.29** and **Fig 3.30** show the RMS voltage and current of PMSG.

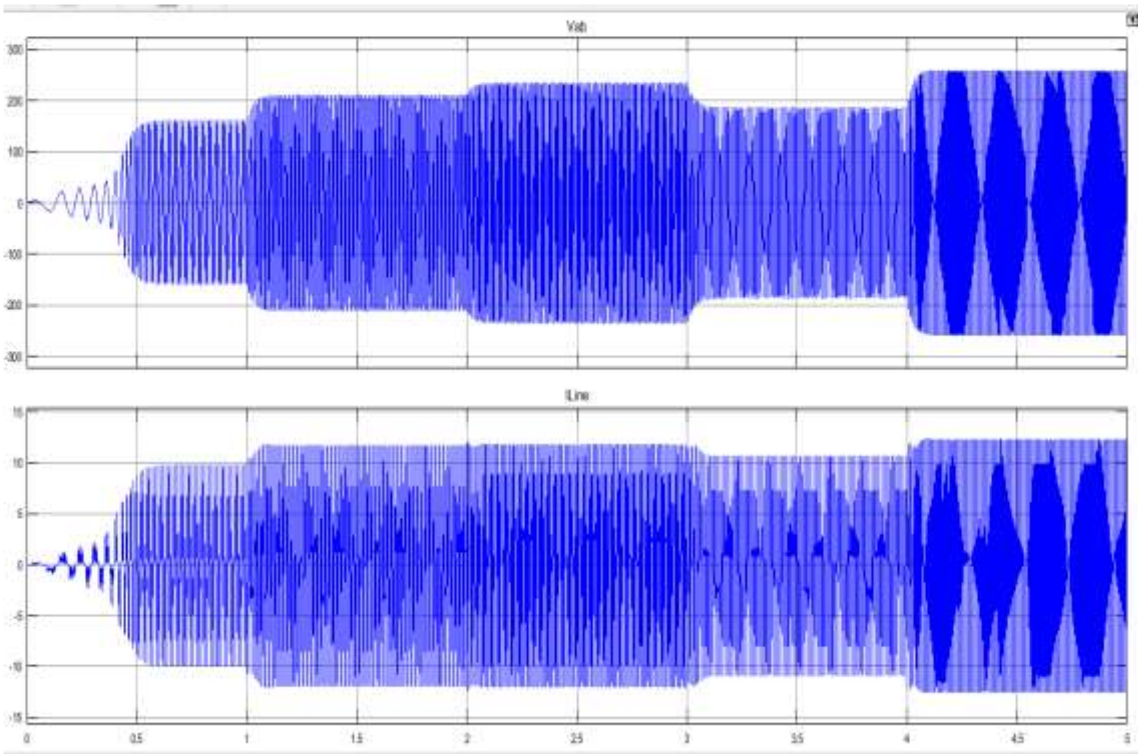

Figure 3.28: RMS voltage and current of PMSG without MPPT

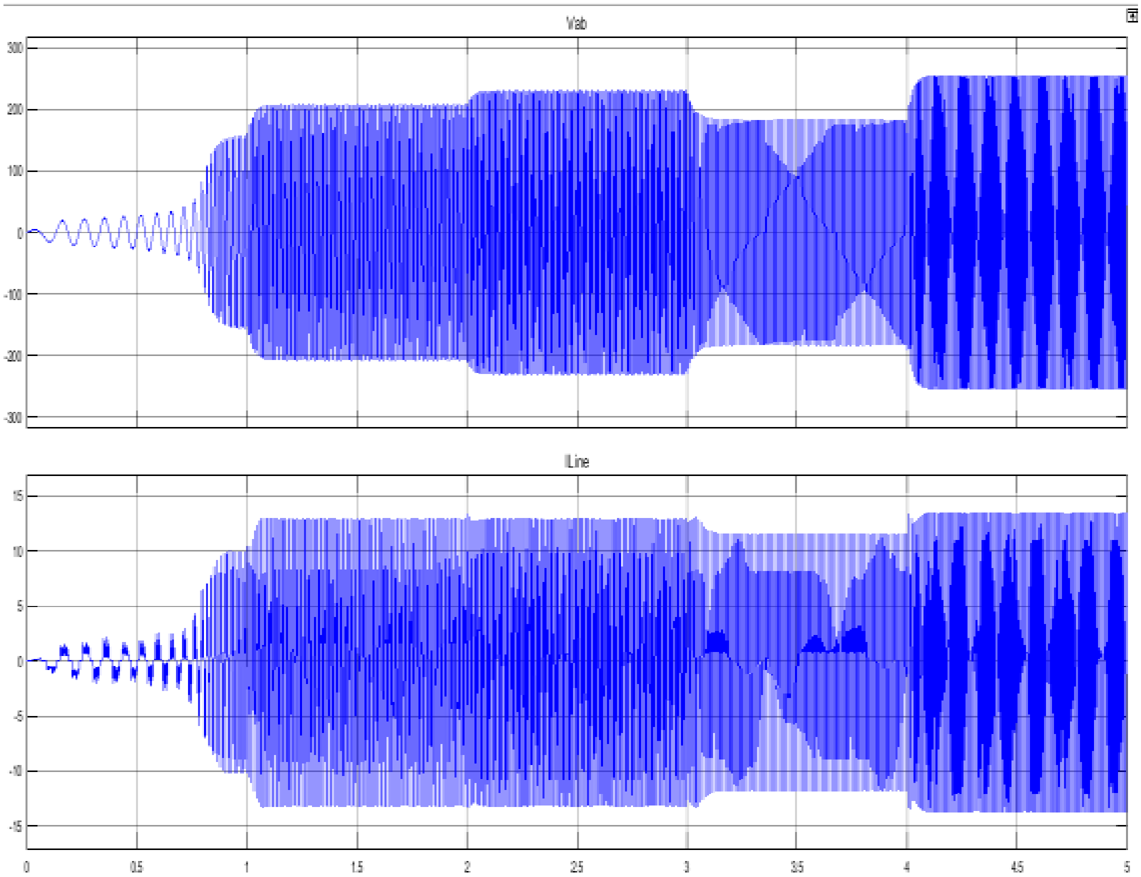

