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Final Year Project Report Presented in Partial Fulfilment of the Requirements for the Degree of

MASTER

In **Power Engineering**
Option: **Power Engineering**

Title:

Design of Hybrid System based on solar and wind energies .

Presented by:

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Registration Number: ……. /2021

Abstract

Renewable energy is useful energy that is collected from renewable resources, which are naturally replenished on a human timescale, including carbon neutral sources like sunlight, wind, rain, tides, waves, and geothermal heat. This type of energy source stands in contrast to fossil fuels, which are being used far more quickly than they are being replenished. Although most renewable energy is sustainable energy, some is not, for instance biomass energy is unsustainable. Reasons to replace conventional energy with renewable energy are due to the disadvantages of the first one with respect to the seond one. Pollution, cost and sustainability are amongst other advantages which favor the renewable energy source.

The presented system includes solar energy source and wind turbine generator being adopted to feed power to the load. As these sources are intermittent, the diesel energy, as a buck-up, is mostly adopted for remote loads such as villages or irrigation system. For better efficiency of the microgrid, a grid connection common coupling point is provided to absorb the excess of energy. Simulation results of the microgrid with energy management system allow continuously satisfying the load and absorbing the available renewable energy effectively.

Dedication

I have a great pleasure to dedicate this modest work

To my Beloved Mother and my Dear Father

To my Dear Sister, Brother, Uncles, Aunts and Cousins,

To all my Friends,

To all my Teachers from my first year of primary school to my last year of university

LIAMINI Zaidi Takieddine

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Bouchedjira abderrahim

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First and foremost, we are thankful to Allah, the most gracious, the most merciful for helping me finish this modest work. It is our belief in him that helped us persevere at times when it seemed impossible to go on.

Thanks to our beloved parents who have pushed us to overpass all obstacles and hitches we faced in our entire life, their love and guidance are with us in whatever we pursue.

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Table of Contents

List of Tables

List of Figures

List of Abbreviations and Acronyms

RE	Renewable energy
GHG	Greenhouse gas
GDP	Gross domestic product
RESs	Renewable energy sources
HRES	Hybrid renewable energy system
MG	Microgrid
DG	Distributed generation
COE	Cost of energy
HPS	Hybrid power system
MPPT	Maximum power point tracking
PWM	Pulse width modulation
VSC	Voltage source converter
VSI	Voltage source inverter
WECS	Wind energy conversion system
VSWT	Variable speed wind turbine
PMSG	Permenent magnet sychronos generator
TSR	Tip-speed ratio
ORBC	Optimal relationship based control
AVR	Automatic voltage regulator
THD	Total harmonic disturtion

General Introduction

Modern Electrical power systems are facing many challenges in development and expansion. These are no longer limited in technical issues, economic, or financial in nature but are environmental and social. Climate change and sustainable development are major challenges of the 21^{st} century, with extraordinary implications for energy and environmental security.

Providing energy for a community, in a sustainable manner, nowadays has become a more and more important issue as we face global warming and climate change realities. Power generation engineers and designers have a responsibility to improve techniques of energy conversion in order to reduce emissions of CO2 and NOx, which are believed to be a source of environmental degradation. Harnessing renewable energy sources which are abundantly available in nature provides an opportunity to produce energy in an environmentally friendly way. Renewable energy resources like wind, solar, hydropower, biomass and geothermal energy have the potential to overcome these difficulties.

Renewable energies are clean energy sources that have a much lower environmental impact than traditional energy technologies and will never run out. Conventional sources of energy are limited and one day they will run out because their primary energy sources are continuously depleting. On the ground, the world is witnessing more deployment of solar and wind power plants. As a result, traditional fossil fuel and nuclear power plants have become uncompetitive with respect to solar and wind energy sources when considering global worm issues and impact on human health. Therefore, with an appropriate design, combining renewable energy generators can solve these economic and environmental problems.

A hybrid energy system usually consists of two or more energy sources combined to provide increased system efficiency as well as greater balance in the energy supply. Hybrid energy systems are best suited to reduce dependence on fossil fuel using available renewable energy sources. However, there is also disadvantage of using hybrid system such as in most cases the system is over-sized because it contains different types of power generation system and hence an individual engineering study is required for each site where there is an interest in using such a technology.

This study addresses power management of hybrid system based on photovoltaic energy conversion system (PVECS),wind energy conversion system (WECS) and diesel generator. WECS and PVECS are used as primary energy sources, while diesel generator is used as a backup source.Also, PVECS and WECS are controlled to track the maximum power point (MPP). To achieve this, the report is organized in four chapters :

Chapter 1 presents Hybrid renewable energy system in general while chapter 2 deals with photovoltaic energy conversion system. Chapter 3 summerizes the wind energy conversion system and diesel generator while simulation results and their discussion are presented in chapter 4.

CHAPTER 1

Hybride renewable energy system

- *Introduction*
- *Microgrid*
- *Distributed generation*
- *Need for hybrid energy system*
- *Renewable energy-based hybrid power system*
- *Thecnical configuration of hybrid power system*
- *Conclusion*

Hybride renewable energy system

1.1 Introduction

The world is gradually moving toward using more renewable energy (RE) resources for electricity generation. The public awareness of shifting away from carbon-heavy energy sources to environment-friendly green energy sources is highly motivated by the urge to reduce greenhouse gas (GHG) emissions to the environment [1]. This helps to reduce global warming, which causes adverse effects on the climate sur- rounding us. As human civilization is also evolving at a faster rate, the world is experiencing a rise in the overall gross domestic product (GDP). As the GDP is rising along with the increase in population, this will lead to a substantial increase in energy and electricity demand [2]. To address the increasing demand, the electricity generation and distribution systems are getting modernized day by day. Although the fossil fuel resources, for example, crude oil, gas, and coal, are dominating the energy mix and dictate energy markets, the world energy outlook provides a precise idea on how the increasing penetration of renewable energy sources (RESs) will have a higher share in the fuel mix within 2040 [2].

For the last few decades, the scientific community has been expressing huge interest in the development of RE systems to decline the environmental effects [3,4]. RE systems employ energy conversion from RE resources, such as solar energy, wind energy, biomass energy, geothermal energy, and hydro energy for producing electricity. Despite considerable development in technology, yest RESs still suffer from their inherent stochastic nature along with higher kwh prices [5]. Also, the electricity that can be produced from such energy sources varies greatly with locations. Some of these energy sources, for example, wind energy, have fast variation, whereas solar energy can only be extracted in the daytime and thus energy storage option is imperative for some critical applications. The energy density of these sources is another concern for their use to supply the electricity in places having limited space. This leads to a delicate situation for renewable-based stand- alone power systems. No single alternative is absolute and therefore a hybrid renewable energy system (HRES) (a combination of multiple resources) is always preferable as this offers resource diversity, enhanced energy security and individual- ity, system redundancy, and long-term sustainable development [6].

1.2 Microgrid

In the last decades, the concept of MG has been introduced for better controlling the total power network. In other words, an overall grid is divided into the number of MGs to increase the reliability, constancy, control, and the performance of the utulity. The ability to inject the electricity into the system is one of the important differences between the MG and the usual distribution network. Therefore a MG has loads and also some energy sources such as distributed energy resources. Both the production and consumption sides of the MG should be managed optimally based on the technical, economic, and environ- mental indices of the network for improving the performance of the MG [7].

Totally, an MG is a group of produced devices and consumers within clearly considered electrical borders that operate as a single controllable unit with consider- ing the technical indices of the overall power network. Moreover, the MG can be operated in both connected and islanded modes; it means that the MG can have/ haven't a connection with the power network. A sample MG with its connections is demonstrated in Fig. 1.1.

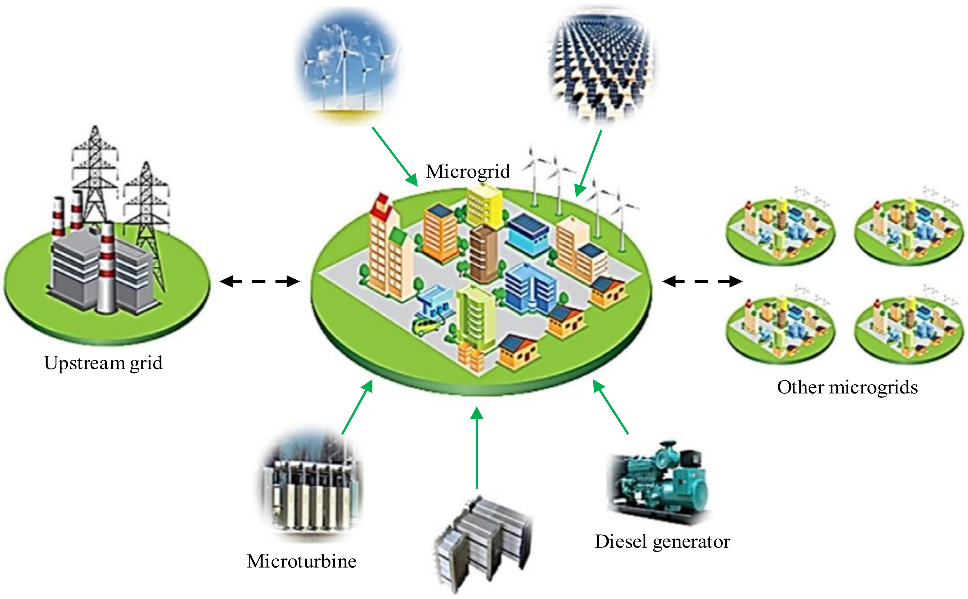

Fig 1.1 *A sample microgrid with its connections*[5].

Hence, MGs are utilized in the power network for improving the local reliabil- ity and flexibility of electric power systems so that the total grid is operated effi- ciently if each of MGs is managed and operated optimally. Although MGs can act in islanded condition, MGs in grid-connected one have a useful ability for pur- chasing electricity from the upstream grid when the demand of consumers is more than the produced power of local renewable and nonrenewable DG technologies. Moreover, the grid-connected MG can inject its extra energy into the grid or other MGs. In this chapter, the grid-connected MG is studied.

1.3 Distributed generation

DG units are one of the important technologies of MGs because the local produc- tion of electricity is the main proviso for calling a system as an MG.

The produced power of distributed energy resources improves the reliability and independence of the MG. The distribution company of MG uses the energy of these technologies for supplying the demand of the MG and selling energy to the upstream network or other MGs. Of course, the distribution company has to buy energy from the upstream grid when the utilized DG units cannot provide the demand of the MG.

DG units have technical, economic, and environmental advantages for both MG and power network. Of course, allocating these energy resources with opti- mum size in the best site affects the performance of them. Technical advantages of DG units consist of several issues such as decreasing the dependence of the MG on the power of the upstream network, increasing the voltage profile, and improving the stability of the power network. The major technical benefits of DG units are presented in Fig. 1.2. Saving transmission and distribution costs and reducing the consumption of world fuel are the samples of economic benefits of distributed energy resources. Fig. 1.3 demonstrates the major economic advan- tages of this type of energy source. Based on environmental aspects such as reducing greenhouse gases, decreasing noises, and saving the natural sources for other applications, renewable DG units are more useful than nonrenewable ones [8],[9].

Totally, DG units can be divided into nonrenewable and renewable units. The output power of nonrenewable DGs depends on their primary fuel and demand of the system; so their power is stable. But the output power of renewable technologies is unstable due to their dependence on the weather conditions. The following sections are dedicated to the description and modeling of nonrenewable energy sources including diesel generator, microturbine, and fuel cell and also renewable technologies including wind turbines and solar panels [8],[10].

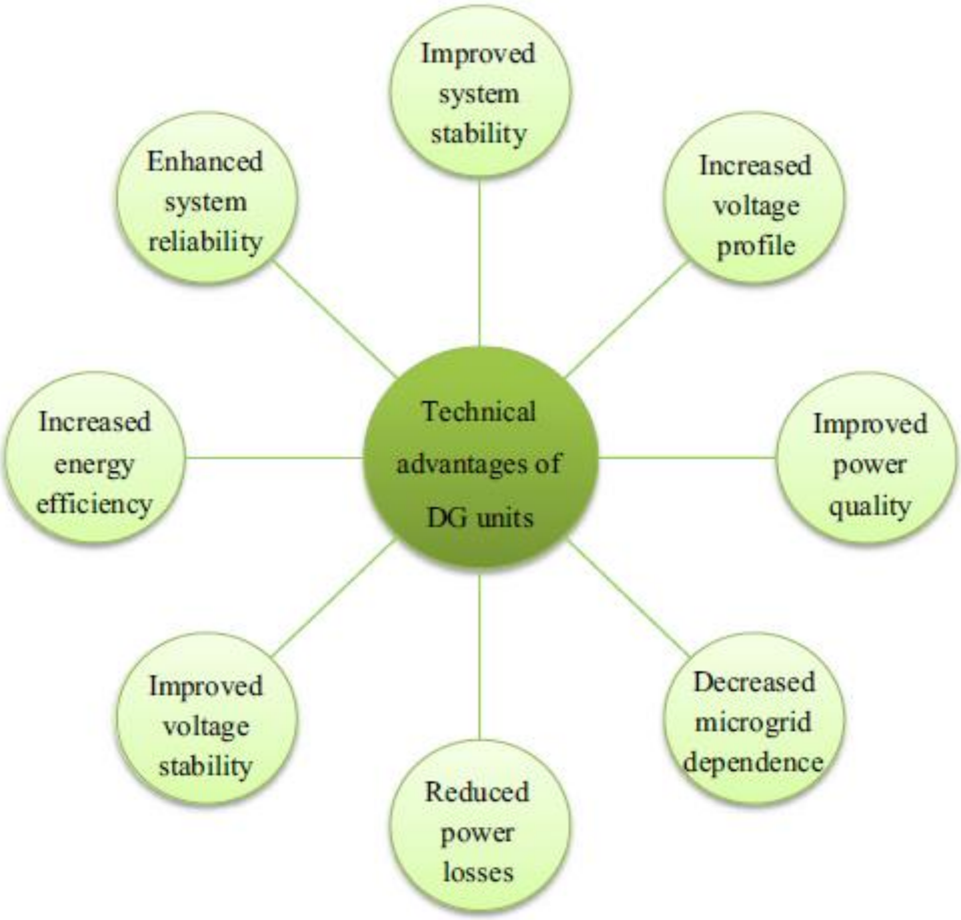

Fig 1.2 The major technical advantages of distributed generation units[8].

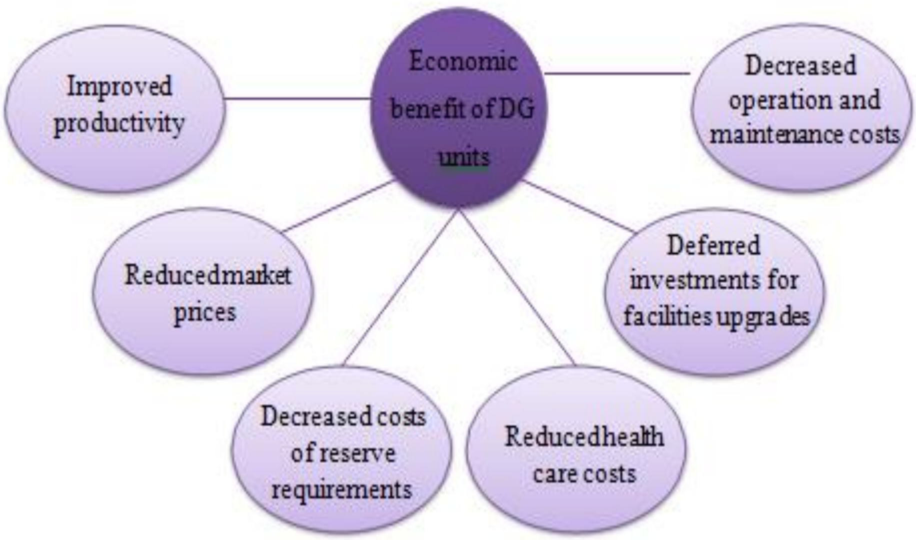

Fig 1.3 The major economic benefits of distributed energy sources.[8].

1.3.1 Diesel generator

A diesel generator utilizes a diesel engine and electric generator to generate electri- cal energy. Liquid fuels or natural gas are usually used as the primary fuel of the diesel generator. Totally, a diesel generator works based on air compression and the fuel. First, the air is blown into the generator until it is compressed. Subsequently, the proper fuel of diesel generator is injected. The combination of air compression and subsequent injection of the fuel will contribute to generate the heat that triggers the inflammation of the fuel. In this way the diesel generator starts combustion and causes the generator to start up. Thus the generator starts to produce the necessary electrical energy to be distributed according to the needs of the MG (loads) con- nected to the diesel generator. A sample diagram of diesel generator is shown in Fig. 1.4.

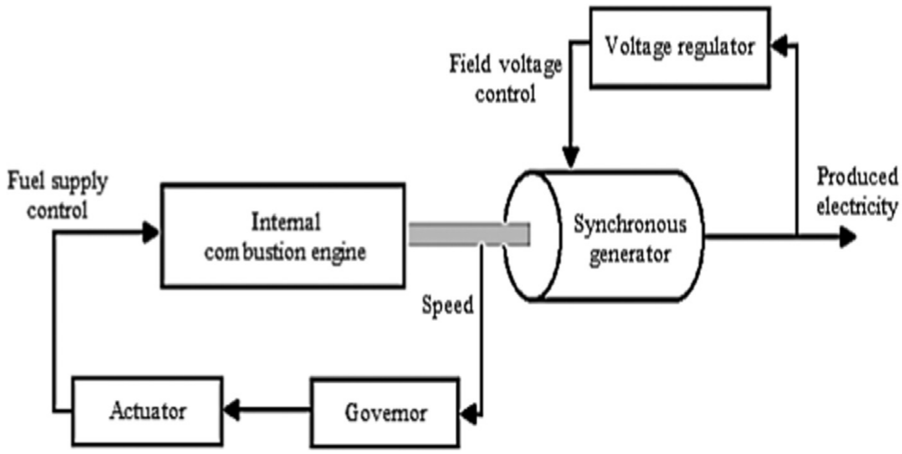

Fig 1.4 *The sample diagram of diesel generator*.[11].

The diesel generator can produce electrical energy according to the demand of the MG. The output power of a diesel generator can be changed based on the load variation of the MG. The diesel generator has the ability to simultaneously inject both active and reactive powers. Hence, in the mathematical equations of the system, the diesel generator is considered as a PQ bus that injects both active and reactive power into the system. Fig. 1.5 demonstrates the detail of the active and reactive power of a bus of the MG in the presence of a diesel generator. Inthis chapter the power factor of the diesel generator is considered equal to 0.85[11].

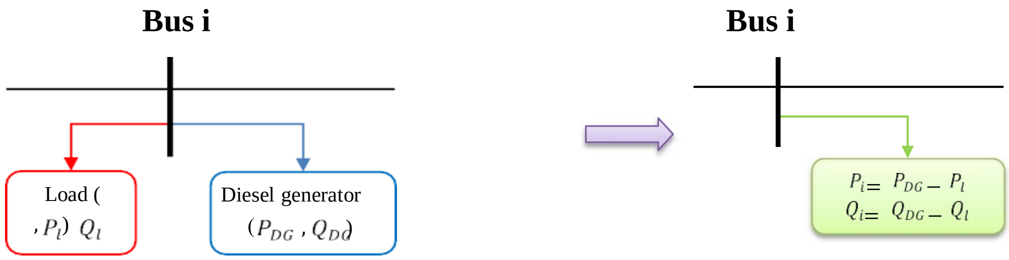

Fig 1.5 *The active and reactive power of a bus with diesel generator.*[11].

1.3.2 Wind turbine

Renewable wind energy is approximately available in most parts of the world during the year. For this reason, it is one of the proper sources for producing electricity. The technology that is used to convert wind energy into electrical energy is called the wind turbine. The operational procedure of a wind turbine is based on a simple prin- ciple. The energy in the wind spins two or three blades around a rotor (turbine). The turbine is connected to the main shaft, which turns a generator for producing the elec- tricity. A sample diagram of the wind turbine is shown in Fig. 1.6.

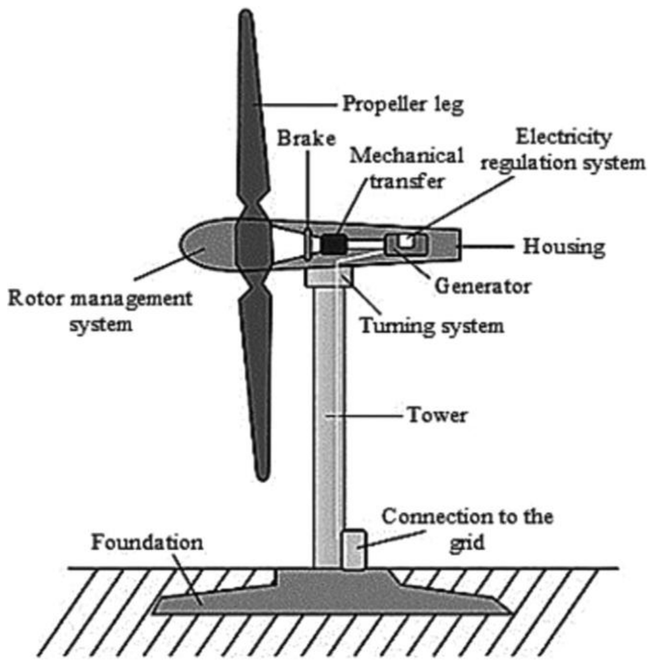

Fig 1.6 *The sample diagram of wind turbines.*[11].