Figure 3.29: RMS voltage and current of PMSG with P&O technique

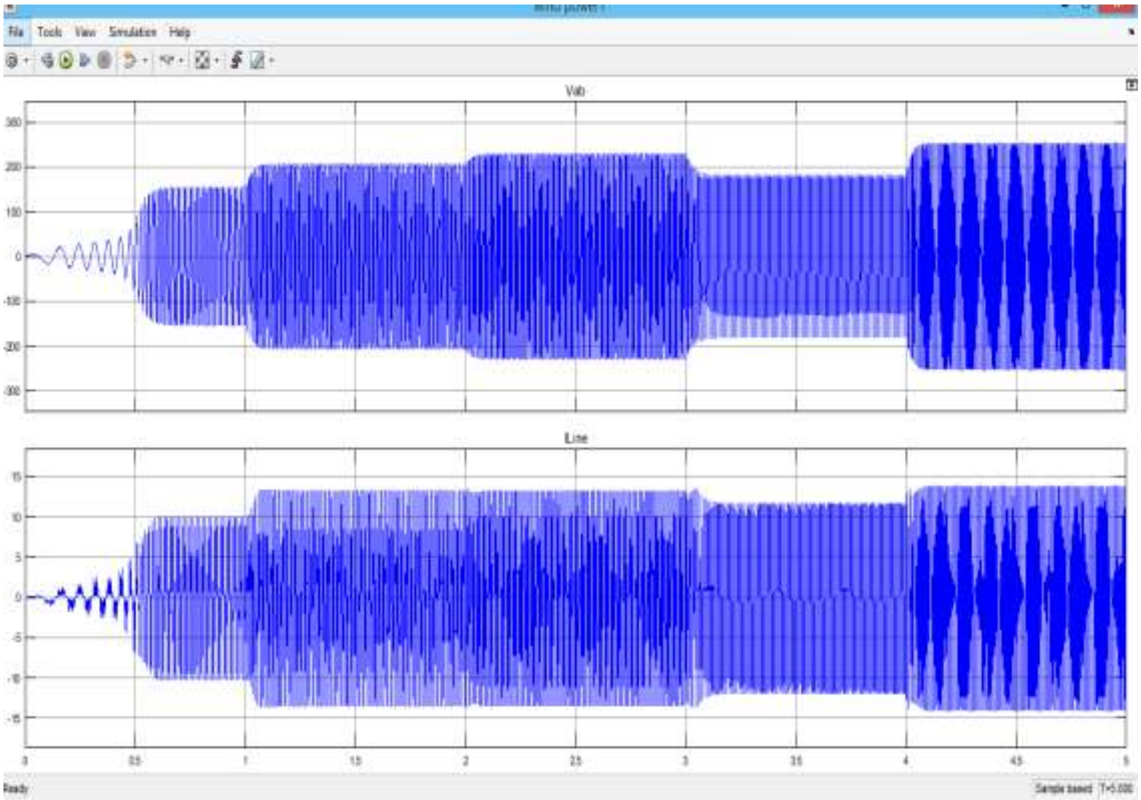

Figure 3.30: RMS voltage and current of PMSG with FLC technique

The **Fig 3.31, Fig 3.32** and **Fig 3.33** show the DC voltage and current of the load.

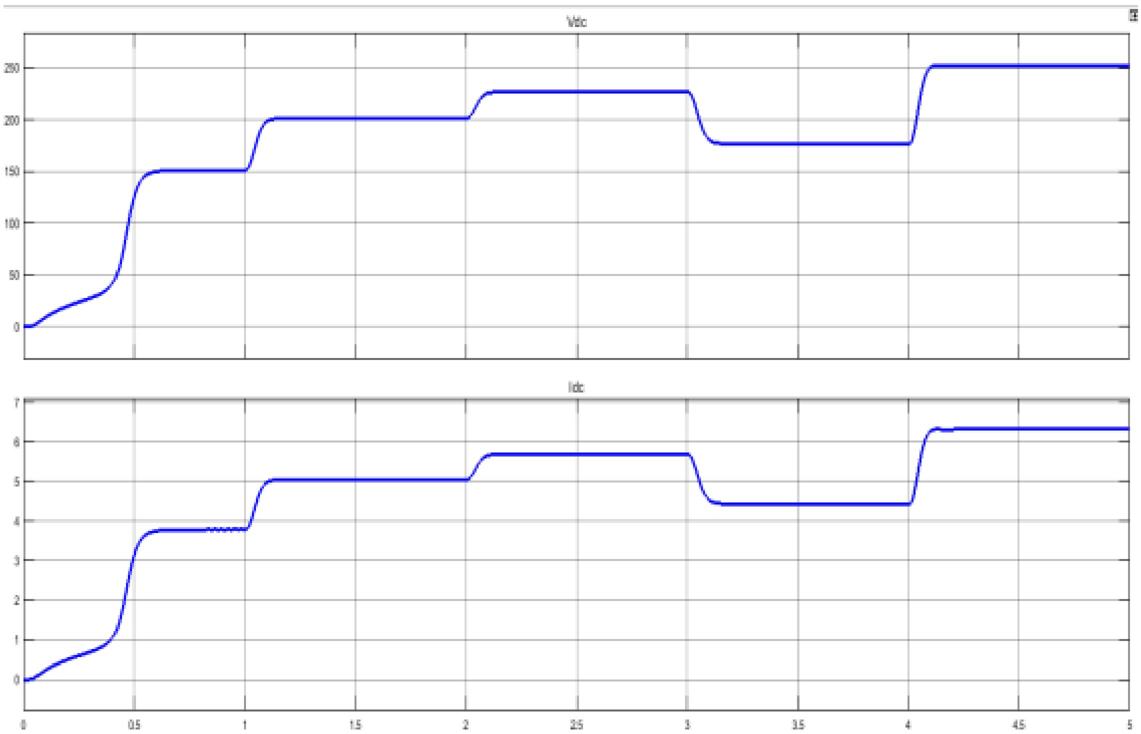

Figure 3.31: DC voltage and current of the load without MPPT

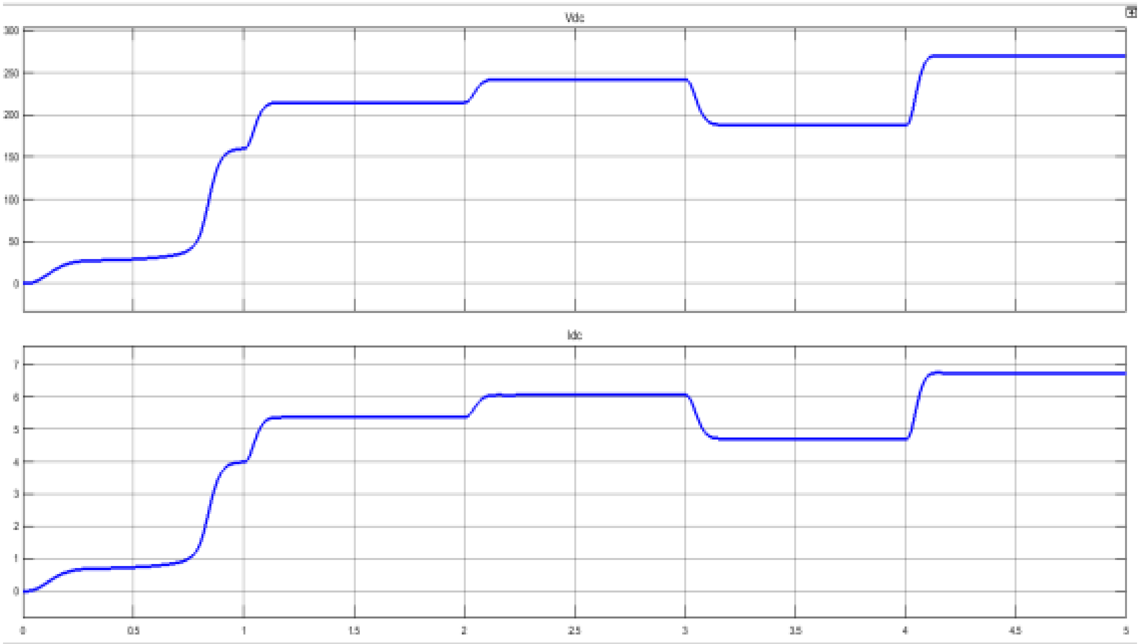

Figure 3.32: DC voltage and current of the load with P&O technique