Wind turbines work based on a simple principle called wind. The wind turns the blades of the wind turbine and causes to spin rotor and generator. Thus the electrical power is produced. Totally, wind turbines are divided into two categories—horizontal- and vertical-axis turbines. The horizontal-axis turbines usually have three blades and operate upwind. The turbine of this type pivots at the top of the tower so the blades face into the wind. The vertical-axis turbines are omnidirectional. It means that they do not need to be adjusted to point into the wind to operate. The horizontal technologies are more popular than vertical ones. .[11]

Wind speed and swept area of the turbine affect the produced electrical energy of the wind turbine. Moreover, air density and power coefficient affect the power of wind turbine. It is worth mentioning that it uses reactive power to inject active power due to its induction generator. Therefore wind turbine can be modeled as a PQ model with changeable reactive power in the mathematical equations of the MG. The consumed reactive power of this renewable technology is presented in the following equation:

$$Q_{WT} = -(0.5 + 0.04P_{WT}{}^2)$$

where P_{WT} and Q_{WT} are the injected active power and consumed reactive power of the wind turbine, respectively. The detail of the active and reactive power of a bus of the MG in the presence of a wind turbine is demonstrated in Fig. 1.7.

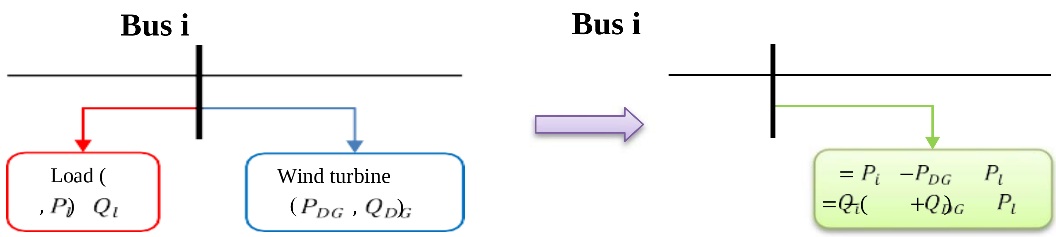

Fig 1.7 *The active and reactive power of a bus with wind turbine.*[11]

1.3.3 Photovoltaic panel

Photovoltaic is one of the popular technologies of renewable DG units, especially in the MGs. The photovoltaic panel is a solar system that utilizes solar cells or solar photovol- taic arrays to turn directly the solar irradiance into electrical power. In other words, photons of light are absorbed in photovoltaic arrays and thus electrons are released in the panel. When they are captured in photovoltaic arrays, the electric current is produced in the panel. The sample diagram of photovoltaic panels is demonstrated in Fig. 1.8.

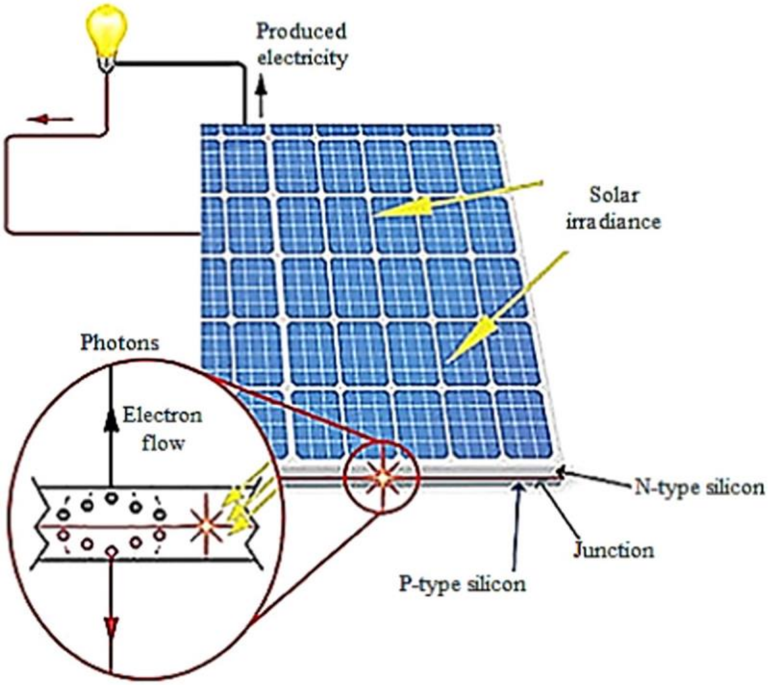

Fig 1.8 *The sample diagram of a photovoltaic panel.*

Basically, the photovoltaic panel works based on the sunlight. The light from the Sun falls onto a photovoltaic panel and creates an electric current through a process called the photovoltaic effect. Each panel generates a relatively small amount of elec- tricity, but panels can be connected together to produce higher amounts of energy as a current that can be used in many electronic devices such as phones and laptops. Of course, it is better that the solar electricity to be converted from direct current to alter- nating current using an inverter. Thus the alternating current of photovoltaic panel can be used to power local electronic devices or be injected into the MG for use elsewhere. Photovoltaic panels are the practical choice for providing the electricity demand of remote areas and the MGs due to the availability of solar energy approximately all points of the world. The produced power of photovoltaic panels is related to the level of solar irradiance, the area, and efficiency of the panel. Moreover, a photovoltaic panel can only produce active power. Hence, in the mathematical equations of the system, it is simulated as a P model. Fig. 1.9 shows the detail of the active and reactive power of a bus of the MG in the presence of a photovoltaic panel[11].

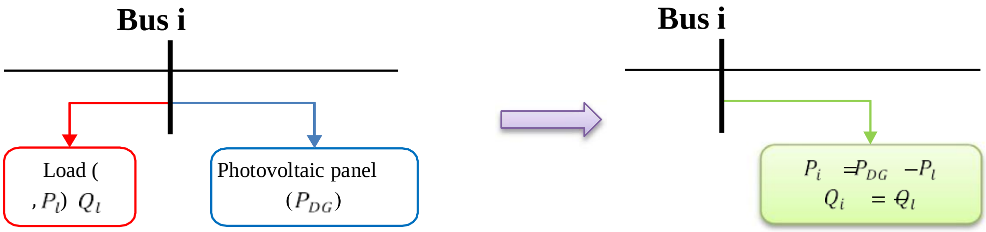

Fig1.9 *The active and reactive power of a bus with photovoltaic panel.*[11].

1.4 Need for hybrid energy system

One of the most promising applications of renewable energy technology is the installation of hybrid energy systems in remote areas, where the grid extension is costly and the cost of fuel increases. Recent research and development in Renewable energy sources have shown excellent potential, as a form of supplementary contribution to conventional power generation systems.

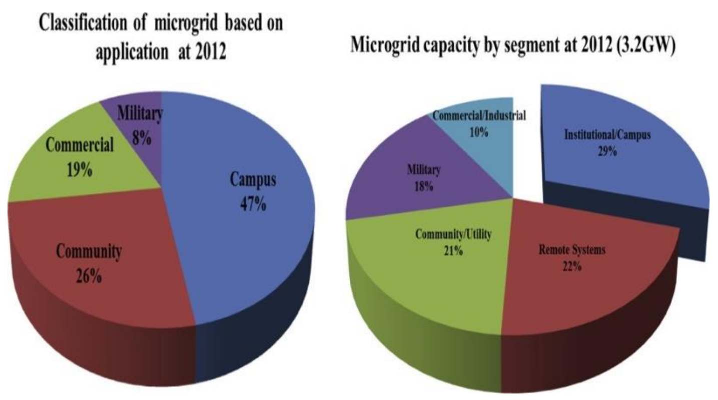

Fig. 1.10 *The classification of micro-grid based on application*[13].

In order to meet sustained load demands during varying natural conditions, different energy sources and converters need to be integrated with each other for extended usage of alternative energy. Renewable energy sources, such as photovoltaic, wind energy, or small scale hydro, provide a realistic alternative to engine-driven generators for electricity generation in remote areas. It has been demonstrated that hybrid energy systems can significantly reduce the total lifecycle cost of standalone power supplies in many situations, while at the same time providing a more reliable supply of electricity through the combination of energy sources [12].

Solar and wind energy are non-depletable, site dependent, non-polluting, and possible sources of alternative energy choices. Many countries with an average wind speed in the range of 5–10 m/s and average solar insolation level in the range of 3–6 KWh/m2 are pursuing the option of wind and PV system to minimize their dependence on fossil-based non-renewable fuels. A merging of solar and wind energy into a hybrid generating system can attenuate their individual fluctuations, increase overall energy output, and reduce energy storage requirement significantly. It has been shown that because of this arrangement, the overall expense for the autonomous renewable system may be reduced drastically [13].

Nowadays, the integration of PV and wind system with battery storage and diesel backup system is becoming a viable, cost-effective approach for remote area electrification. Wind and solar systems are expandable, additional capacity may be added as the need arises. Moreover, the combination of wind and solar PV system shrinks the battery bank requirement and further reduces diesel consumption [13].

The prospects of derivation of power from hybrid energy systems are proving to be very promising worldwide. The use of hybrid energy systems also reduces combustion of fossil fuels and consequent CO2 emission which is the principle cause of greenhouse effect/global warming. The global warming is an international environmental concern which has become a decisive factor in energy planning. In wake of this problem and as a remedial measure, strong support is expected from renewables such as solar and winds. The PV–wind hybrid energy system using battery bank and a diesel generator as a back-up can be provided to electrify the remotely located communities (that need an independent source of electrical power) where it is uneconomical to extend the conventional utility grid. All possible advantages of a hybrid energy system can be achieved only when the system is designed and operated appropriately [13].

1.5 Renewable energy-based hybrid power system

HRESs provide a solution to many challenges that a single RES-based standalone power system poses. HRES could be referred to as an electricity-generating system having more than one energy source, at least one of them being an RES. A HRES may consist of RE conversion technology, conventional energy conversion technol- ogy (often fossil fuel), and energy storage devices [14]. By combining two or more RE generation technologies in an HRES utilizes the appropriate use of their respec- tive operational characteristics to obtain higher efficiency than a single-source energy system [15]. A hybrid power system is usually a low-voltage power distribu- tion system that can operate as an off-grid system. The cost of energy (COE), reli- ability, power quality access to remote or islanded areas, energy efficiency, extractable clean RE, and climate change mitigation are the key factors for the rapid deployment of HRESs [16]. Fig. 1.11 shows a basic schematic diagram of HRESs where electricity is supplied to the energy storage device from conventional and RESs, which will then be supplied to the load as required.

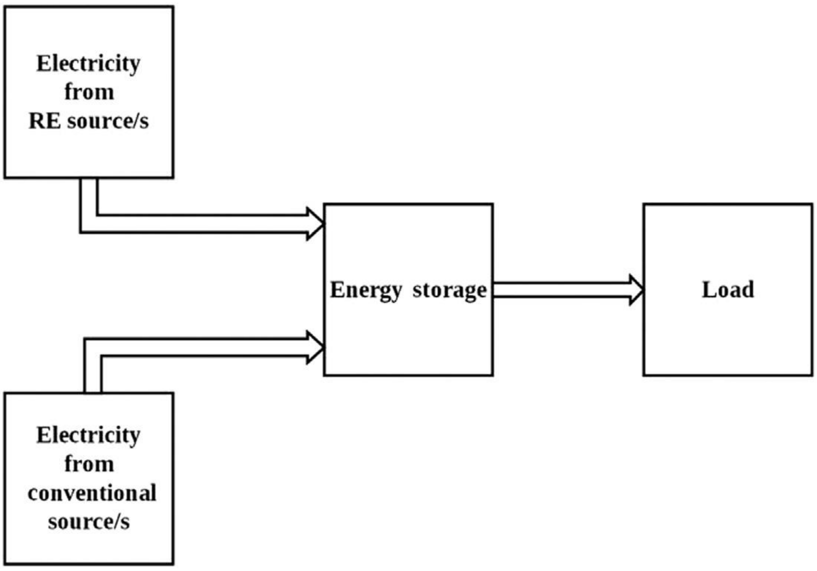

Fig 1.11 *General schematic diagram of a hybrid renewable energy system with energy storage*[17].

HRESs have the potential to provide reliable electricity to the end users, espe- cially in microgrids operating in remote localities [17]. Diesel is often incorporated in HRESs to supply partial load demand due to its reliable nature and economy of scale [18]. Having different intermittent RESs in the hybrid RESs can complement each other when optimized, from technical and economic perspectives, for a partic- ular load scenario. This type of energy system can, in fact, be used to provide the electricity with lower cost, high system efficiency, and lower environmental emis- sion [17].

1.6 Thecnical configuration of hybrid power system

The hybrid system can be designed following different configurations to effectively use the locally available renewable energy sources and to serve all power appliances.

1.6.1 AC/DC-coupled Hybrid Power Systems

For the hybrid power system whose demand is to be supplied from wind turbine, PV system, a diesel generator and a battery, different configurations are explained in [19], [20], [21]. In general, there are three accepted categories hybrid system technological configurations according to the voltage they are coupled with each other and the load. These are:

- AC-coupled hybrid power systems.
- DC-coupled hybrid power systems.
- Mixed-coupled hybrid power systems.

1.6.2 AC-coupled Hybrid Power Systems

With this type of configuration, the different HPSs are connected at the AC-buswith the load. The AC coupled HPSs are further divided into two sub-topologies.

- Centralized AC-coupled HPSs.
- Distributed AC-coupled HPSs.

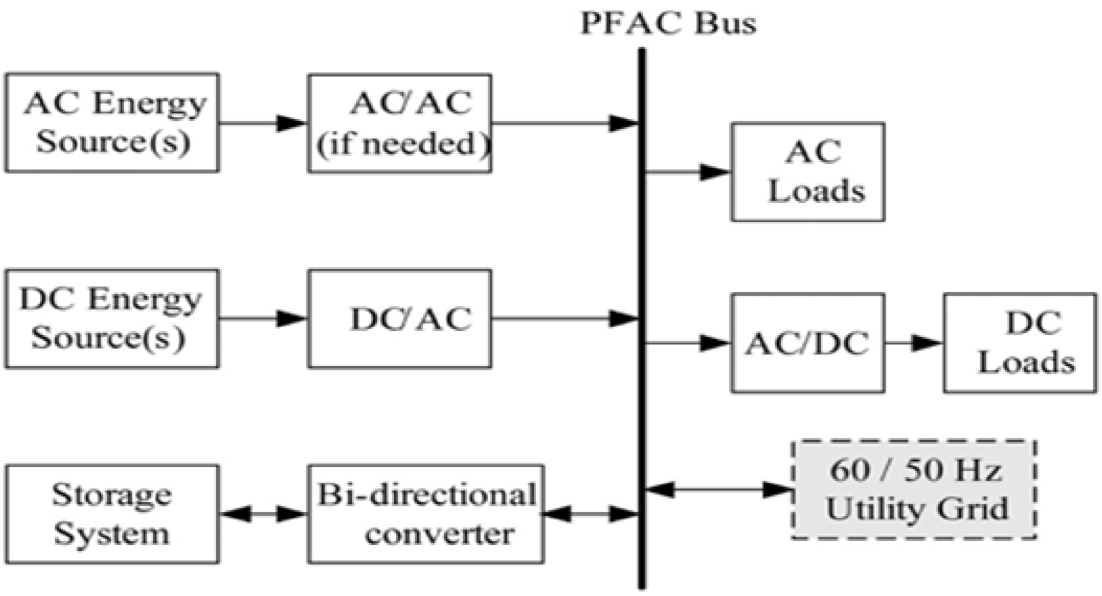

Fig 1.12 *Schematic diagram of a AC-coupled hybrid energy system.*[20].

1.6.3 DC-Coupled Hybrid Power Systems

In DC-coupled HPSs configuration, all the electrical circuits, unlike AC-coupledHPSs, are connected to a DC main bus before being connected to the load. Connection with the AC loads is done through a main inverter.

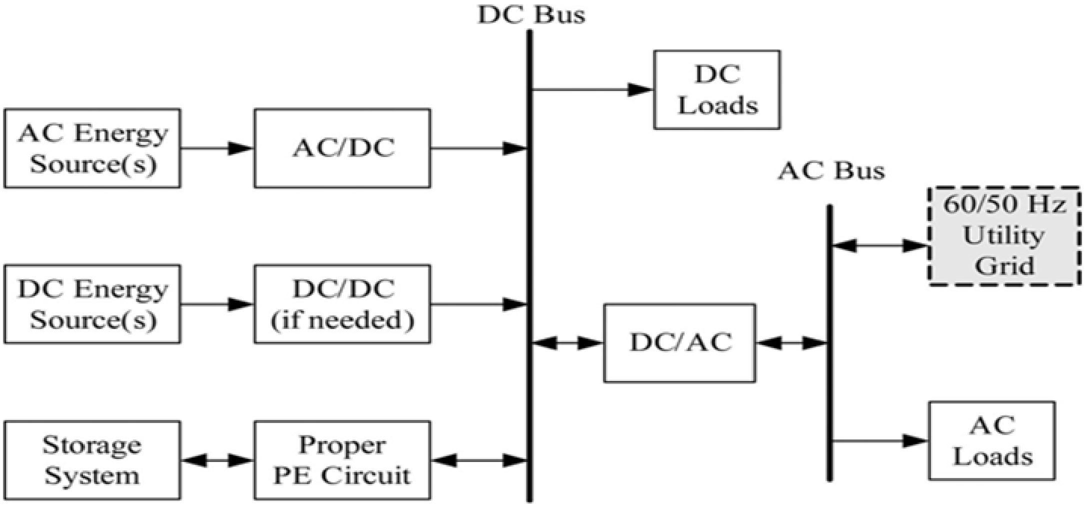

Fig.1.13 *Schematic diagram of a DC-coupled hybrid energy system.*[20]

1.6.4 Mixed-coupled Hybrid Power Systems

It is also possible to combine AC-coupled and DC-coupled hybrid power systems and form mixed hybrid power system. With this type of configuration, some of the renewable energy sources (PV-array, in this case) are connected with the battery bank atthe DC-bus and other RESs (wind turbine, in this case) are connected with the generatorat the AC-bus.

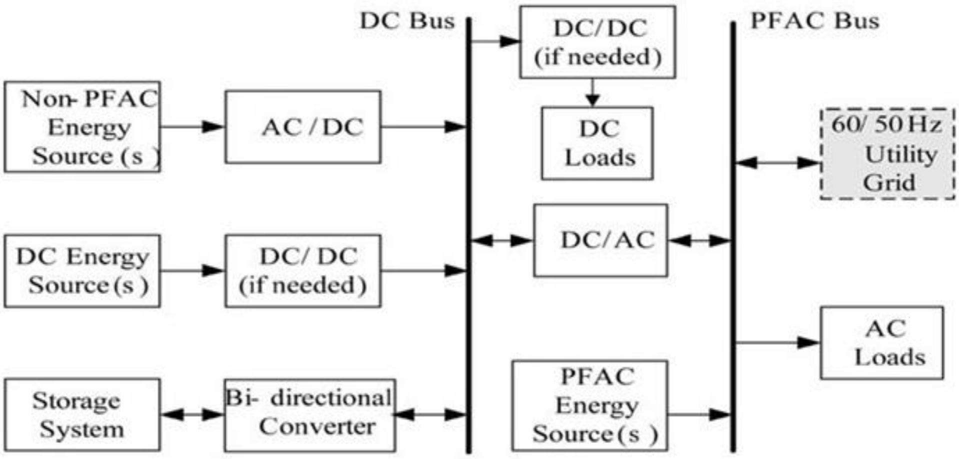

Fig 1.14 *Schematic diagram of a hybrid-coupled hybrid energy system*[20].

1.6.5 Grid connected versus stand-alone HPS

HPSs can be also categorized into two other categories depending on their final stage connection. The two systems are explained in detail in [22].

- **Stand-alone HPS**

the final stage of this system is the load and it must have some means of energy storage and buck source. The major application of the stand-alone power system is in remote area where utility lines are uneconomical to install due to terrain.

- **Grid connected HPS**

from its name we can tell that the system is connected to the utility grid, this last providespower to the site loads when needed, or absorbs the excess power from the site when available. The utility interconnection brings a new dimension in the renewable power economy by pooling the temporal excess or the shortfall in the renewable power with theconnecting grid. This

improves the overall economy and the load availability of the renewable plant; the two important factors of any power system.

1.7 Conclusion

The renewable energy sources are cost effective, user-friendly, they can easily beat the fossil fuels. By promoting renewable energy sources, we can avoid, air pollution, soil pollution and water pollution. Country's economy will increase. Throughout the year these sources are available without affecting the Environment. . Solar and wind energy sources are pooled to form a hybrid renewable energy grid with other sources. Hence, greater efficiency in power production can be achieved by making the best use of their advantages to overcome their limitations.

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CHAPTER 2

Photovoltaic Energy Conversion System

- *Introduction*
- *PV cell , module and array*
- *Maximum Power Point Tracking MPPT*
- *Direct MPPT methods*
- *Three-phase , three-level voltage source converter*
- *Phase-locked loop(PLL)*
- *Simulation and results*
- *Conclusion*

Photovoltaic Energy Conversion System

2.1 Introduction

Photovoltaic systems are used in a wide range of applications and can be designed in a range of configurations, including grid-connected or stand-alone.In general it converts sunlight into electricity . This chapter deals with the theoretical background of each element of a stand-alone Photovoltaic Energy Conversion system and the basic operation of solar cells and structure will be introduced in details, along with mathematical equations and model.Finally , the simulation results will be given in details .

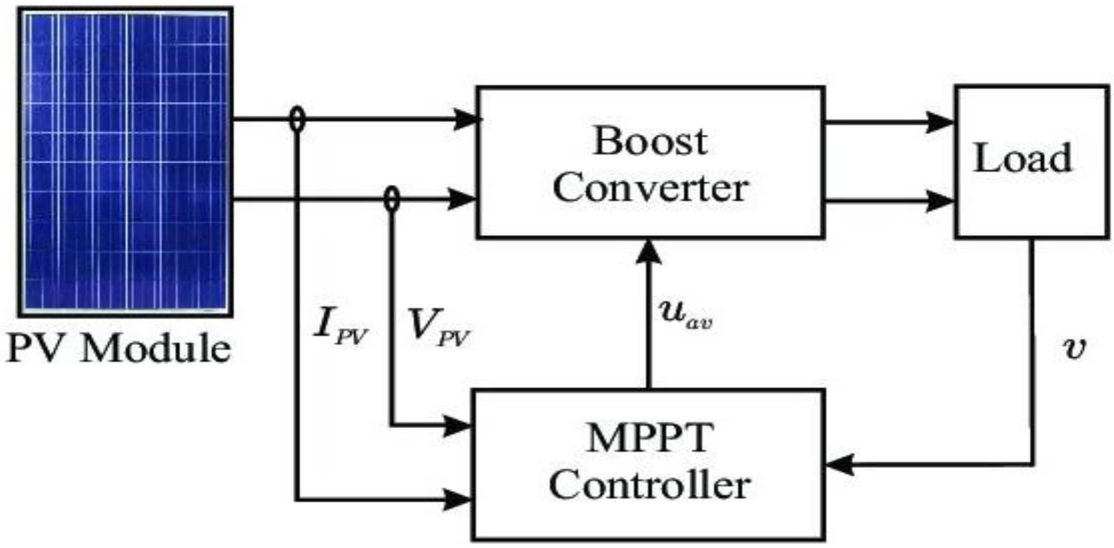


Figure 2. 1: *Schematic diagram of PVECS*[23].

2.2 PV cell , module and array

2.2.1 PV cell

A solar cell is an electronic device which directly converts sunlight into electricity. Light shining on the solar cell produces both a current and a voltage to generate electric power. This process requires firstly, a material in which the absorption of light raises an electron to a higher energy state, and secondly, the movement of this higher energy electron from the solar cell into an external circuit. The electron then dissipates its energy in the external circuit and returns to the solar cell. A variety of materials and processes can potentially satisfy the requirements for photovoltaic energy conversion, but in practice nearly all photovoltaic energy conversion uses semiconductor materials in the form of a *p-n* junction.[23].

A PV cell can be represented by a current source connected in parallel with a diode, since it generates current when it is illuminated and acts as a diode when it is not. The equivalent circuit model also includes a shunt and series internal resistance that can be represented by resistors R_s and R_{sh} as shown in Fig. 2.

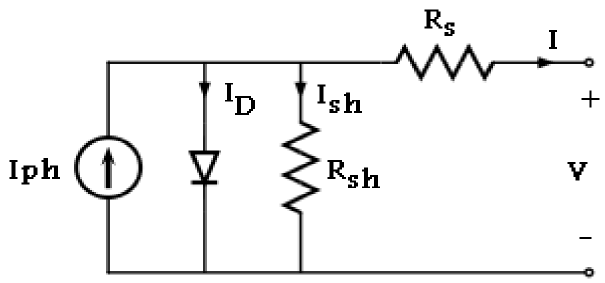


***Fig 2.2** PV cell equivalent circuit.*[23].

The physical structure of a solar cell is similar to that of a diode in which the p–n junction is subjected to sun exposure. The basic semi-conductor theory is captured in the following equations :

$$I = I_{ph,cell} - I_D \text{ ....} (2.1)$$

$$I_D = I_{o,cell} * exp\left[\left(\frac{qV}{KT_c}\right) - 1\right] \text{ ....}(2.2)$$

Where

I: Cell output current, A.

$I_{ph,cell}$: The Photocurrent, is the current produced by the incident light and function of irradiation level and junction temperature, A.

I_D : The diode current modeled by the equation for a Shockley diode, A.

$I_{o,cell}$: The saturated reverse current or leakage current, A.

q : Electron charge (1.602×10^{19} C).

K : Boltzmann constant (1.38 x 10 -23 J/^{o}k) V : Cell output voltage V.

T_c: Cell operating temperature, ^{o}kA : The diode ideality factor.

Eq. (1, 2) can be modified to obtain the current–voltage characteristics of a photovoltaic cell employed in the solar panel by adding some parameters as given in Equations (3, 5,6)[23, 24].

$$I = I_{ph} - I_o * exp\left[\left(\frac{(V+IR_s)}{\alpha K T_c}\right) - 1\right] - \left(\frac{V+IR_s}{R_{sh}}\right) \text{..............}(2.3)$$

With :

$$I_{ph} = \frac{G}{G_n} * (I_{phn} + K_i * (T - T_n)) \ldots\ldots (2.4)$$

$$I = \frac{\alpha K T_c}{q} * ln \left[\frac{I_{ph} + I_o - I}{I_o}\right] - IR_s \ldots\ldots (2.5)$$

$$I = I_{ph} - I_o * exp \left[\left(\frac{q(V + IR_s)}{\alpha V_t}\right) - 1\right] - \left[\frac{V + IR_s}{R_{sh}}\right] \ldots\ldots (2.6)$$

$$I_o = \frac{I_{scn} + K_i * (T - T_n)}{\frac{V_{ocn} + K_v * (T - T_n)}{\alpha V_t}} \ldots\ldots (2.7)$$

$$V_t = \frac{N_s K T_c}{q} \ldots\ldots (2.8)$$

Where:

I_{ph}: Photocurrent, The photovoltaic current, A.

Iphn: nominal photon current at STC.

I_o : Reverse saturation current, A

R_s : Series resistance of the cell, **Ω**

R_{sh}: Shunt resistance of the cell, **Ω**

V_t: Thermal voltage, V.

α: Ideality factor [1.6 for silicon].

N_s : Number of series cells.

N_p : Number of parallel cells branches.

Rsh: Shunt resistance in Ω.

Rs: Series resistance in Ω.

Ki: Short circuit current temperature coefficient.

Kv: open circuit voltage temperature coefficient at Isc.

G: Solar irradiation in 1 KW/m2.

Gn: Solar irradiation in KW/m2.

Iscn: is the nominal short circuit current at STC.

Vocn: is the nominal open circuit voltage at STC.

Both K and T_c should have the same temperature unit, in Kelvin.

2.2.2 PV module

A PV module consists of many PV cells wired in parallel to increase current and in series to produce a higher voltage. 36 cell modules are the industry standard for large power production.[25].

The module is encapsulated with tempered glass (or some other transparent material) on the front surface, and with a protective and waterproof material on the back surface. The edges are sealed for weatherproofing, and there is often an aluminum frame holding everything together in a mountable unit. In the back of the module there is a junction box, or wire leads, providing electrical connections.There are currently four commercial production technologies for PV Modules:

Single Crystalline

This is the oldest and more expensive production technique, but it's also the most efficient sunlight conversion technology available. Module efficiency averages about 10% to 12%*

Polycrystalline or Multicrystalline

This has a slightly lower conversion efficiency compared to single crystalline but manufacturing costs are also lower. Module efficiency averages about 10% to 11%.

String Ribbon

This is a refinement of polycrystalline production, there is less work in production so costs are even lower. Module efficiency averages 7% to 8%.

Amorphous or Thin Film

Silicon material is vaporized and deposited on glass or stainless steel. The cost is lower than any other method. Module efficiency averages 5% to 7%.)[26].

The performance of PV modules and arrays are generally rated according to their maximum DC power output (watts) under Standard Test Conditions (STC). Standard Test Conditions are defined by a module (cell) operating temperature of 25o C (77 F), and incident solar irradiant level of 1000 W/m2 and under Air Mass 1.5 spectral distribution. Since these conditions are not always typical of how PV modules and arrays operate in the field, actual performance is usually 85 to 90 percent of the STC rating.

Today's photovoltaic modules are extremely safe and reliable products, with minimal failure rates and projected service lifetimes of 20 to 30 years. Most major manufacturers offer warranties of twenty or more years for maintaining a high percentage of initial rated power output. When selecting PV modules, look for the product listing (UL), qualification testing and warranty information in the module manufacturer's specifications. Large 72-cell modules are now quite common, some of which have all of the cells wired in series, in which case theyare referred to as 24-V modules. The following equation characterized its I – V relations:

$$I = I_{ph} - I_o * exp\left[\left(\frac{(V+IR_s)}{\alpha V_t N_s}\right) - 1\right] - \left(\frac{V+IR_s}{R_{sh}}\right) \text{........(2.9)}$$

To increase total voltage of the module, cells have to be connected in series as shown in Fig. 3 ($V_{out}=V_1+V_2+V_3+\ldots$). Connecting PV cells in parallel, as shown in Fig. 4, increases the total current generated by the module ($I_{out}=I_1+I_2+I_3+\ldots$). The total current is equal to sum of current produced by each cell. [26,27].

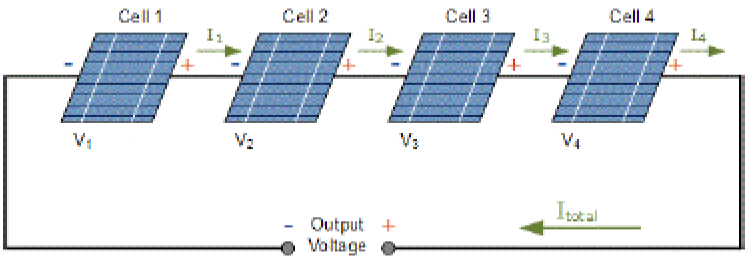


***Fig 2.3** Connecting PV cell in series.*[27]

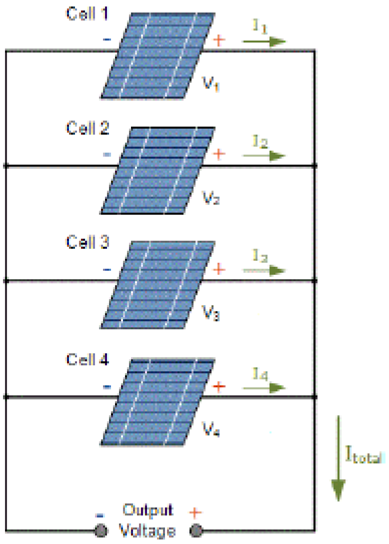


***Fig 2.4** Connecting PV cell in parallel.*[27].

For N_p cells branches in parallel and N_s cells in series, the total shunt resistances ($R_{sh,Module}$) and series resistances ($R_{s,Module}$) in module are equal to:

$$R_{sh,module} = \frac{N_p}{N_s} R_{sh,cell} \quad (2.10)$$

$$R_{s,module} = \frac{N_s}{N_p} R_{s,cell} \quad (2.11)$$

Where :

$R_{sh,Module}$: Total shunt resistance in the photovoltaic module, Ohm.

$R_{s,Module}$: Total series resistance in the photovoltaic module, Ohm.

$R_{sh,Cell}$: Shunt resistance in one photovoltaic cell, Ohm.

$R_{s,Cell}$: Series resistance in one photovoltaic cell, Ohm.

N_s: Number of cells in series

N_p: Number of cells branches in parallel.

2.2.3 PV array

A PV Array consists of a number of individual PV modules or panels that have been wired together in a series and/or parallel to deliver the voltage and amperage a particular system requires. An array can be as small as a single pair of modules, or large enough to cover acres.12 volt module is the industry standard for battery charging. Arrays are made up of some combination of series and parallel modules to increase power.

For modules in series, the I – V curves are simply added along the voltage axis, at any given current (which flows through each of the modules), the total voltage is just the sum of the individual module voltages. [28,29].

For modules in parallel, the same voltage is across each module and the total current is the sum of the currents. That is, at any given voltage, the I – V curve of the parallel combination is just the sum of the individual module currents at that voltage [30].The equivalent circuit of solar array is shown in the next page :

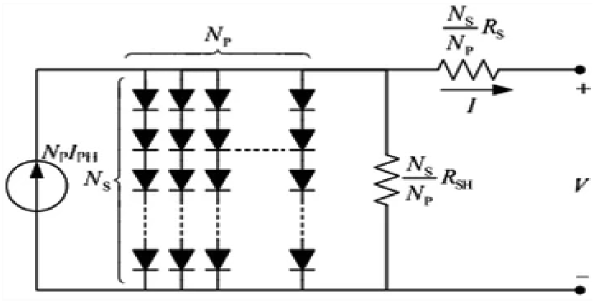


Fig 2.5 *Equivalent circuit of solar array.* [29]

The following equation characterized its I – V relations:

$$I = N_{pp} * I_{ph} - N_{pp} * I_o \; * \; exp \left[\left(\frac{V+IR_s}{N_{pp}N_s}\right)\left(\frac{1}{\alpha V_t * N_s}\right) - 1\right] - \left(\frac{V\frac{N_{ss}}{N_{pp}}+IR_s}{R_{sh}}\right) \quad \text{……..(2.12)}$$

Where:

Npp: is the number of modules connected in parallel,

Nss: is the number of modules connected in series.

2.3 Maximum Power Point Tracking MPPT

Maximum power point tracking (MPPT) is a technique that ensures the maximum power extraction from non-linear energy sources like solar PV systems. The algorithm allowsthe controller to operate PV module at optimum voltage and current so the extraction of maximum power is ensured. [31,32]

As discussed before the solar cells has an IV and PV curves such that (P = IV)

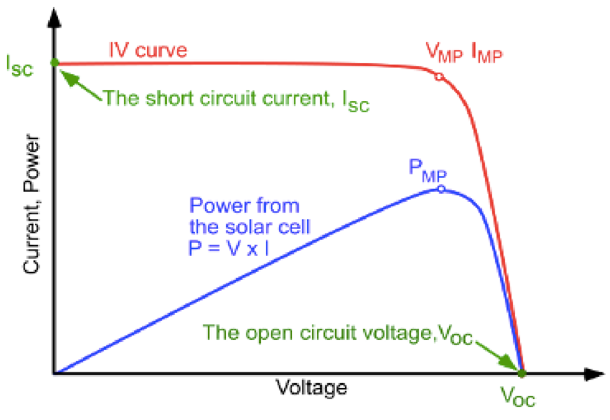


Fig 2.6 *Maximum power point on IV & PV curves.* [31]

2.4 Direct MPPT methods

The direct MPPT is more accurate & faster than the indirect MPPT:

2.4.1 Perturb & observe method

This method works with increasing and decreasing the voltage as shown in figure below:

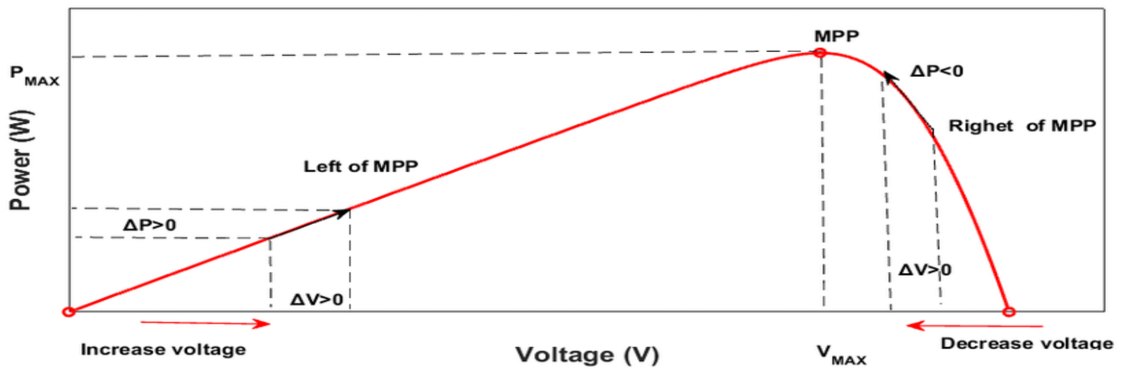


Fig 2.7 *The P&O behavior to track the MPP.*[32]

- If increase in voltage leads to increase in power this means that the operating point is to the left of the MPP & hence further the voltage perturbation is required towards the right to reach the MPP.
- If the increase of voltage leads to a decrease in power this means that the operating point is to the right of the MPP & hence further voltage perturbation towards to the left to reach the MPP. [31,32]

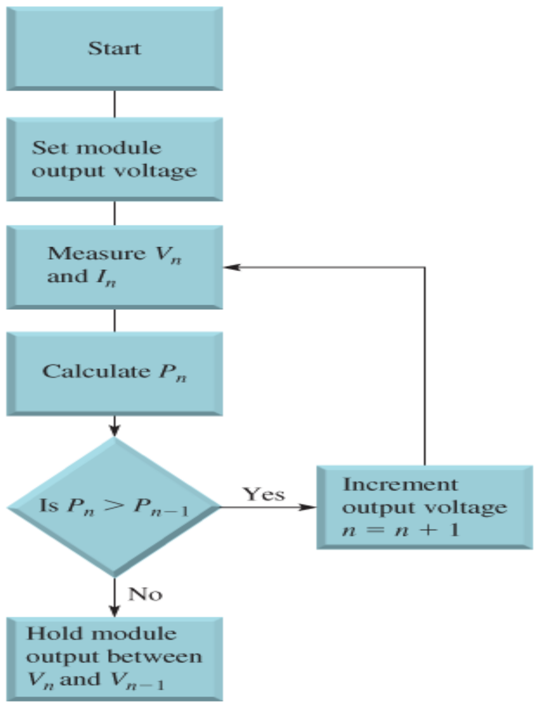


Fig 2.8 *Flowchart describes the P&O method.* [32]

2.4.2 Incremental conductance method

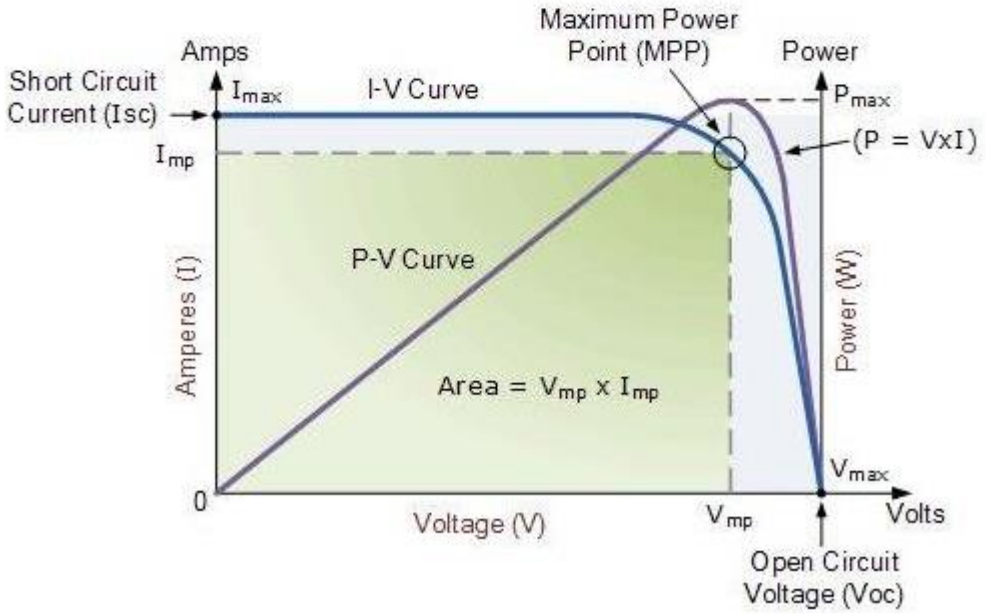


Fig 2.9 *The incremental conductance method behavior to track the MPP.*[32]

The instantaneous conductance: "$\frac{I}{V}$"

The incremental conductance: "$\frac{dI}{dV}$"

As shown in fig 2.4 at MPP the slop of the PV curve $\frac{dP}{dV} = 0$

$$\frac{dP}{dV} = \frac{d(V*I)}{dV} = I + V\frac{dI}{dV} \qquad (2.13)$$

In general the algorithm imposes a voltage on PV module at every iteration measures the incremental change in conductance and compares it with the instantaneous conductance and decides if the operating point is to the left or to the right of MPP:

- At the MPP

$$-\frac{I}{V} = \frac{dI}{dV} \qquad (2.14)$$

- The operating point is to the left of the MPP this means

$$-\frac{I}{V} < \frac{dI}{dV} \qquad (2.15)$$

- The operating point is to the right of the MPP

$$-\frac{I}{V} > \frac{dI}{dV} \quad \text{...(2.16)}$$

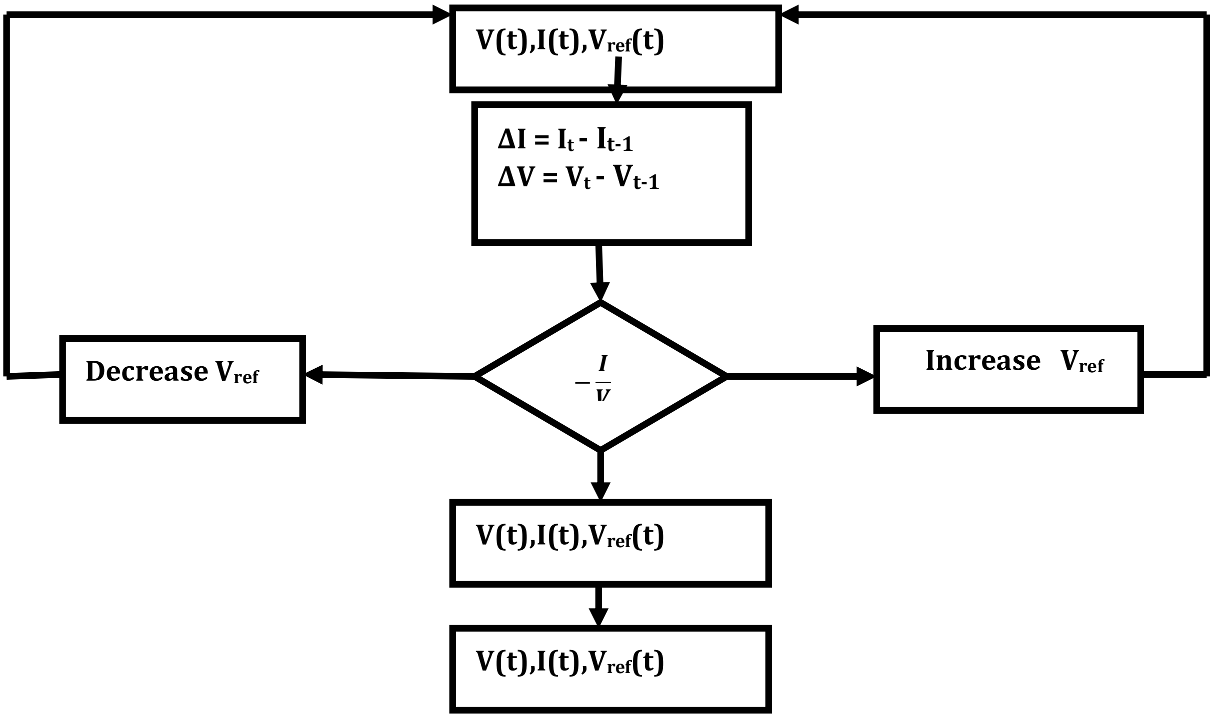


***Fig 2.10** Flowchart describes the incremental conductance method*.[32].

2.5 Three-phase ,Three-level Voltage Source Converter

This type of converter has been widely used in industry form different applications including solar and wind energy systems.Voltage Source Converter (VSC) is an indispensable part of a variety of power electronic systems. It finds application in motor drives, power factor correcting equipment, grid integration of renewable energy sources etc. Among other types of inverters, Voltage Source Inverter (VSI) is more efficient, more robust and gives faster dynamic response. Due to these reasons, VSC finds a suitable place in most industrial applications [33,34]. The three-level bridge implements a three-level power converter that consists of one ,two , three arms of power switching devices .Each arm consists of four switching devices along with their antiparallel and two neutral clamping diods as shown in the figure in the next page :

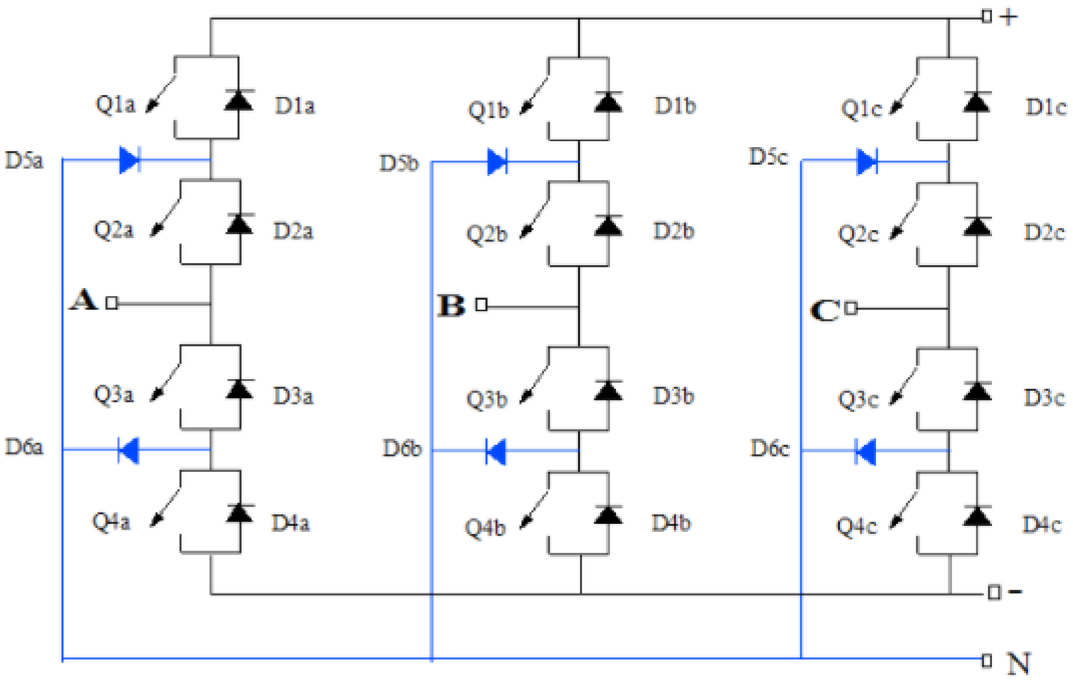


Fig 2.11 *Circuit diagram of a three-phase, three-level voltage source converter.*[34]

2.6 Phase-locked loop (PLL)

A phase-locked loop (PLL) is an electronic circuit with a voltage or voltage-driven oscillator that constantly adjusts to match the frequency of an input signal. PLLs are used to generate, stabilize, modulate, demodulate, filter or recover a signal from a "noisy" communications channel where data has been interrupted. At its simplest, a phase-locked loop is a closed-loop feedback control circuit that's both frequency- and phase-sensitive. A PLL is not a single component, but a system that consists of both analog and digital components -- interconnected in a "negative feedback" configuration. Consider it analogous to an elaborate operational amp (op amp)-based amplifier circuit.Parameters of the control block are represented in the table below :

Table 2.1 Parameters of the control block .

Nominal power (Pnom)	100KW
Frequency (Fnom)	60Hz
Nominal primary voltage (Vrms LL)	260KW
Nominal secondary voltage (Vrms LL)	25KW
Nominal VDC bus voltage (V)	500V

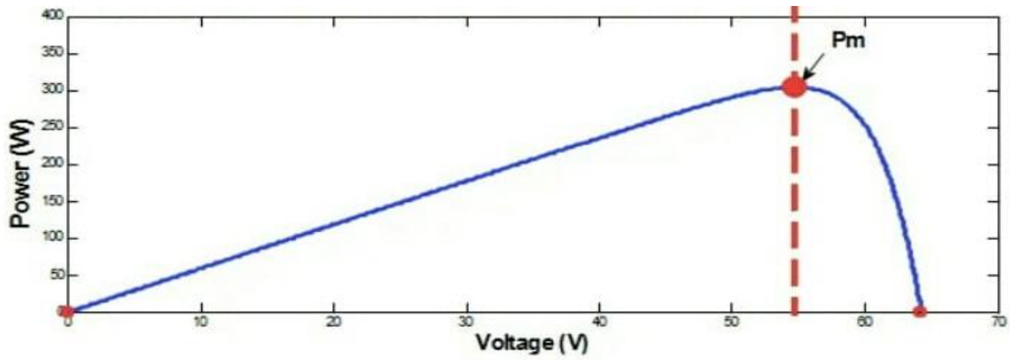
2.7 Simulation and results

2.7.1 Simulation model of solar PV module

Equations; (2.2), (2.3), (2.4), (2.5), are implemented in Matlab/Simulink to design and simulate solar PV module, the following table shows the key specification of the PV module under Standard Test Conditions (STC):

Table 2.2: Solar PV module parameters

Isc	Imp	Voc	Vmp	Pmax	Ns	Ki	Kv	α	Rs	Rsh
5.96	5.58A	64.2V	54.7V	305W	66	0.061 A/^{0}C	-0.27 V/°C	0.94	0.37 Ohm	269.59 Ohm



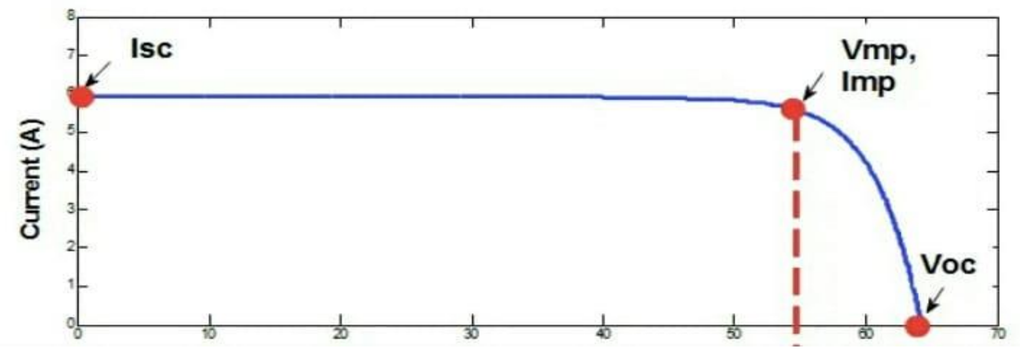


***Fig 2.12:** IV and PV curves of single solar PV module under STC Conditions.*

2.7.2 Simulation of overall Solar Photovoltaic Energy Conversion System

As mentioned before, Matlab/Simulink is used to design and implement Solar Photovoltaic Energy Conversion System with a PV array, a MPPT controlled DC/DC boost converter, a three-phase two-level VSC controlled by load voltage regulator, and load. The schematic of the model is shown in **Fig 2.16.**

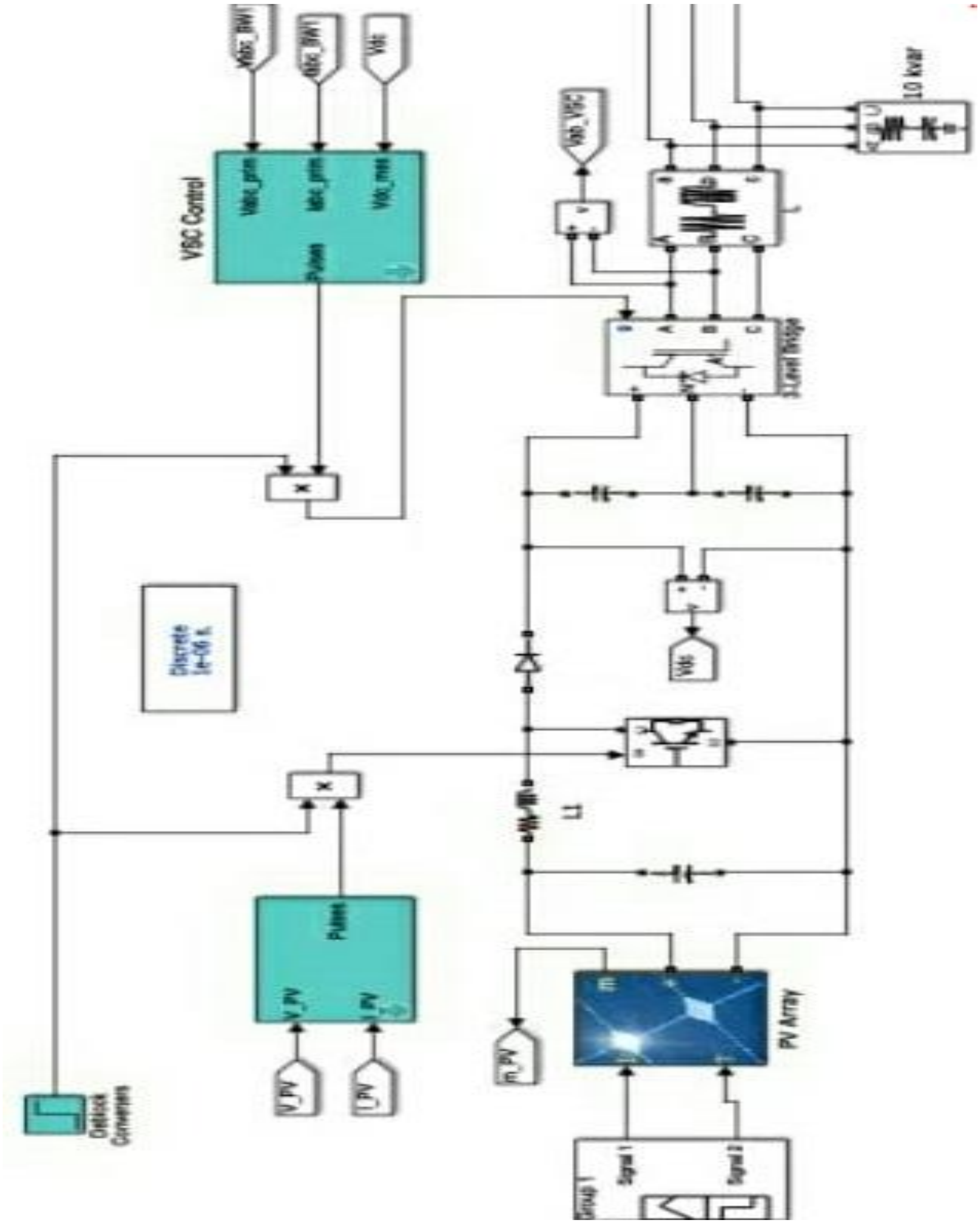


Fig 2.13: *SIMULINK model for overall Solar Photovoltaic Energy Conversion System*

This simulation is executed for 10 seconds with variable solar irradiance and under STC conditions where cell temperature is 25° C. Results obtained from the simulation are presented below :

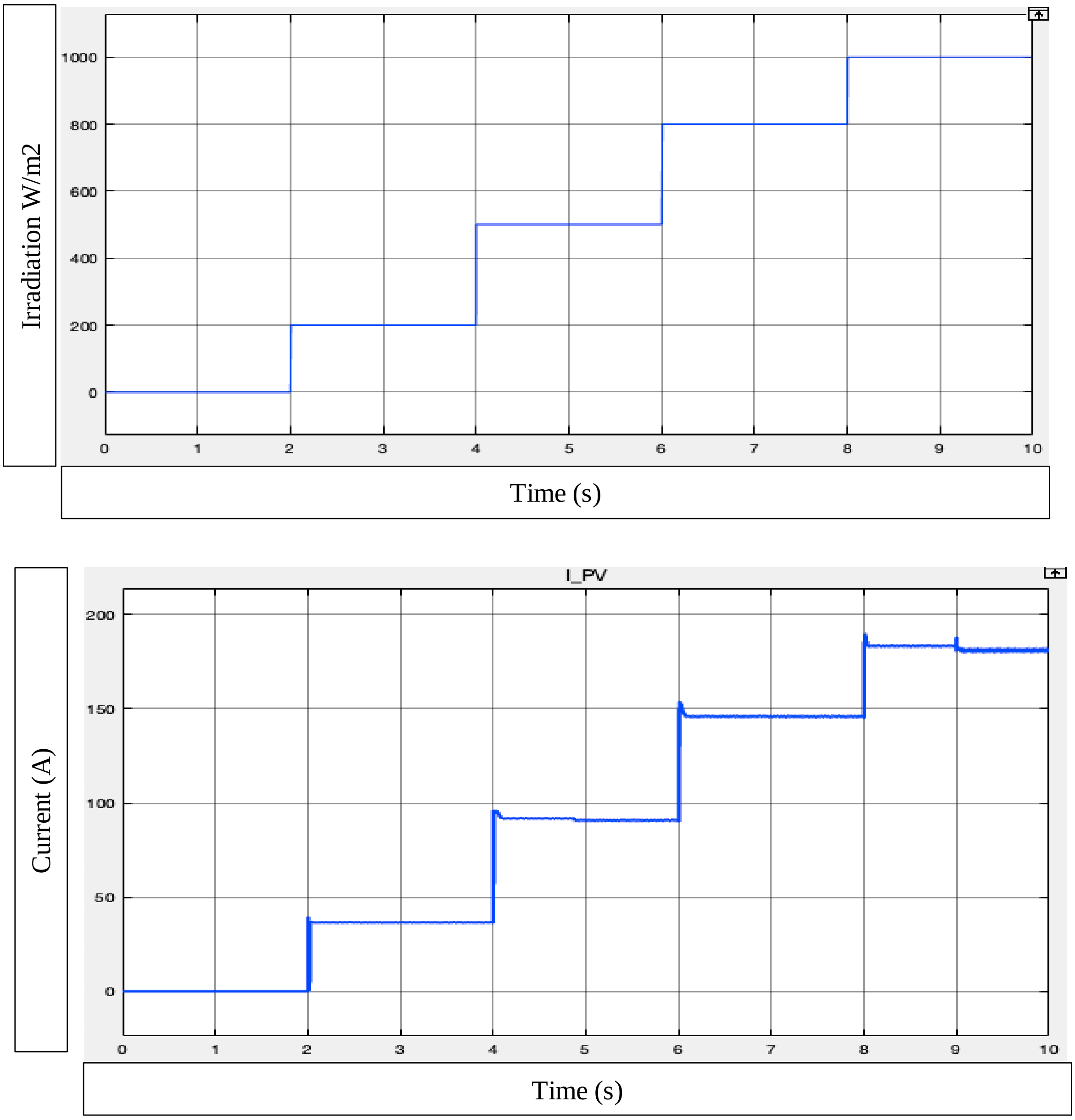


Fig 2.14: *Variable solar irradiation (W/m2) and current generated by solar PV*

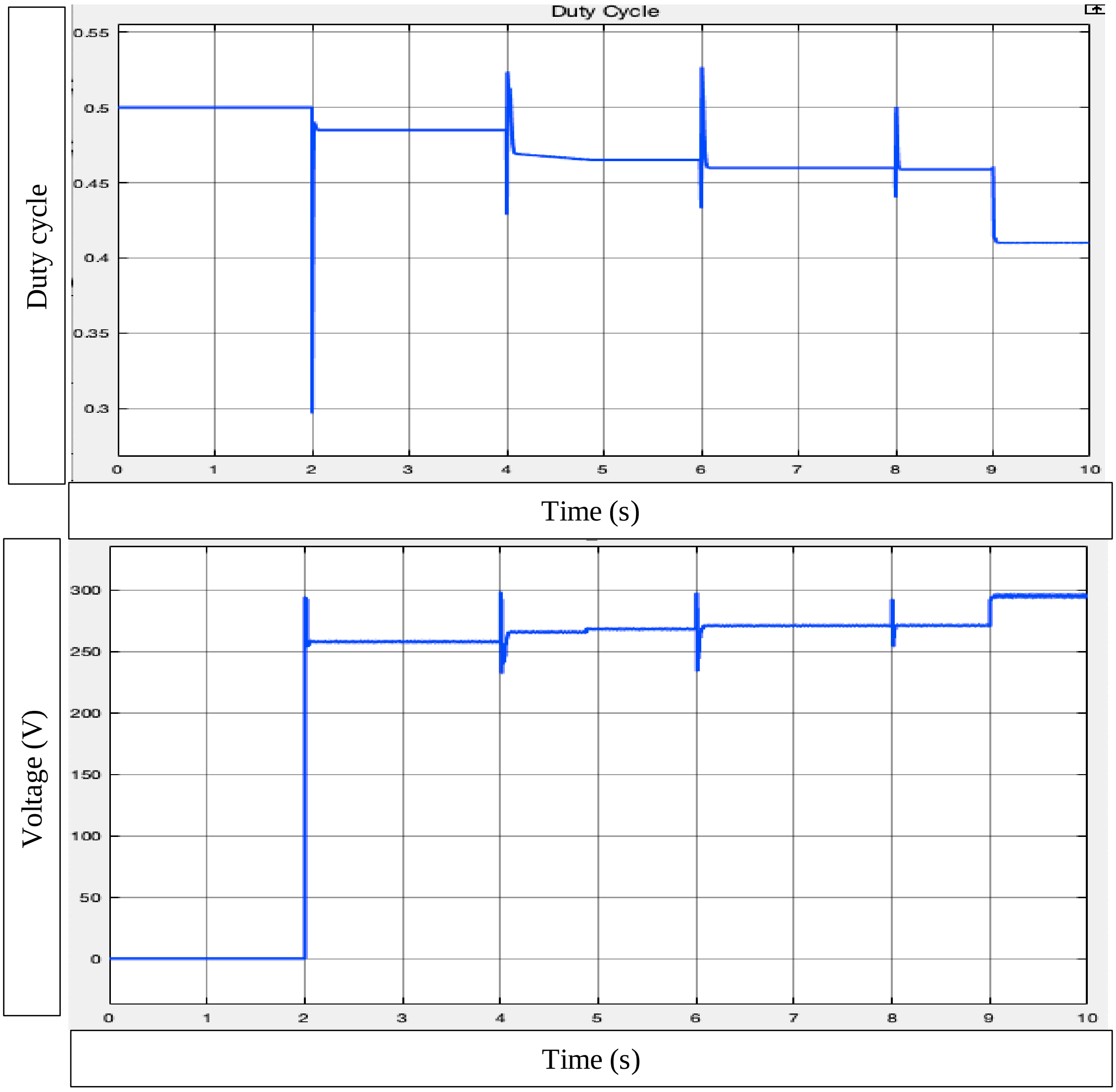


Fig 2.15: *Duty cycle generated by MPPT and voltage induced by solar PV array*

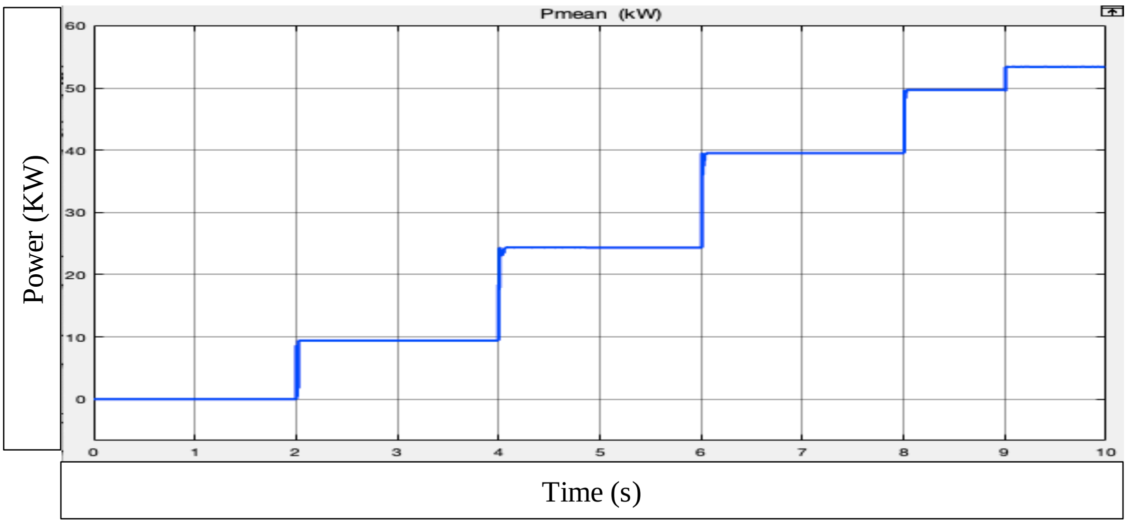


Fig 2.16: *Power Generated by solar PV (W).*

Fig 2.15 shows the variable solar irradiance applied to the system and generated current following the variation of irradiation. In this simulation, solar irradiation varies from 0 to 1000 W/m^2 and the generated current varies in a limit from 0 A to 175 A approximately depending on the solar irradiation.