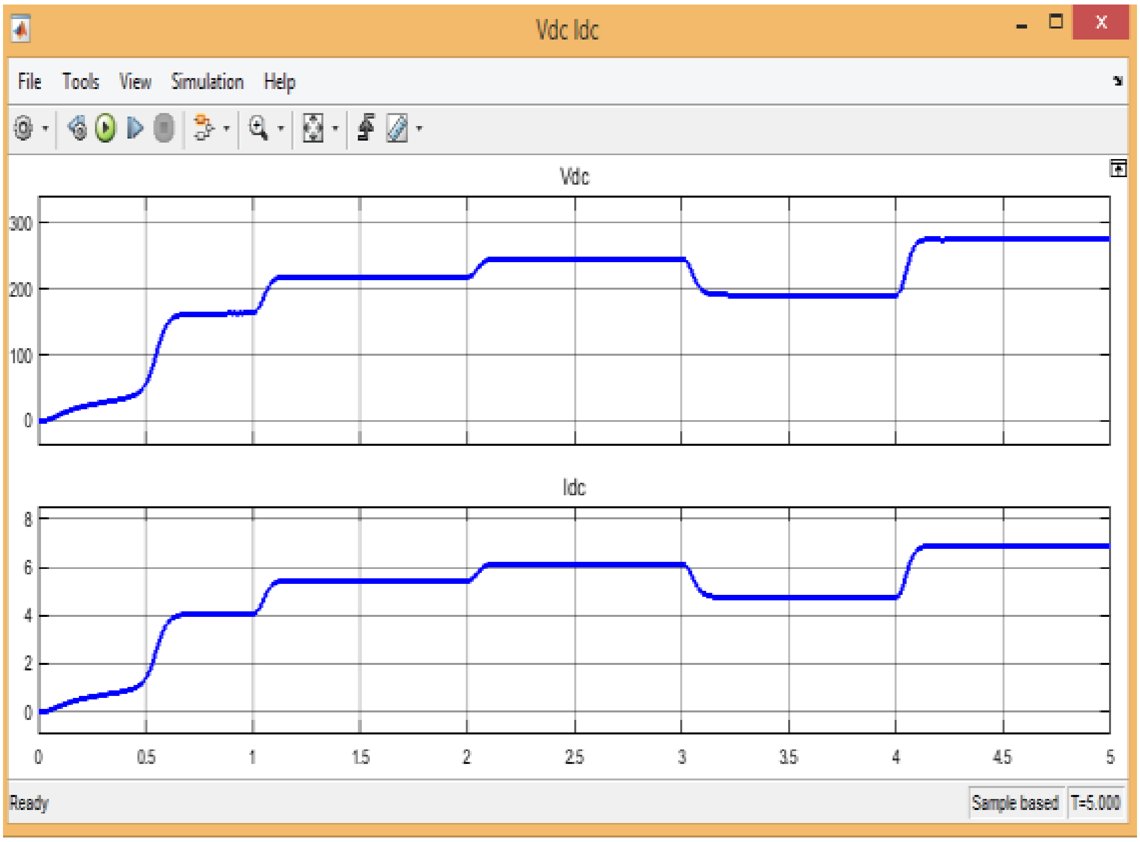

Figure 3.33: DC voltage and current of the load with FLC technique

The **Fig 3.34, Fig 3.35** and **Fig 3.36** show the DC power delivered by the system.