Fig 2.16 states the duty cycle generated by MPPT and voltage induced at solar PV array.

Fig 2.17 shows the total power generated by solar PV and the power consumed by resistive load.It varies depending on the variance of the irradiance until it's rich the maximum .

2.8 Conclusion

This chapter provided an overview of solar photovoltaic energy conversion system. The fundamentals of modeling solar PV cell, module and array are described. The major components of PVECS were discussed, including maximum power point tracking algorithm, AC/DC power electronic converter, DC/AC three-phase inverter, three-level VSC control system and phase-locked loop. The obtained results in this chapter show I-V and P-V characteristics curve generated by the simulation models of solar PV module, Also The behavior of a stand-alone solar PVCES under variable solar irradiance associated with MPPT controller has been simulated.

CHAPTER 3

Wind energy conversion system and diesel generator(buck-up)

- *Introduction*
- *Wind power*
- *Components of wind energy conversion systems*
- *Maximum power point tracking(MPPT)*
- *Simulation and results*
- *Diesel generator*
- *Automatic voltage regulator (AVR)*
- *Conclusion*

Wind energy conversion system and diesel generator (buck-up)

3.1 Introduction

Renewable energy sources including wind power offer a feasible solution to distributed power generation for isolated communities where utility grids are not available. A wind energy conversion system (WECS) is converting the wind kinetic energy into electric power and injecting this electric power into the electrical load or the utility grid. In such cases, stand-alone wind energy systems (i.e., systems not connected to the utility grid) can be considered as an effective way to provide continuous power to electrical loads [35]. A WECS is composed of Wind turbine, an electric generator, a power electronic converter and a control system, as shown in Fig. 3.1.We also add a pitch controller regulates the wind turbine's blade pitch angle to enhance the efficiency of wind energy conversion and power generation stability.

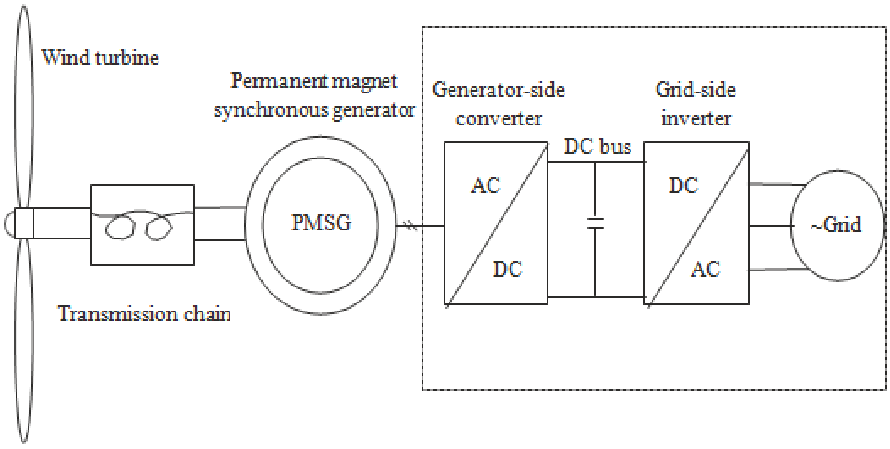


Fig. 3.1 *Structure diagram of WECS* [35].

3.2 Wind power

Kinetic energy exists whenever an object of a given mass is in motion with a trans-lational or rotational speed. When air is in motion, the kinetic energy in moving air can be determined as:

$E_c = \frac{1}{2}mv^2$………………………………..… (3.1)

With: $m = \rho v S \Delta t$

Where;

S: Swept area by turbine blades,

ρ = Air density.

The wind power can be obtained by differentiating the kinetic energy in wind withrespect to time :

$$P_w = \frac{\boldsymbol{d}}{\boldsymbol{dt}} E = \frac{\mathbf{1}}{\mathbf{2}} \rho S v^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.2)}$$

The mechanical power that the turbine extracts from the wind, P_m, is inferior to P_w. So, the power coefficient of the turbine $C_p$can be defined by:

$$C_P = \frac{\boldsymbol{P_m}}{\boldsymbol{P_w}} = \frac{\textbf{\textit{Actual turbine power}}}{\textbf{\textit{Theoritical wind power}}} = \frac{\boldsymbol{P_m}}{\mathbf{2.}\boldsymbol{A}.\boldsymbol{V_w}} \text{ with } C_p < 1$$

The recuperated power is given by:

$$P_{\text{m}} = \frac{\mathbf{1}}{\mathbf{2}} \rho \pi R^2 v^3 C_p \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.3)}$$

Where; R: radius of the rotor.

An examination of **Eq (3.2)** reveals that in order to obtain a higher wind power, it requires a higher wind speed, a longer length of blades for gaining a larger swept area, and a higher air density. Because the wind power output is proportional to the cubic power of the mean wind speed, a small variation in wind speed can result ina large change in wind power.

The algorithm that tracks the maximum power point of the wind turbine is called maximum power point tracking (MPPT). This is actually the main advantage of a variable speed wind turbine (VSWT).

C_p depends on the tip speed ratio λ of the wind turbine and β, angle of the blades.

$$C_p = (\lambda, \beta) \text{ with: } \lambda = R\,\frac{\boldsymbol{w}}{\boldsymbol{v}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.4)}$$

Where ω: is the rotation speed of the rotor.

This function has maximum and is known as the limit of Betz:

$$C_{Pmax} = \frac{\mathbf{16}}{\mathbf{27}} = 0.593 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.5)}$$

3.2.1Mechanical torque of wind turbine

The wind turbine torque on the shaft can be calculated from the power:

$$T_m = \frac{\boldsymbol{P_m}}{\boldsymbol{w}} = \frac{\mathbf{1}}{\mathbf{2}}\rho\pi R^2 \frac{\boldsymbol{v3}}{\boldsymbol{w}} C_p \quad (3.6)$$

By replacing **Eq (3.4)** in **Eq (3.5)** we get:

$$T_m = \frac{1}{2}\rho\pi R^3 \frac{v2}{\lambda} C_p \quad (3.7)$$

Often the torque coefficient C_T is used:

$$C_T = \frac{\boldsymbol{C_p}}{\lambda} \quad (3.8)$$

This gives:

$$T_m = \frac{1}{2}\rho\pi R^3 v^2 C_T \quad (3.9)$$

3.3 Components of wind energy conversion system

3.3.1 Wind turbine

Wind turbines are used to convert wind energy to electricity. The first automatically operated wind turbine in the world was designed and built by Charles Brush in 1888. This wind turbine was equipped with 144 cedar blades having a rotating diameter of 17 m. It generated a peak power of 12 kW to charge batteries that supply DC current to lamps and electric motors [36]. As a pioneering design for modern wind turbines, the Gedser wind turbine was built in Denmark in the mid 1950s [37]. Today, modern wind turbines in wind farms have typically three blades, operating at relative high wind speeds for the power output up to several megawatts. The rotor extracts kinetic energy from the wind and converts it into mechanical torque and then a generating system will convert this torque to electricity.

Different types of wind turbines can be used for different applications (stand-alone, grid connected...) and they can be categorized into two major types: horizontal axes and vertical axes wind turbines.

3.3.2 Gearbox

A gearbox is often used in a wind turbine to increase the rotational speed from a low-speed main shaft to a high-speed shaft connecting with an electrical generator. Gears in wind turbine gearbox are subjected to severe cyclic loading due to variable wind loads that are stochastic in nature. Thus, the failure rate of gearbox system is reported to be relatively higher than the other wind turbine components.

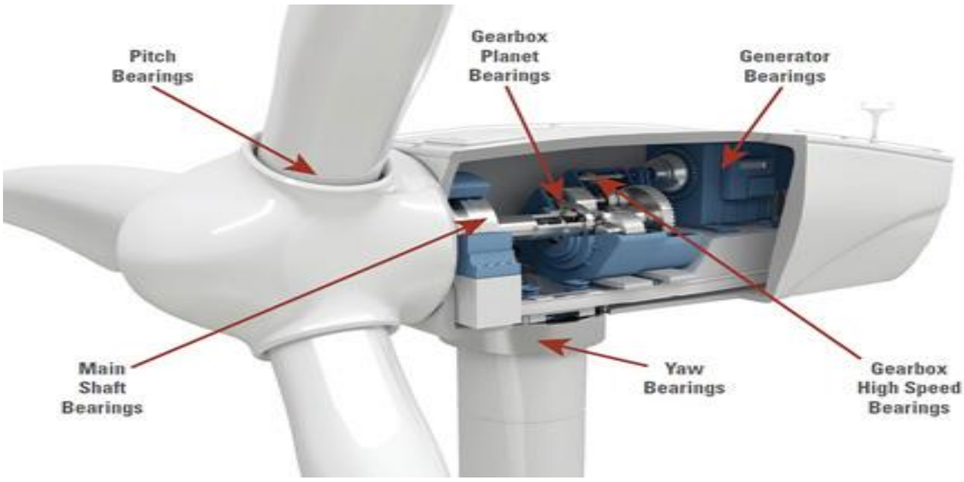


Fig 3.2 *Global view of gearbox*[37].

3.3.3 Pitch controller

The pitch control system is a vital part of the modern wind turbine. This is because the pitch control system not only continually regulates the wind turbine's blade pitch angle to enhance the efficiency of wind energy conversion and power gen- eration stability, but also serves as the security system in case of high wind speeds or emergency situations. It requires that even in the event of grid power failure, the rotor blades can be still driven into their feathered positions by using either the power of backup batteries or capacitors [38] or mechanical energy storage devices [39].

Early techniques of active blade pitch control applied hydraulic actuators to control all blades together. However, these collective pitch control techniques could not completely satisfy all requirements of blade pitch angle regulation, espe- cially for MW wind turbines with the increase in blade length and hub height. This is because wind is highly turbulent flow and the wind speed is proportional to the height from the ground. Therefore, each blade experiences different loads at dif- ferent rotation positions. As a result, more superior individual blade pitch control techniques have been developed and implemented, allowing control of asymmet-ric aerodynamic loads on the blades, as well as structural loads in the non-rotating frame such as tower side-side bending. In such a control system, each blade is equipped with its own pitch actuator, sensors and controller.

In today’s wind power industry, there are primarily two types of blade pitch control systems: hydraulic controlled and electric controlled systems. As shown in Fig. 3.2, the hydraulic pitch control system uses a hydraulic actuator to drive the blade rotating with respect to its axial centreline. The most significant advantages of hydraulic pitch control system include its large driving power, lack of a gear- box, and robust backup power. Due to these advantages, hydraulic pitch control systems historically dominate wind turbine control in Europe and North America for many years.

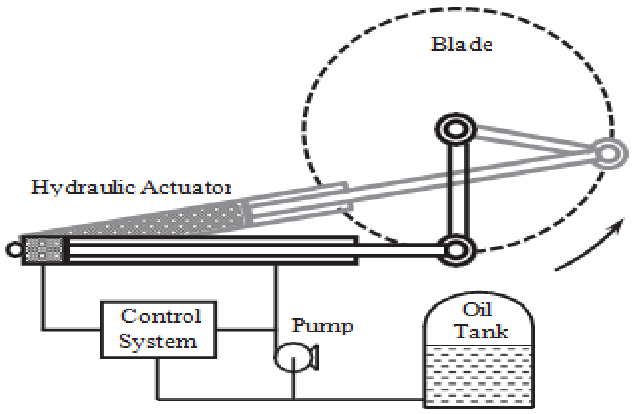


Fig. 3.3 *Hydraulic pitch control system*[38].

The electric pitch control systems have been developed alternatively with the hydraulic systems. This type of control system has a higher efficiency than that of hydraulic controlled systems (which is usually less than 55%) and avoids the risk of environmental pollution due to hydraulic fluid being split or leaked.

In an electric pitch control system as shown in Fig.3.3, the motor connects to a gearbox to lower the motor speed to a desired control speed. A drive pinion gear engages with an internal ring gear, which is rigidly attached to the roof of the rotor blade. Alternatively, some wind turbine manufacturers use the belt-drive structure adjusting the pitch angle. The use of electric motors can raise the responsiveness rate and sensitivity of blade pitch control. To enhance operation reliability, the use of redundant pitch control systems was proposed to be equipped in large wind turbines [40].

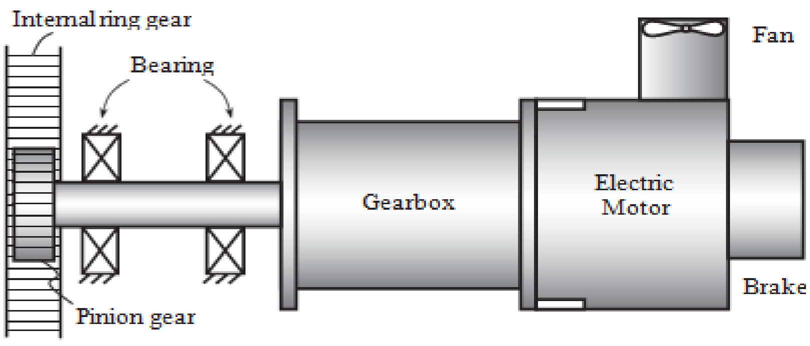


Fig. 3.4 *Electric pitch control system*[40].

3.3.4 Electrical generator

A generator is an electrical machine that converts mechanical energy to electrical one. In wind turbines applications three types of generators are used [41], [42]:

- Squirrel cage induction generator.
- Wound rotor (doubly fed) induction generator.
- Permanent magnet synchronous generator (PMSG).

Each one of these generators has its own properties, PMSG are becoming increasingly popular because of their ability to reduce failures in the gearbox and lower maintenance problems.

It also have the highest advantages because they are stable and secure during normal operation and they do not need an additional DC supply for the excitation circuit (winding). Initially used only for small and medium powers, the PMSG's are now used also for higher

powers (because of their already mentioned advantages) [43].

Modeling of PMSG.

Dynamic model of the PMSG is obtained from the two phase synchronous reference frame, which the q axis is 90 degree ahead of the d axis with respect to the direction of rotation.

The synchronization between the dq rotating frame is maintained by a phase locked loop.Fig3.4 shows the dq reference frame used in a salient -pole synchronous machine.

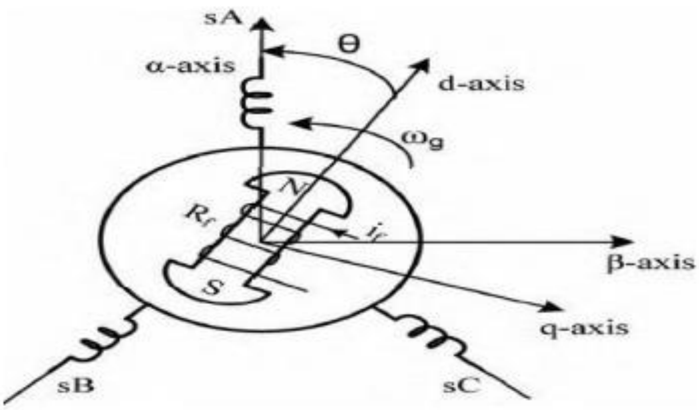


Fig 3.5: *Salient-pole permanent magnet synchronous machine in dq reference frame*[43].

Where θ is the mechanical angle ,the angle between the rotor d axis and the stator axis .The stator windings are positioned sinusoidal along the air-gap as far as the mutual effect with the rotor. The stator winding is symmetrical, damping windings are not considered, the capacitance of all the windings can be neglected and the resistances are constant.Our PMSG parameters are summarized in the table below:

Table 3.1 Parameters of synchronous machine.

Stator phase resistance Rs (ohm)	0.006 ohm
Armature inductance (H)	0.0004 H
Flux linkage	1.48
Power supplied	50 KW
Inertia	1000
Number of poles	48

The mathematical model of the PMSG in the synchronous reference frame is :

$$V_{qs} = R_s i_{qs} + \omega_m \psi_{ds} + \frac{d\psi_{qs}}{dt} \quad \ldots\ldots\ldots\ldots(3.10)$$

$$V_{ds} = R_s i_{ds} + \omega_m \psi_{qs} + \frac{d\psi_{ds}}{dt} \quad \ldots\ldots\ldots\ldots(3.11)$$

Where; V is the voltage, i the current, ψ the flux linkage, R_s the resistance, ω_m the angular velocity of turbine rotor.

The flux linkages are given by:

$$\psi_{qs} = (L_{qm} + L_{\sigma s}) \ldots\ldots\ldots\ldots (3.12)$$

$$\psi_{ds} = (L_{dm} + L_{\sigma s})\, i_{ds} + \psi_f \ldots\ldots\ldots\ldots (3.13)$$

Where; ψ_f is the flux produced by the permanent magnets.

In order to simplify analysis of the wind generator, the transients occurred in the stator,, can be neglected. By substituting flux linkages **Eq (3.12), (3.13)** in system of **Eq (3.10), (3.11)** the voltage current relationship can be obtained:

$$V_{qs} = -R_s\, i_{qs} + (L_{dm} + L_{\sigma s})\, i_{ds} + \omega_m \psi_f \ldots\ldots\ldots\ldots(3.14)$$

$$V_{ds} = -R_s\, i_{ds} - (L_{dm} + L_{\sigma s})\, i_{qs} \ldots\ldots\ldots\ldots(3.15)$$

The mechanical Torque equation is:

$$T_m = T_{em} + J\frac{d\omega}{dt} + F\omega \qquad (3.16)$$

Where:

J: Inertia moment of the turbine, axle and generator,

F: Friction coefficient,

Tem: Electromagnetic torque.

3.3.5 Three-phase diode bridge rectifier

In order to supply the DC-link, the PMSG should be connected to a rectifier that converts the AC voltage into DC voltage.

The uncontrolled three-phase bridge rectifier is the simplest, cheap, and rugged topology used in power electronic applications. The most disadvantage of this diode rectifier is its disability to work in bi-directional power flow.If V_m is the peak value of the phase voltage, then the average output voltage is found from:

$$V_{d,} = \frac{6}{\pi}\int_0^{\pi/6}\sqrt{3}\,V_m \cos \omega t \, d(\omega t) \qquad (3.17)$$

Then the output dc voltage from bridge rectifier can be obtained from Eq (2.12) where the overlap due to the internal inductance of PMSG is ignored [44].

$$V_{d,} = \frac{3\sqrt{2}\,V_{LL}}{\pi} \qquad (3.18)$$

Where; $V_{d,}$: output dc voltage of the rectifier,

V_{LL}: line to line voltage.

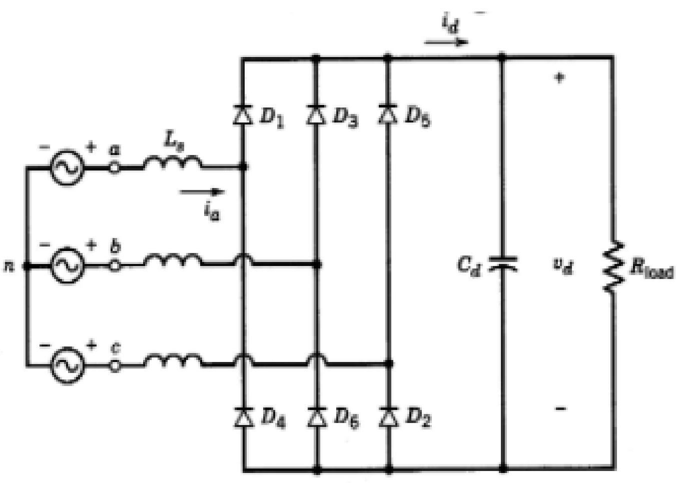


Fig 3.6: Three phase uncontrolled rectifier (AC-DC converter) [44].

3.3.6 Converter

In addition to the three bridge rectifier which converts AC voltage to DC voltage we have also a DC-DC converter .It is used to locally supply any component or part of a system with the desired DC voltage and current .

3.3.7 Inverter

Structure, function and control of inverter are given in the previous chapter. It is requiredto provide AC power to AC load or grid utility.

3.3.8 Phase-locked loop (PLL)

We have used PLL as well for feeding the machine side and the grid side converter pulses and its explained in the previous chapter.

3.4 Maximum power point tracking (MPPT)

Maximum power point tracking (MPPT) is a technique that ensures the maximum power extraction from non-linear energy sources like wind energy system. In order to extract the maximum energy from the WECS, the generator rotational speed must be controlled by the MPPT algorithm; therefore, the MPPT is one of the important factor in WECS. The goal of MPPT is to maximize the wind power capture at different wind speeds by adjusting the turbine speed. Different MPPT techniques employed in WECS are classified as:

- Tip-speed ratio (TSR) control
- Optimum relationship based control (ORBC)
- Perturb and observe (P&O) control
- Hybrid control
- Intelligent control techniques like fuzzy logic control, neural network control, etc.

Perturb and observe (P&O) control

This is the technique used in this section and it is described in details in the previous chapter .

3.5 Simulation and results

The system described in Fig 3.1 is implemented in Matlab/Simulink as shown in Fig 3.7.

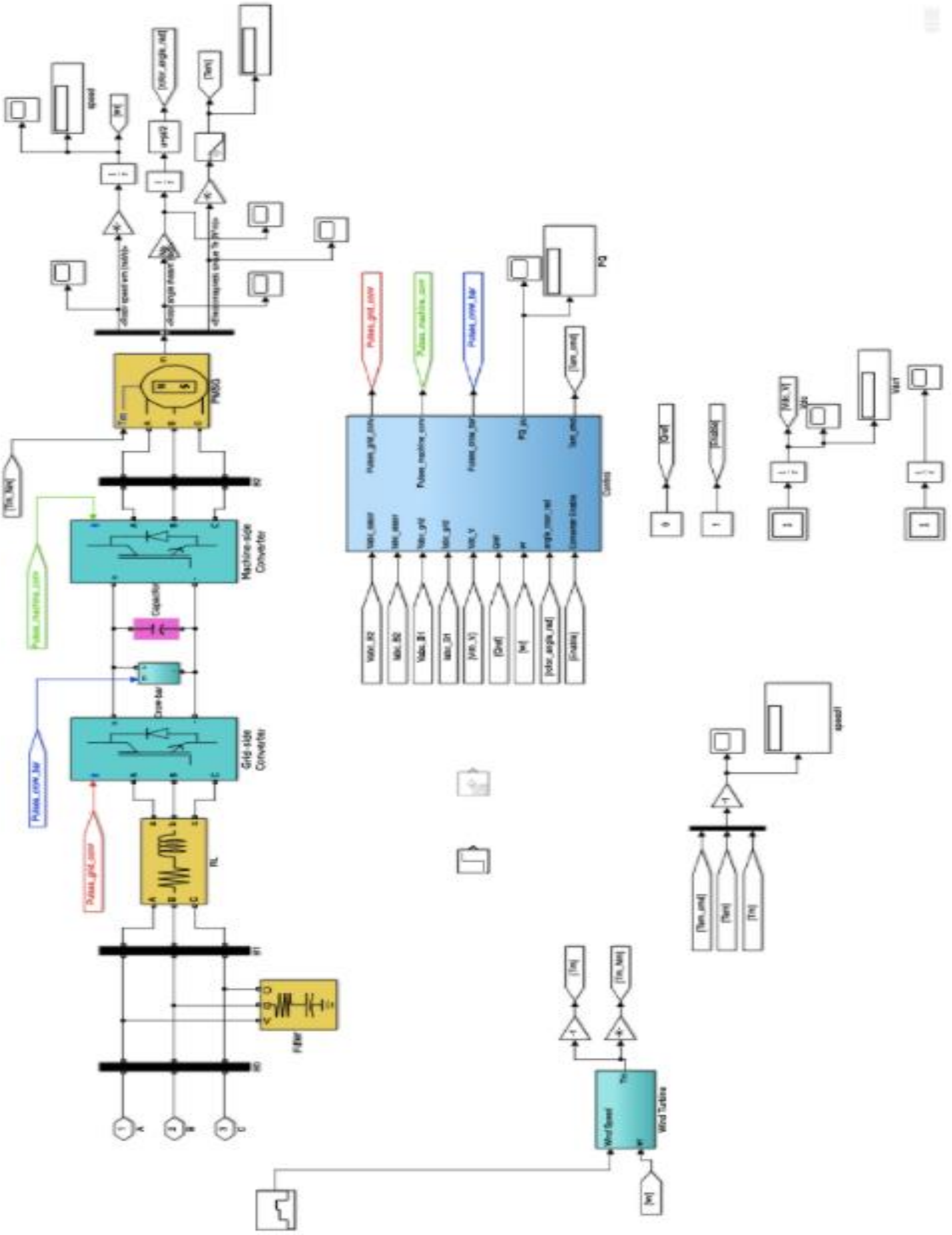


Fig 3.7: *Matlab/simulink model for WECS.*

We simulate our model for WECS within 10s using the wind speed profile shown below in Fig 3.7 :

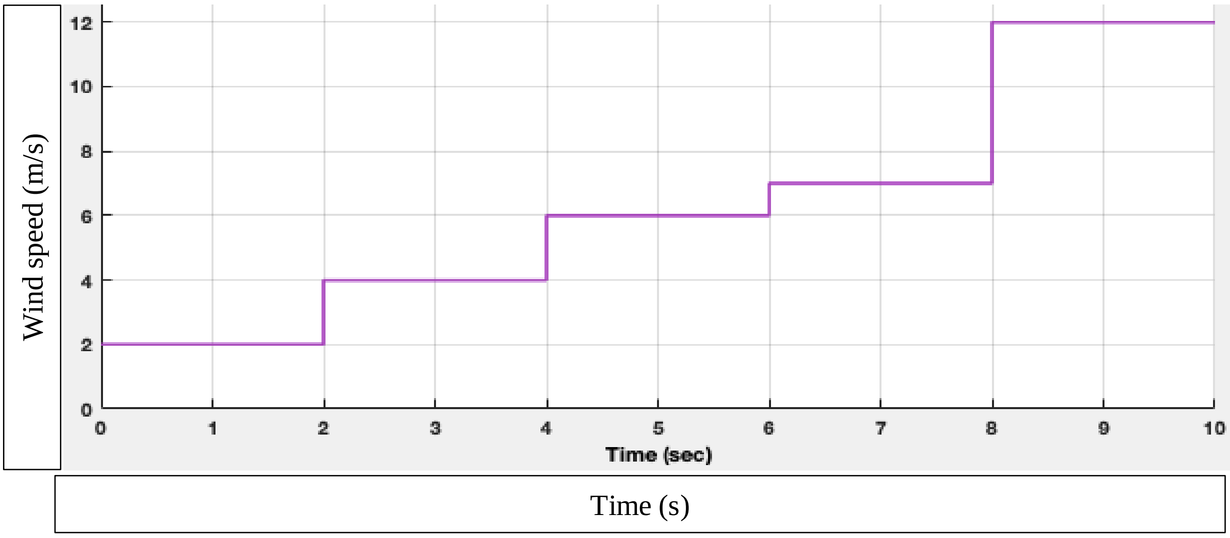


Fig 3.8 *Wind speed profile for WECS.*

After simulation, the output power of the WCES and the rotor speed are presented in Fig 3.9 and Fig 3.10.

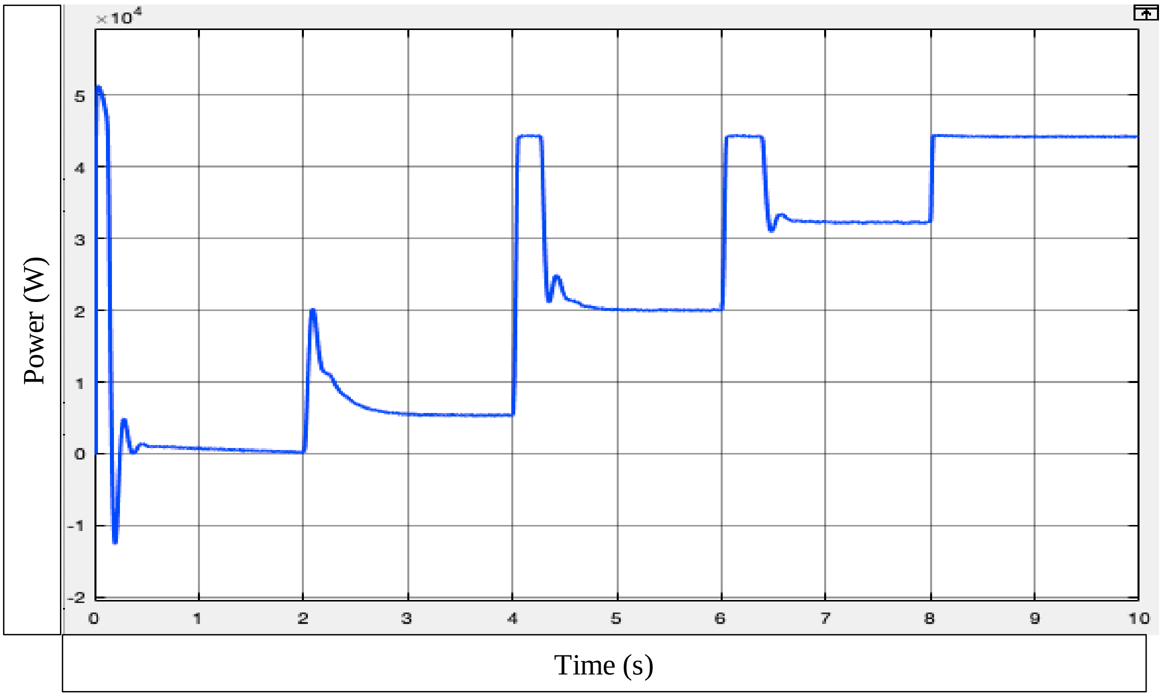


Fig 3.9 *Output power of the wind turbine.*

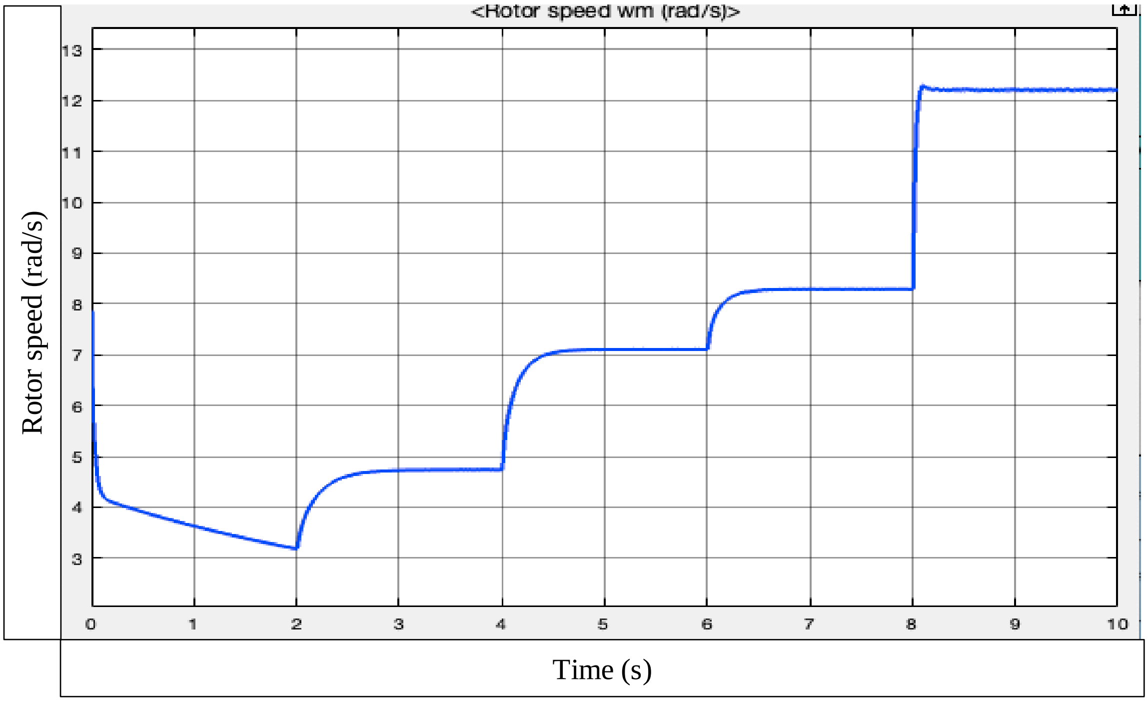


Fig 3.10 Rotor speed of the wind turbine.

As shown in Fig 3.9 and Fig 3.8 the output power increase as the wind speed increases. Also the rotor speed changes with time as the increasing wind speed .the MPTT controller has attracted the maximum power and the optimal rotor speed for each value of wind speed. This power is attracted by the MPTT controller as shown in Fig 3.9. Therefore, the P&O ensures the maximum efficiency operationof the WECS based on PMSG operation.

Pitch controller cases

Case 1: We simulate a new win profile as shown in the Fig 3.11 below:

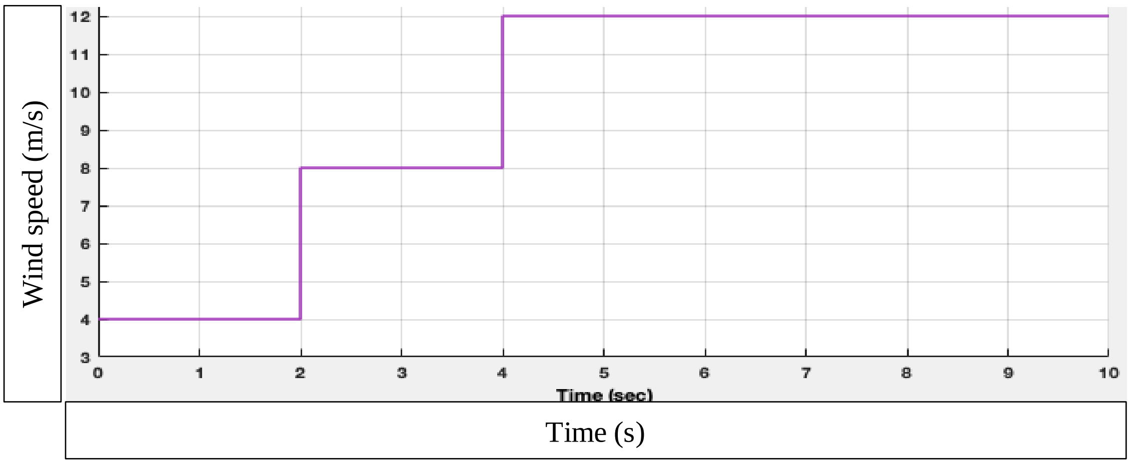


Fig 3.11 Wind speed profile for case1 of the pitch controller .

The results are presented in the Fig3.12 and Fig3.13 :

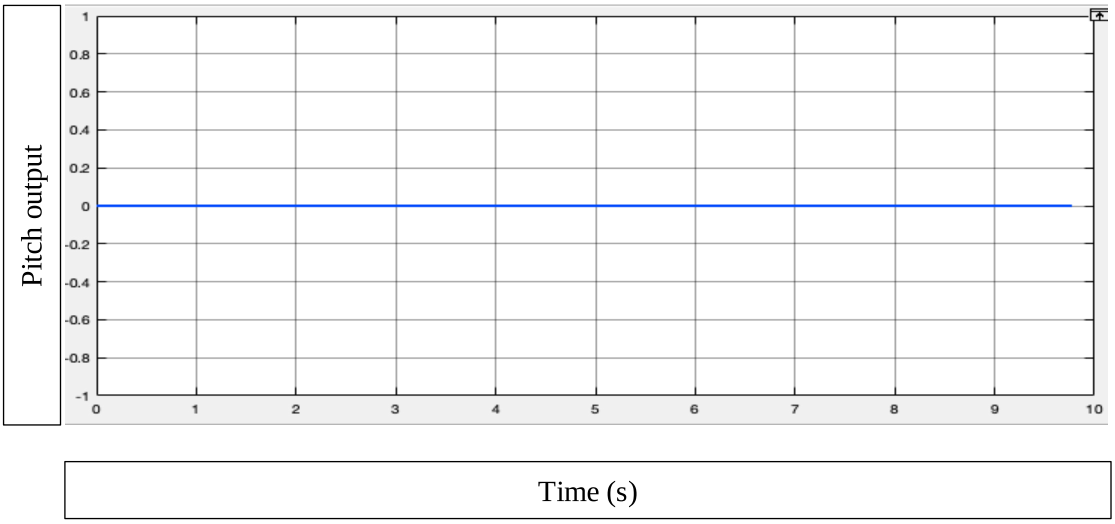


Fig 3.12 *Pitch controller output case1 .*

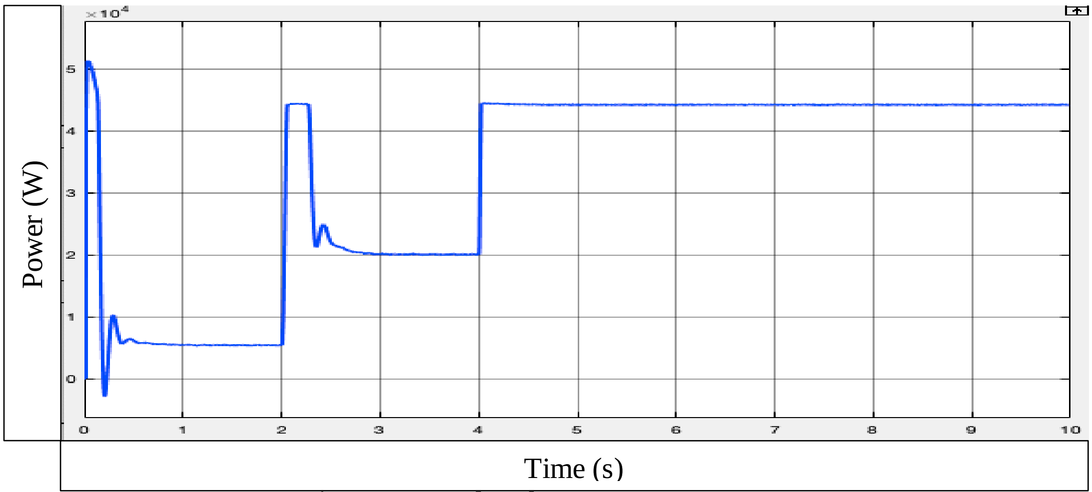


Fig 3.13 *Wind turbine output power case1 .*

Case 2: We simulate a new win profile as shown in the Fig 3.14 below:

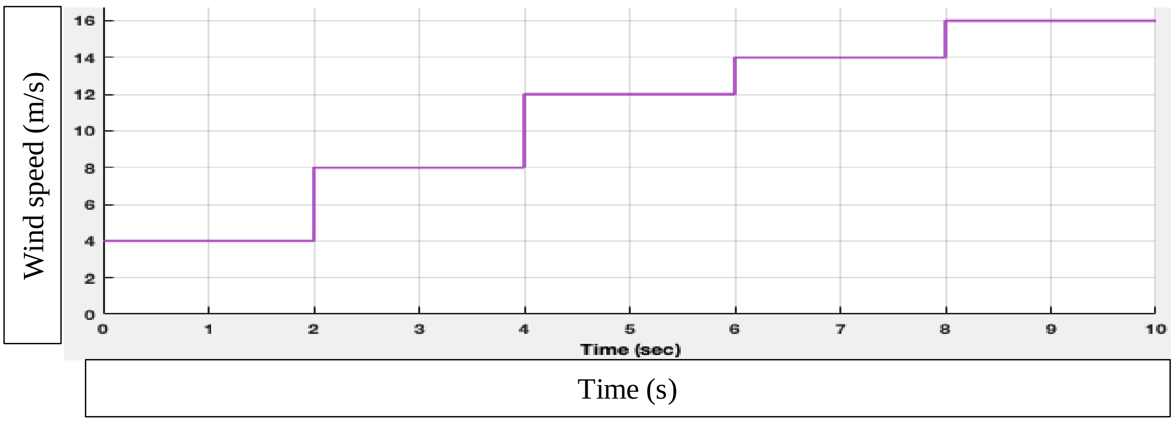


Fig 3.14 *Wind speed profile for the seconde case of the pitch controller .*

The results are presented in the Fig3.15 and Fig3.16 :

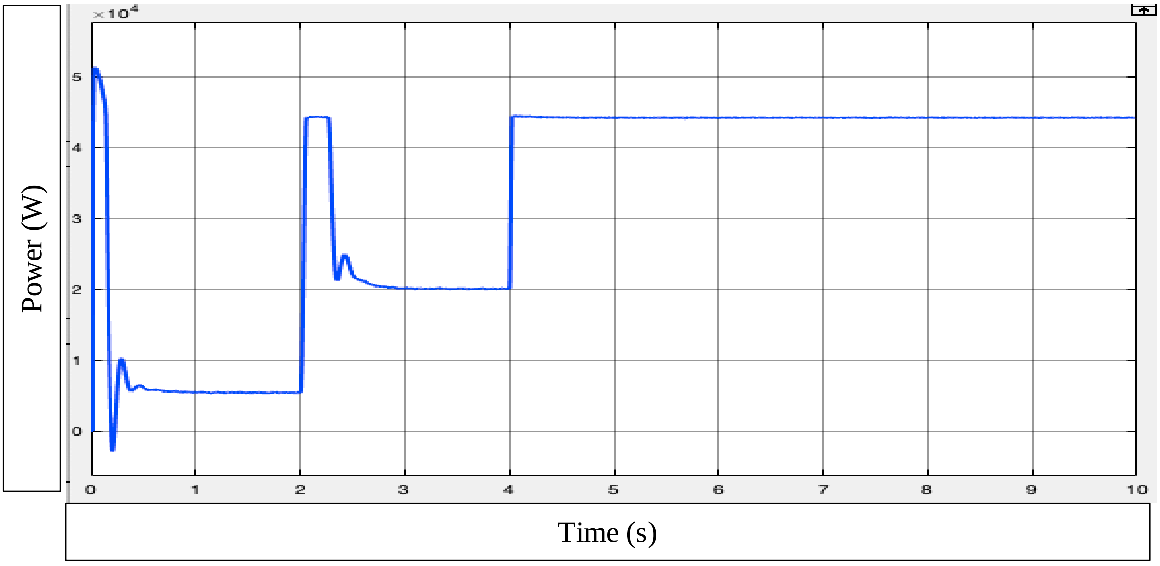


Fig 3.15 *Wind turbine output power case2*

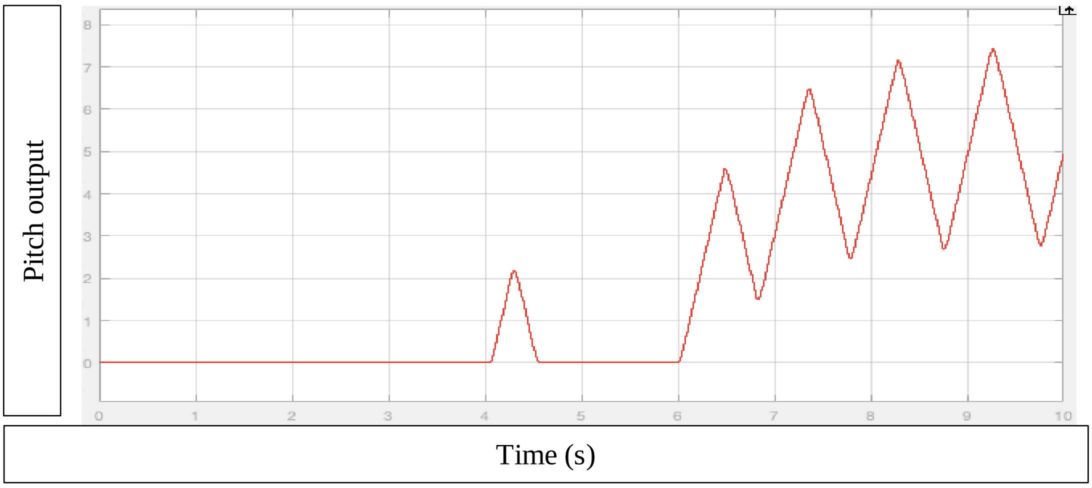


Fig 3.16 *Pitch controller output case 2.*

Pitch controller results discussion

We distinguish two cases in the principal of operation of the pitch controller :

Case 1 : The output power changes as the wind speed increases and it reaches it maximum as the wind speed is 12m/s w, also the pitch controller doesn't work because it effect start at the maximum for 12 m/s wind speed .