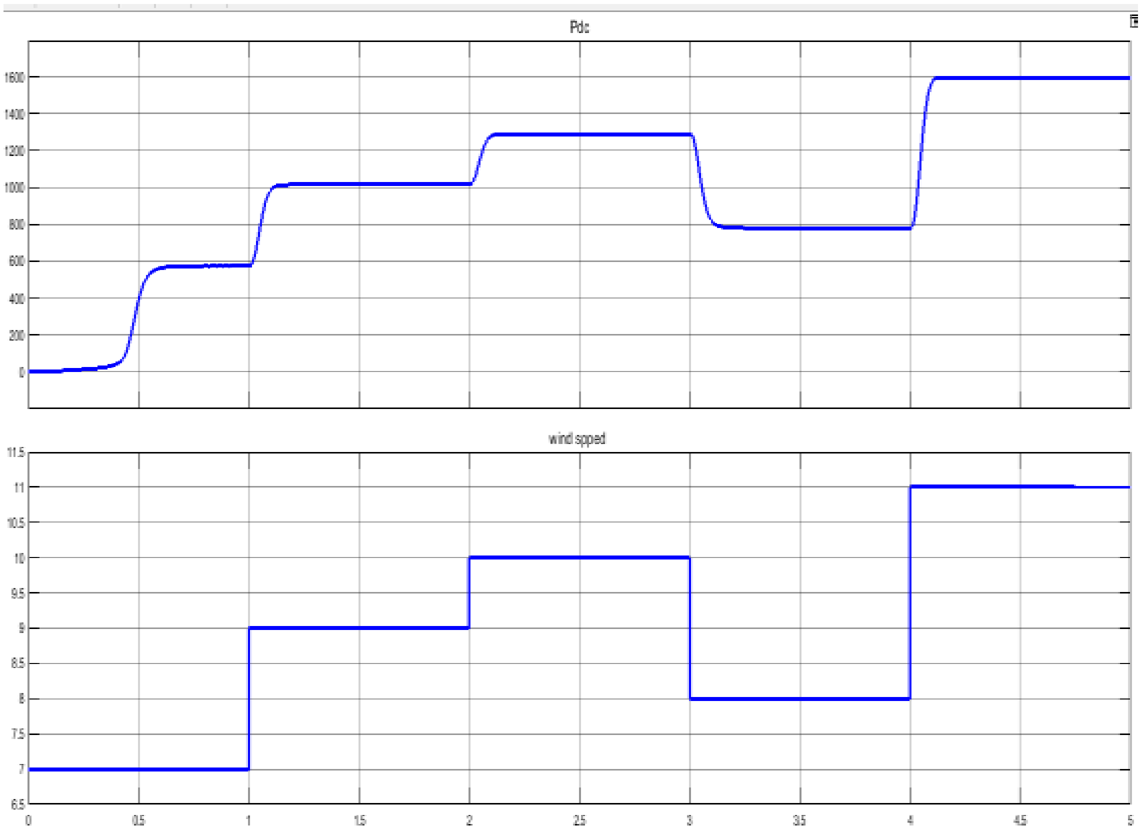

Figure 3.34: DC power with no MPPT

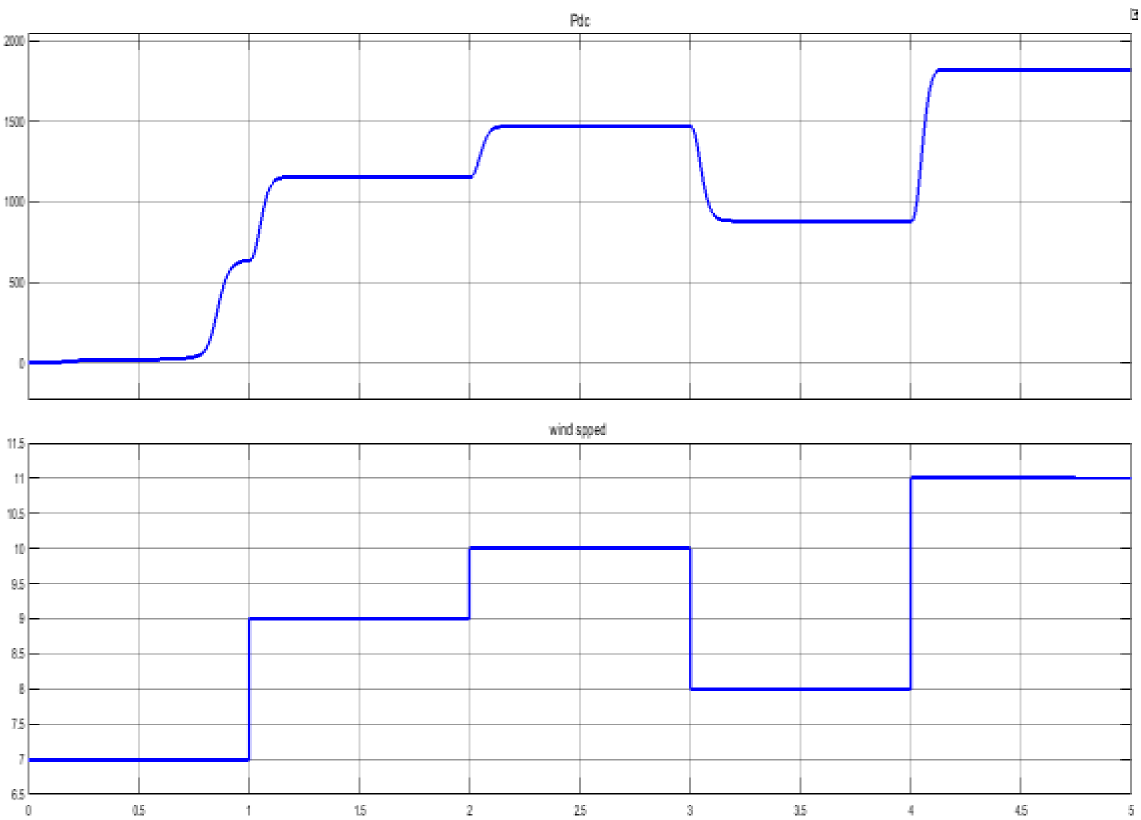

Figure 3.35: DC power with P&O technique

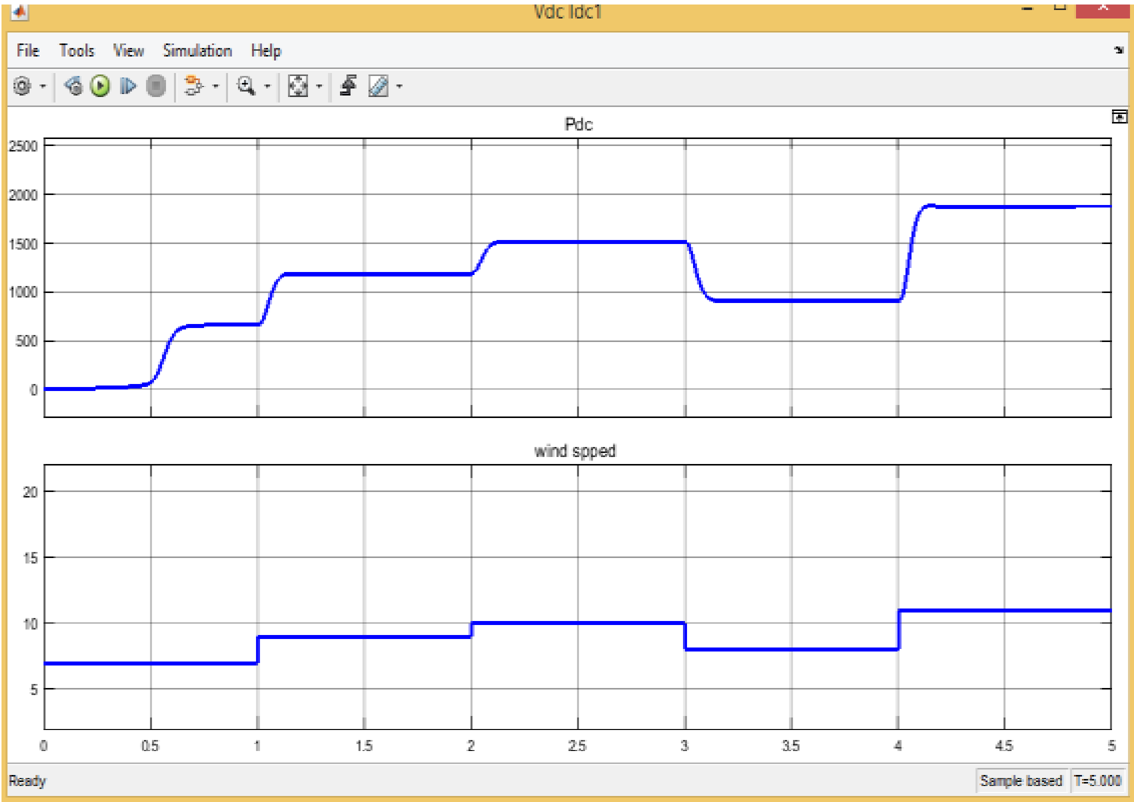

Figure 3.36: DC power with FLC technique

3.4 system configuration of WEC connected to grid:

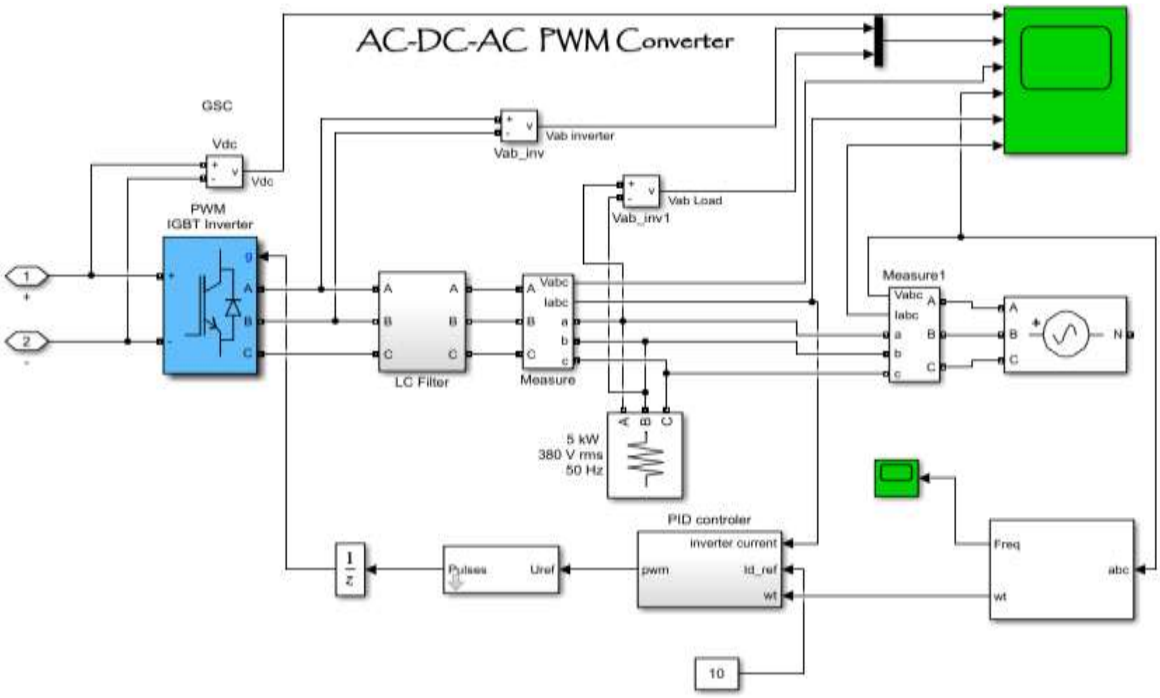

Figure 3.37: grid controller configuration

The results obtained from the controller above **Figure 3.36** are mostly satisfactory yet not so accurate due to different software difficulties in the grid side but finding the solution is our main focus in the future work .

3.5 Discussion and comments:

Based on simulation results we will discuss mainly the properties of our system with and without MPPT and compare them to deduce which method has the best performance:

3.5.1 Power comparison:

As shown above we used different wind speed data to track the performance of each method as accurate as possible and putting the results in a graph will make the comparison more clear

3.5.1.1 Power produced by PMSG

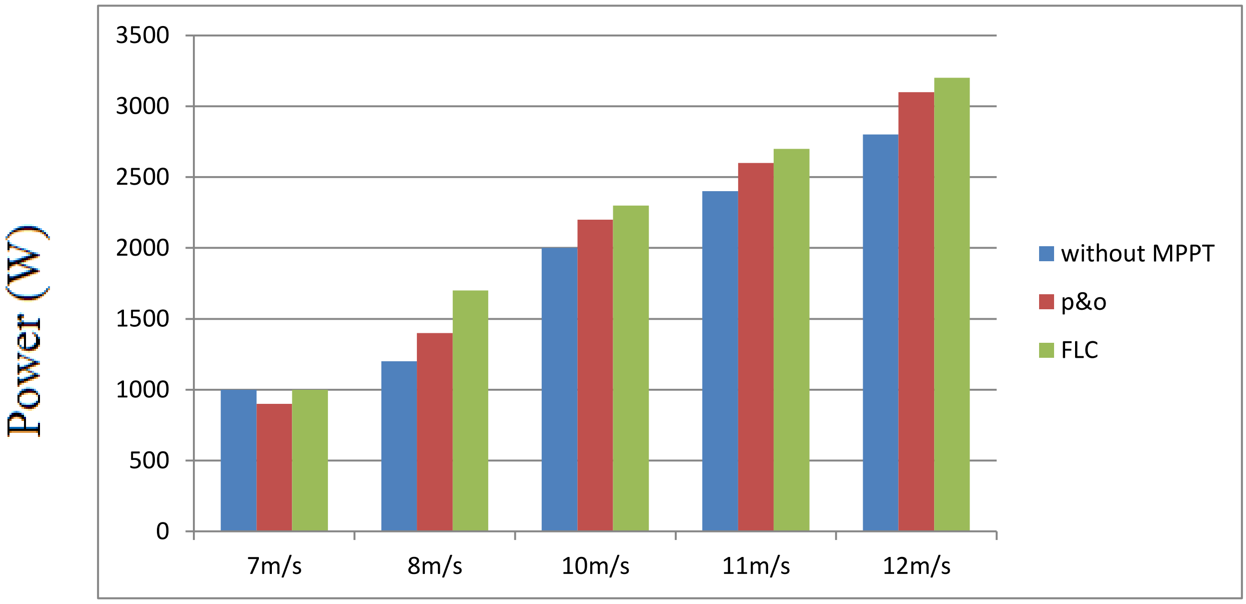

Figure 3.38: power produced by PMSG comparison

The figure **3.38** shows that the power delivered by PMSG is improving with every time we increase the speed to be near the fixed speed we choose (12m/s) also we can clearly see that using the MPPT (P&O,FLC) makes the results more optimized.

3.5.1.2 DC power delivered by the system

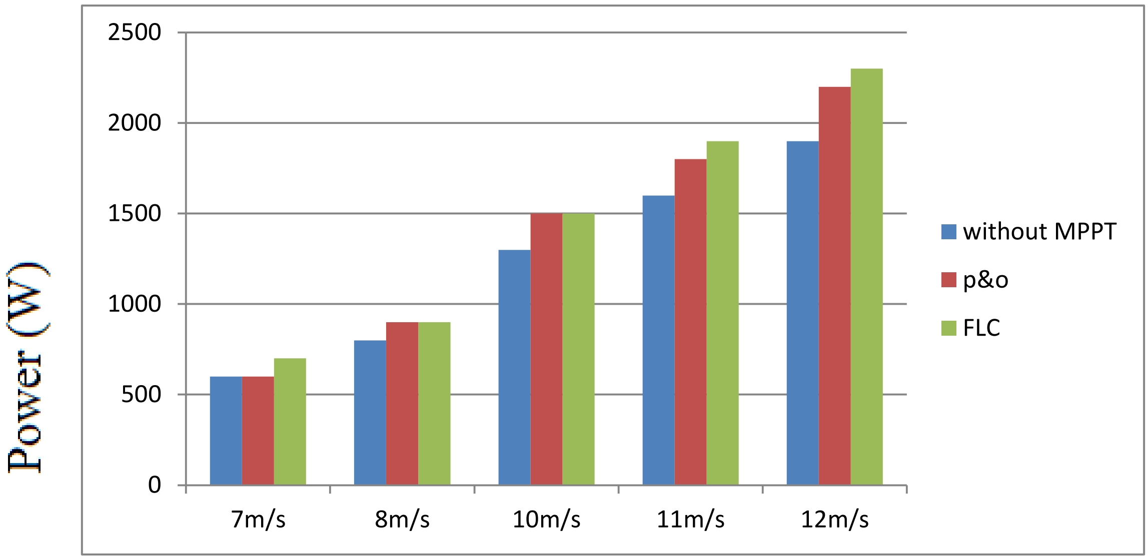

Figure 3.39: DC power delivered by the system

The figure **3.39** shows the power delivered by the system with and without the MPPT in different wind speed data, the simulation results show that the proposed system with MPPT has high accuracy and reliability in comparison with the results without it, Table **3.4** present numerical comparisons between the system results with and without MPPT According to table **3.4**, it is observed that the MPPT approach has higher accuracy in comparison with the system without it.

Table 3.4: power delivered comparison

Wind speed (m/s)	P (w) without MPPT	P(w)P&O	P(w) FLC
7	622	650	704
8	851	922	925
10	1322	1502	1518
11	1674	1817	1944
12	1911	2233	2300

3.5.2 MPPT methods comparison:

For the evaluation of the performance of the FLC and to P&O MPPT controller, in terms of convergence speed, accuracy, and stability (oscillations at the MPP) we got the table **3.5**

Table 3.5: Comparison results

	Convergence speed	stability	Accuracy
P&O	**31 s**	**400w**	**96%**
LFC	**40 s**	**10w**	**97%**

The comparison shows that the P&O MPPT algorithm has a better time response. When it comes to efficiency both algorithms are good and have a high efficiency. Furthermore, the FLC stability is much better than the P&O, but a further improvement is required. In sum, the FLC MPPT algorithm in WECS has a better performance than the P&O MPPT algorithm.

3.6 conclusion:

In This chapter the results of our simulation has been presented. We illustrated the power, the RPM, the voltage and the current of the system with and without MPPT

And with fixed wind speed then variable speed after that we compared these results to deduce the best performance we can get from the MPPT methods which are the main focus in our study; finally we concluded that the MPPT improve the system’s functionality as we presumed.

General Conclusion and Further Work

General Conclusion and Future Work

In this project we have presented the concept of the wind turbine conversion system with PMSG and how the MPPT can improve its performance. First we gave a general idea about the design of a variable-speed wind energy conversion system (WECS) driven by permanent magnet synchronous generator (PMSG), the WECS was direct driven (gearless). Second we discussed the control part which consisted of two levels the wind turbine control and the generator control, in this latter we used the MPPT the main focus in our study, we applied two MPPT methods on machine side to control the input of the boost; thus, control the rotor generator speed which are the perturb and observe and the fuzzy logic control method and we deduced that the FLC has slightly better performance. At last we studied the results of our system using Simulink file in MATLAB, The outcome of this work was mostly achieved, the results obtained from the design of WECS and GSS MPPT were very satisfying, for the grid connection As future work it is intended to add other features to the system to make it more solid and fix most of the errors.

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