Case 2 : The output power changes as the wind speed increases and it reaches it maximum as the wind speed is 12m/s w and it stablies even if we still increasing the wind speed , also the pitch controller works because it effect start at the maximum for 12 m/s wind speed and we see different output values with the change of the wind speed .

Comparing the two cases , we conclude that the pitch controller have a maximum wind speed witch insure its work , and the power output will be constant and at the maximum with this increasing wind speed above the maximum value .

3.6 Diesel generator

As our thesis presents a hybrid system based on renewable energies and the conventional source, we are using a diesel generator (DG) as the last one source which utilizes a diesel engine and electric generator to generate electrical energy. Liquid fuels or natural gas are usually used as the primary fuel of the diesel generator. Totally, a diesel generator works based on air compression and the fuel,or mechanical machines.

Modeling of diesel generator

To attenuate shortfalls in energy production during periods of poor sunshine and wind, hybrid systems require a backup diesel generator for increased system availability . The choice of diesel generator depends on type and nature of the load. To determine rated capacity of the engine generator to be installed, following two cases should be considered:

1. If the diesel generator is directly connected to load, then the rated capacity of the generator must be at least equal to the maximum load, and
2. If the diesel generator is used as a battery charger, then the current produced by the generator should not be greater than CAh/5 A, where CAh is the ampere hour capacity of the battery.

$$\eta_{over-all} = \eta_{breakthermal} \times \eta_{generator} \ldots\ldots\ldots\ldots\ldots\ldots..(4.1)$$

Here $\eta_{breakthermal}$ is brake thermal efficiency of diesel-engine. Normally, diesel generators are modeled in the control of the hybrid power system in order to achieve required autonomy. It is observed that if the generator is operated at 70–90% of full load than it is economical. In the absence of peak demand, diesel generators are normally used for meeting load requirements and for battery charging.

The hourly fuel consumption of DG is assessed using the following equation (4.2) :

$$D_f\ (t) = \alpha_D\ P_{Dg} + \beta_D\ P_{Dgr} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.2)$$

Where, $D_f(t)$ is the hourly fuel consumption of DG in L/h, P_{Dg} is the average power per hour of the DG, kW, P_{Dgr} is the DG rated power, kW, αD and βD are the coefficients of the fuel consumption curve, L/kWh, these coefficients have been considered in this book as 0.246 and 0.08145, respectively [46].

3.7 Automatic voltage regulator (AVR)

The automatic voltage regulator is used to regulate the voltage. It takes the fluctuate voltage and changes them into a constant voltage. The fluctuation in the voltage mainly occurs due to the variation in load on the supply system. The variation in voltage damages the equipment of the power system. The variation in the voltage can be controlled by installing the voltage control equipment at several places likes near the transformers, generator, feeders, etc., The voltage regulator is provided in more than one point in the power system for controlling the voltage variations.

3.7.1 Ecitation system

The system which is used for providing the necessary field current to the rotor winding of the synchronous machine, such type of system is called an excitation system. In other words, excitation system is defined as the system which is used for the production of the flux by passing current in the field winding. The excitation system consists of an exciter and AVR.

3.8 Conclusion

This chapter provided an overview of pitch controller of wind energy conversion system and diesel generator. Equations related to the wind turbine and its mechanical torque are given. The major components of WECS were discussed, including maximum power point tracking algorithm, wind turbine, gearbox, pitch controller, electrical generator, AC/DC power electronic converter, DC/AC three-phase inverter and PLL. The obtained results in this chapter show wind speed effect on the output wind power and the rotor speed of the wind turbine .Also pitch controller principale of work .Finally ,diesel generator , automatic voltage regulator and excitation system has been defined.

CHAPTER 4

General simulation results and discussion

- *Introduction*
- *Key components*
- *Results and discussions*
- *Conclusion*

General simulation results and discussion

General simulation results and discussion

4.1 Introduction

As discussed, earlier hybrid power system is a combination of more than one energy source, each one generates different form of energy (DC or AC), to meet all scenarios of load demand and buck up source is desirable. Connecting all these elements requires the use of different types of power electronic conversion systems. Different topologies of connection can be made.

In this chapter, our objective is to model and simulate a hybrid power system for different situations based on a variable load, irradiance and wind speed . The studied system includes photovoltaic panel, wind turbine and synchronous diesel generator. The modeling and simulation of the whole system has been performed under Matlab/Simulink environment.

The simulation is performed in three main cases presented within this chapter sections:

- Only PV array .
- Only wind turbine .
- PV + Wind .
- only the diesel generator (DG) with variable load .

4.2 Key components

4.2.1 Three phase transformer

A three-phase transformer consists of six windings, three for the primary and three for the secondary. The windings on each side (primary and secondary side) can be connected in either delta or star configurations. These windings can be viewed as separate single-phase windings. In theory, three single-phase transformers can be connected creating a three-phase transformer.

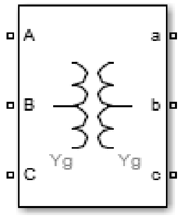


Fig 4.1 *Three phase transformer .*

4.2.2 Three phase breaker

The Three-Phase Breaker block implements a three-phase circuit breaker where the opening and closing times can be controlled either from an external Simulink® signal (external control mode), or from an internal control timer (internal control mode).The Three-Phase Breaker block uses three Breaker blocks connected between the inputs and the outputs of the block. It can be used in series with the three-phase element. The arc extinction process of the Three-Phase Fault block is the same as for the Breaker block.

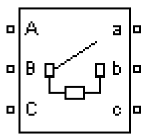


Fig 4.2 *Three phase breaker .*

4.2.3 Three phase V-I measurement

The three-phase V-I measurement block is used to measure instentanous three-phase voltages and currents in a circuit When connected in series with three-phase elements ,it returs the three pahse-to-ground or phase-to-phase peak voltages and currents.The block can output the voltages and current in per unit(pu) values or in volts and ampers.

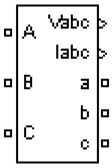


Fig 4.3 *Three-phase V-I measurement .*

Internation power Standards

All systems are sychronyzed , frequency 60Hz unity power factor.

Total harmonic distortion : THD ≤ 5%.

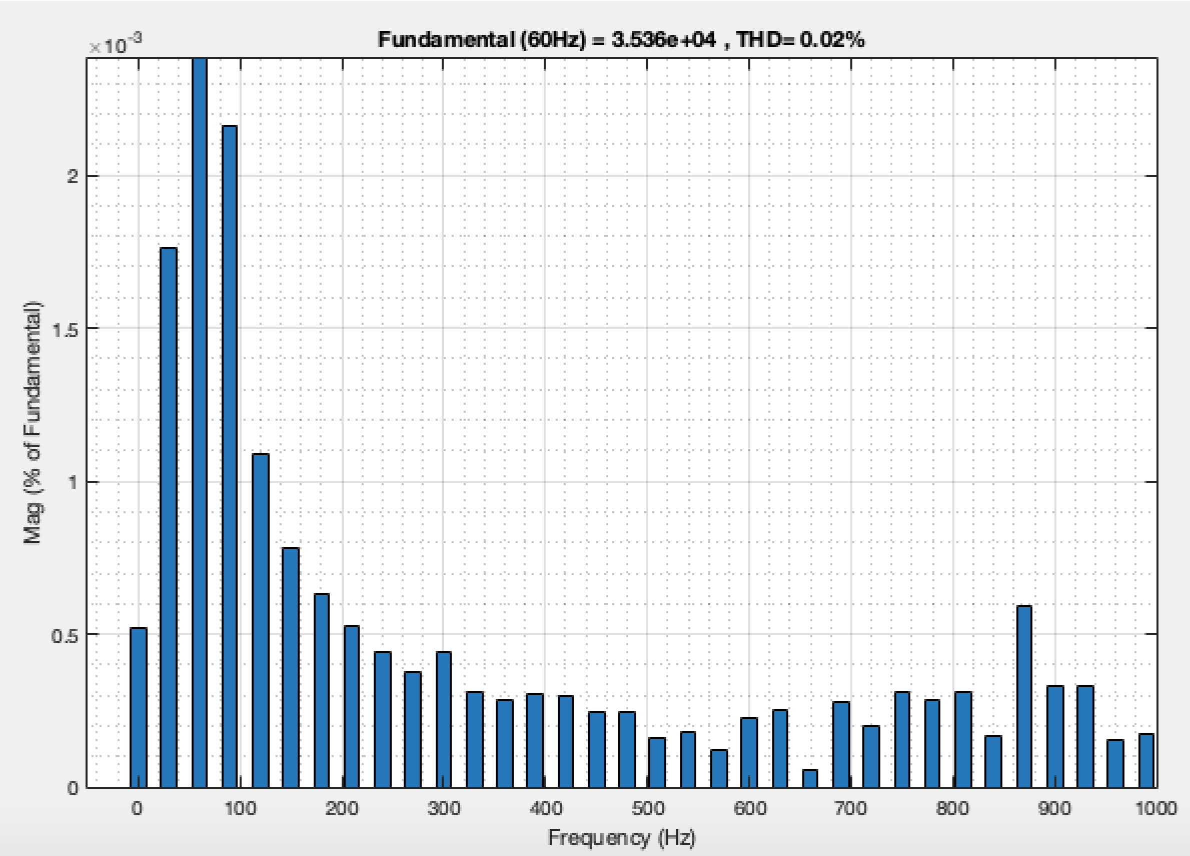


Fig 4.4 *Total harmonic disturtion .*

4.3 Simulation results and discussion

Our simulations have been done under the conditions of variable loads and grid connection as shown in the figure below :

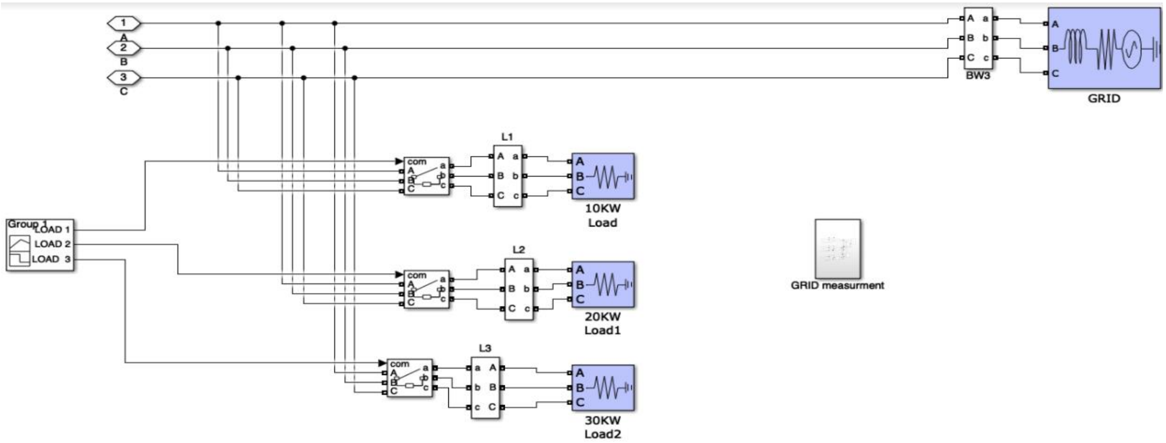


Fig 4.5 *Circuit diagram of variable loads and grid connection.*

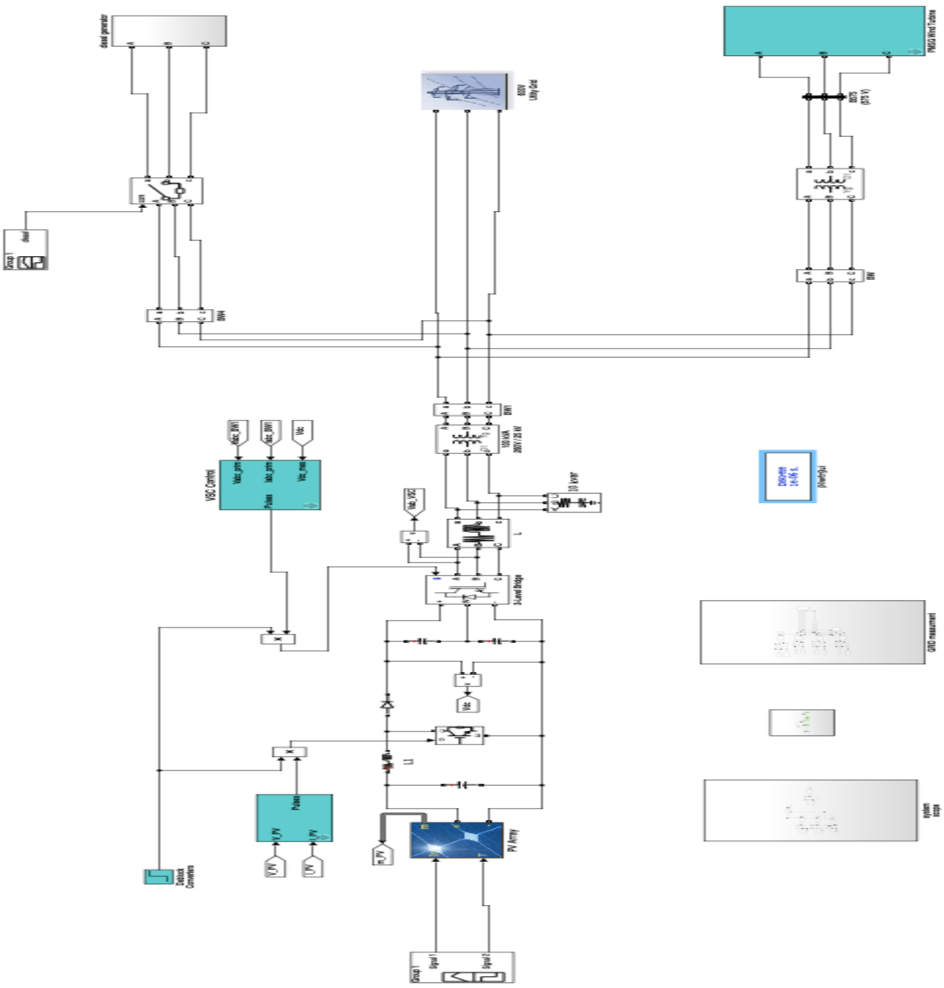


Fig 4.6 *Matlab /Simulink circuit diagram of the general system*

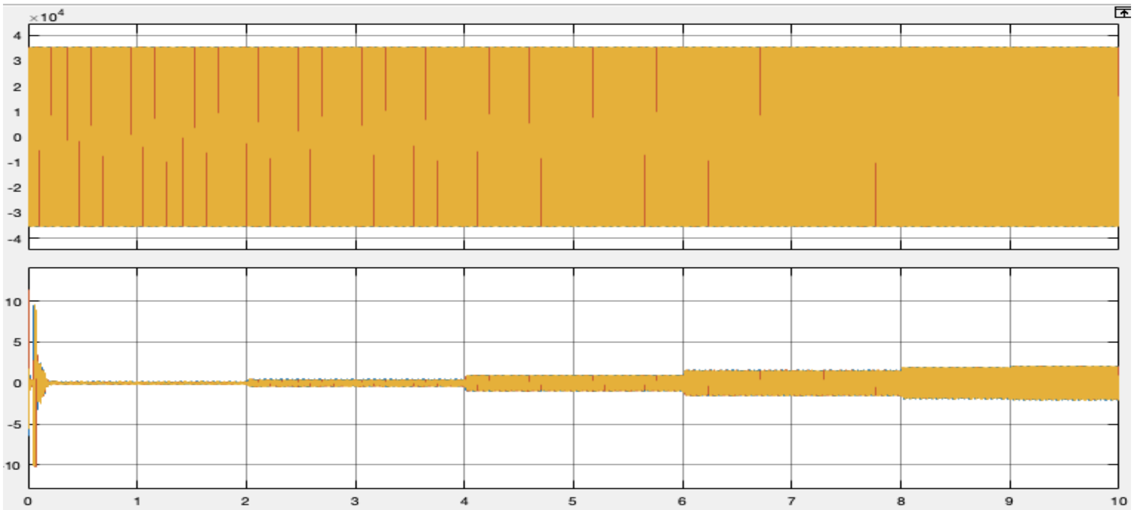


Fig 4.7 *Three phase output voltage and current .*

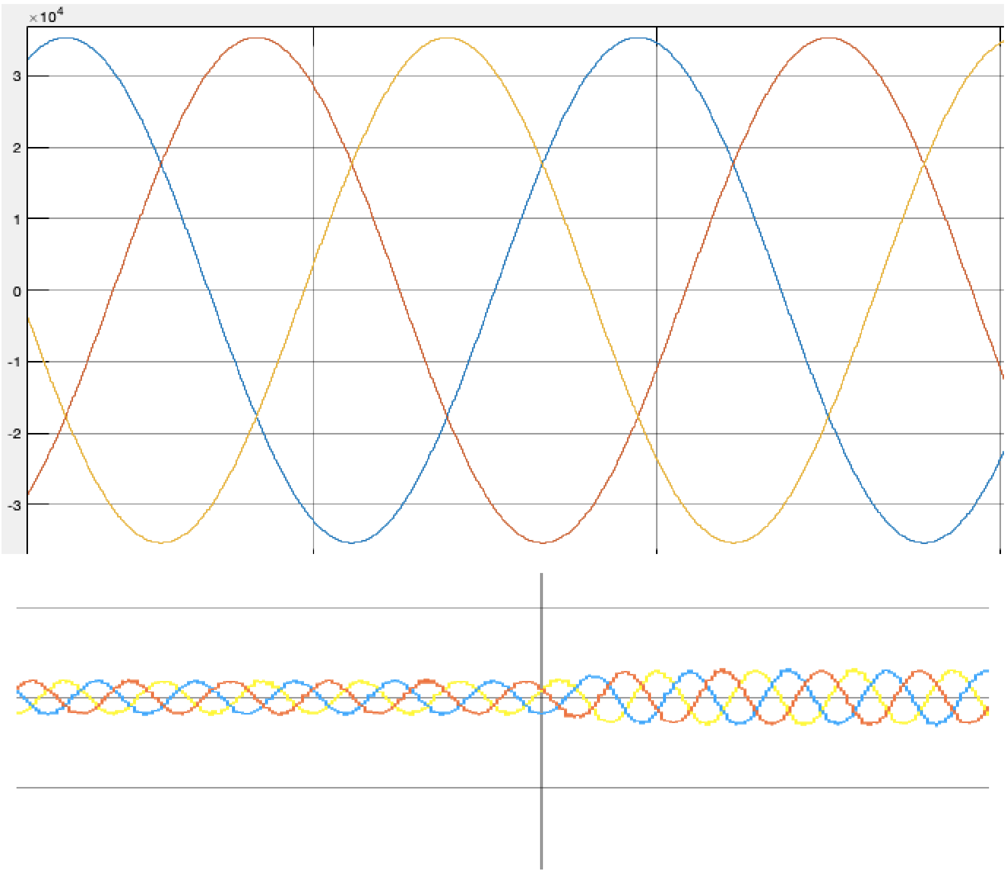


Fig 4.8 *Three phase output current and voltage (Zoom in).*

4.3.1 Simulation results (Exictance of the sun only)

We simulate our system presented in Fig 4.6 connected to variable loads and grid under the condition of exictance of the sun only with the same variable solar irradiation .The results are presented in the figures below:

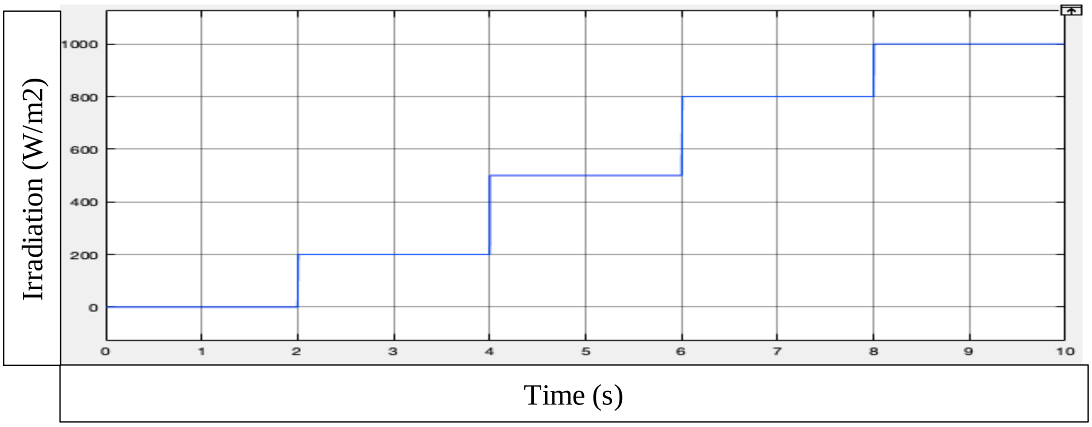


Fig 4.9 *Variabale solar irradiance of the PV system.*

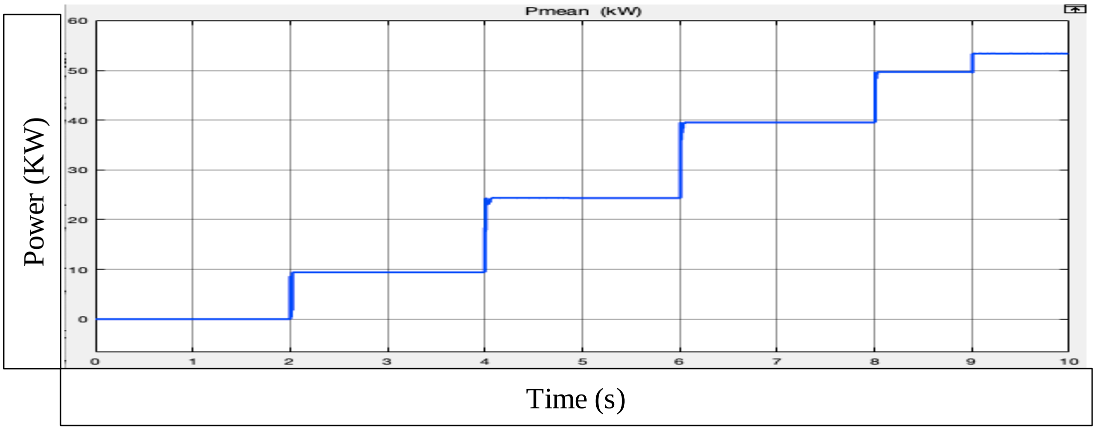


Fig 4.10 *Power generated by solar PV.*

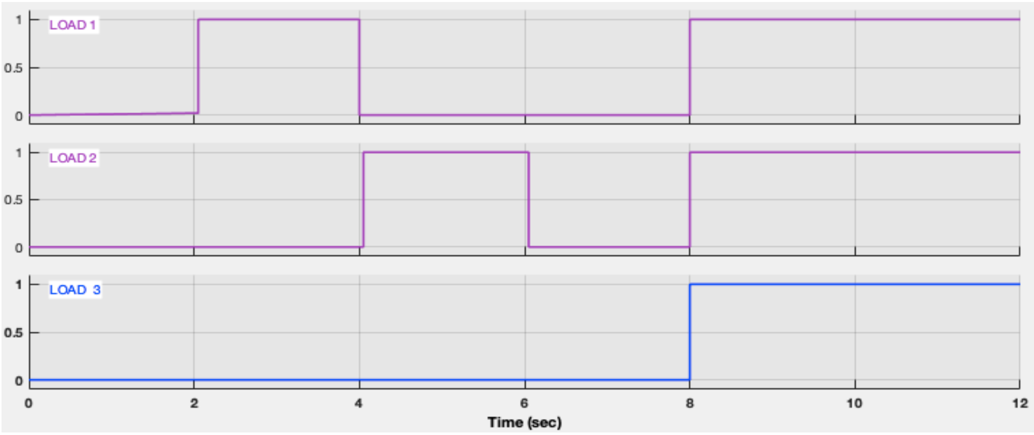


Fig 4.11 *Switch condition of each load(PV) .*

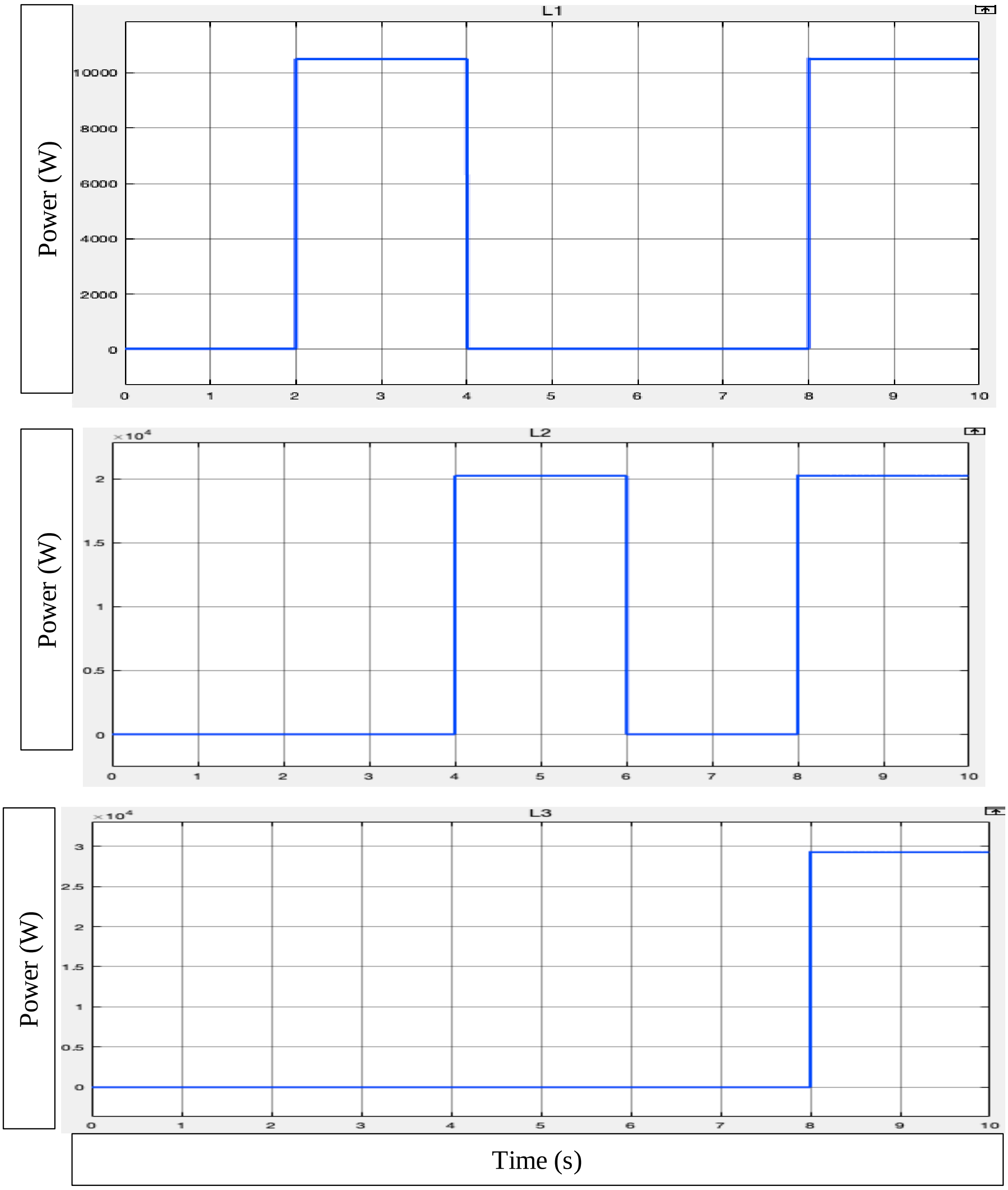


Fig 4.12 *Output power demand of each load (PV).*

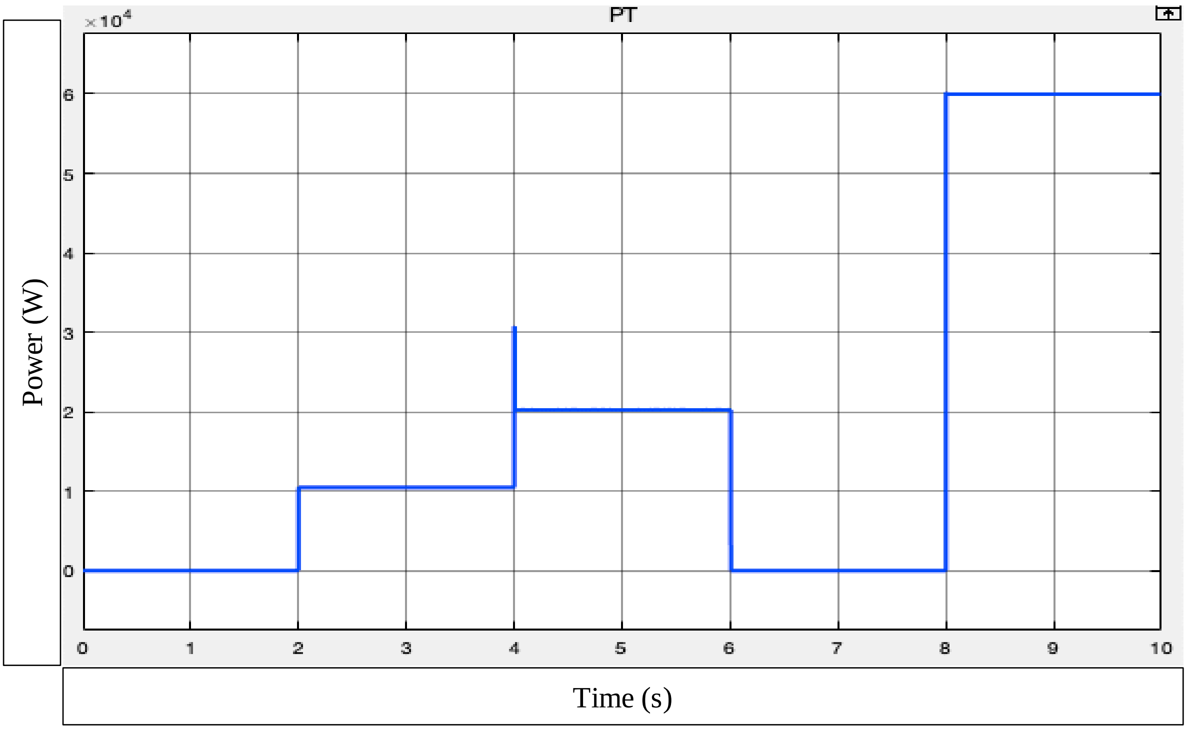


Fig 4.13 *The total output power demand (PV).*

Discussionof the results

We can summarize three main periods :

[2s-4s]: Switch one is on , load 1 is satisfied with 10KW as the power of the PV in the same periode on solar irradiation of 200W/m^2 is 10KW .

[4s-6s]: Switch two is on , load 2 is satisfied with 20KW as the power of the PV in the same periode on solar irradiation 500W/m^2 is 25KW .The additional 5KW is absorbed by the grid .

[8s-10s]: All switches are on , load 1 and load 2 are satisfied with 10KW and 20KW respectively unlike load three witch absorbes only 20KW as the power of PV in the same periode on solar irradiation 1000W/m^2 is 50KW. Deficient energy of 10KW is absorbed from the grid .

4.3.2 Simulation results (Exictance of wind only)

We simulate our system presented in Fig 4.6 again whitch is connected to variable loads and grid under the condition of exictance of the wind only with the same wind speed profile. The results are presented in the figues of the next page :

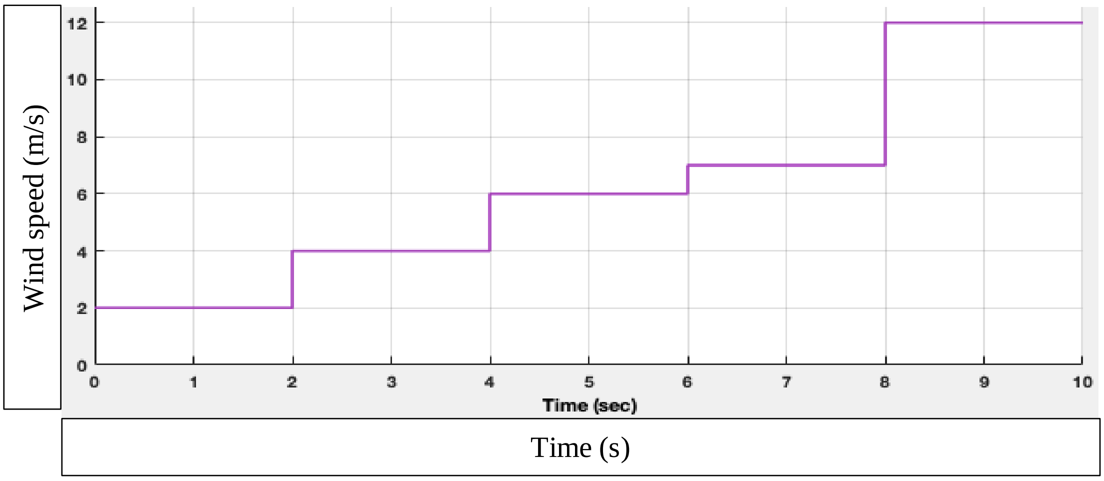


Fig 4.14 *Wind speed profile.*

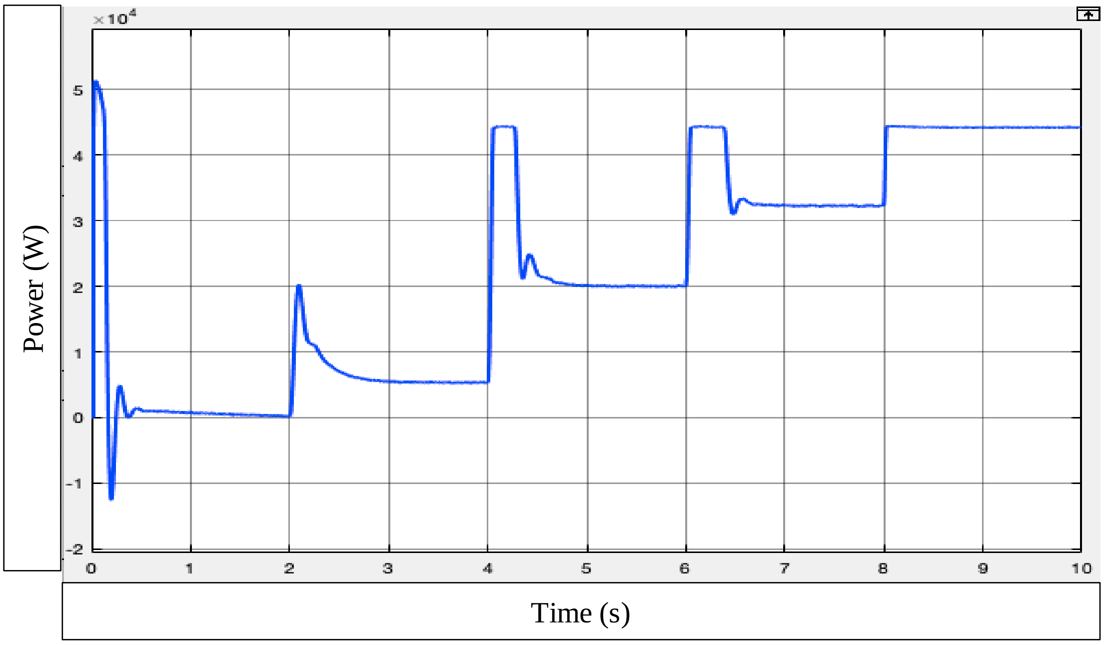


Fig 4.15 *Output power of the wind turbine.*

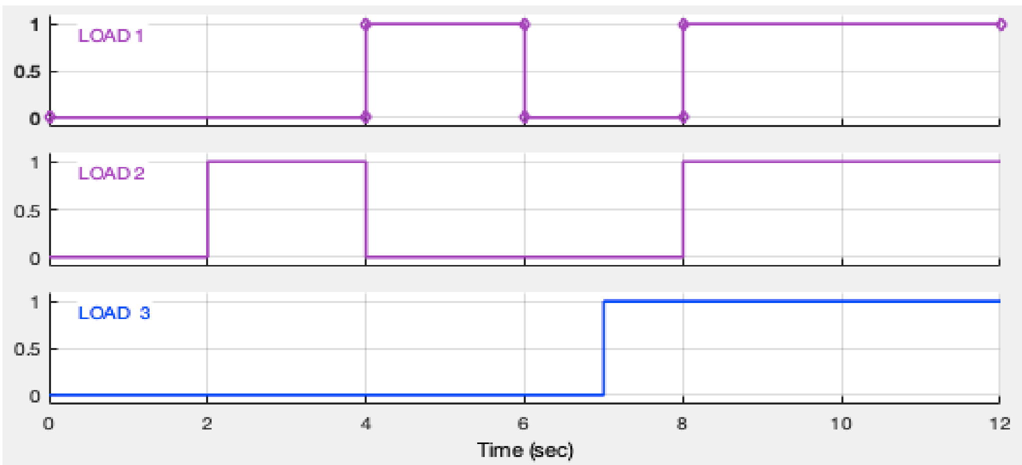


Fig 4.16 *Switch condition of each load (Wind).*

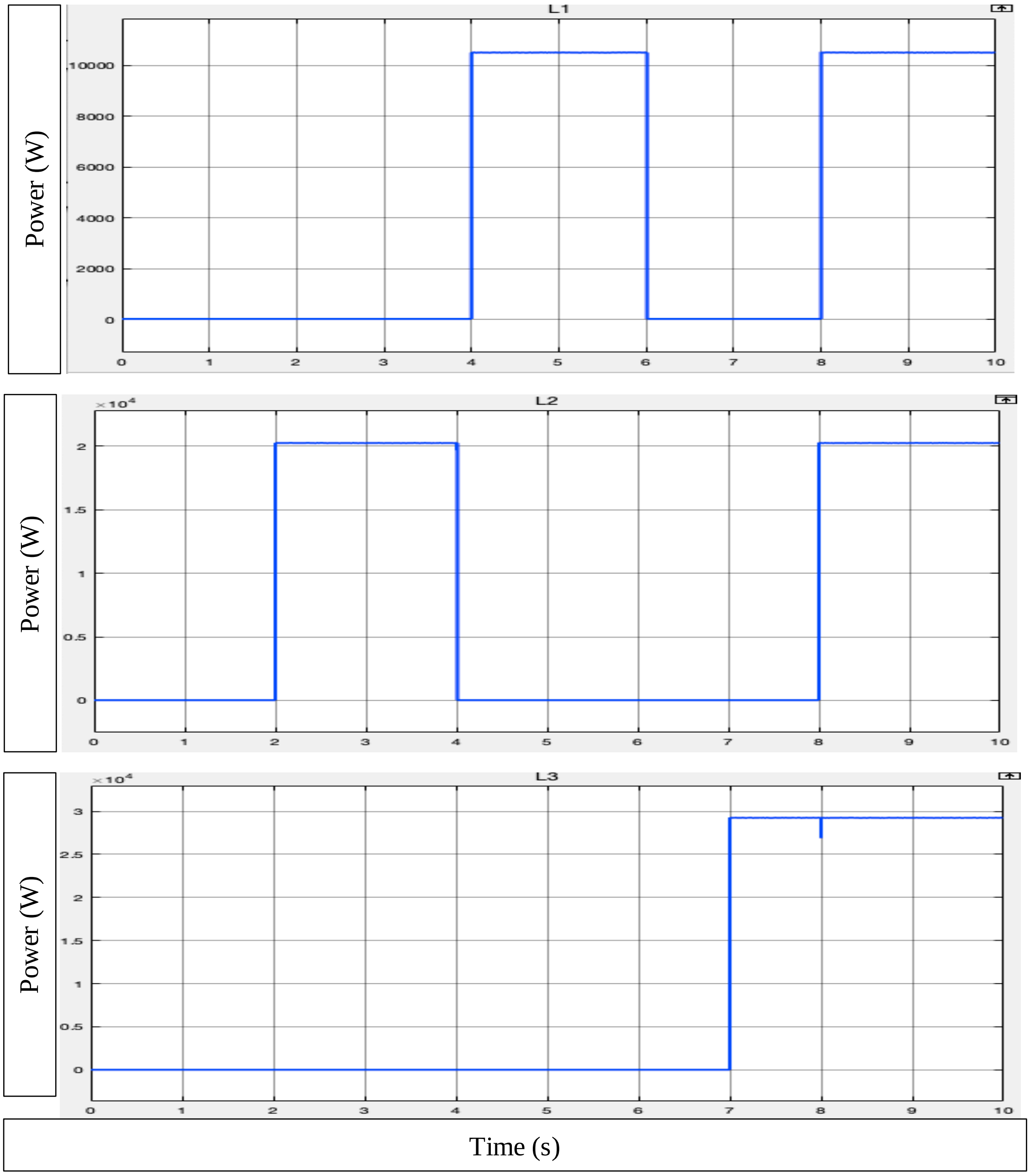


Fig 4.17 *Output power demand of each load (Wind).*

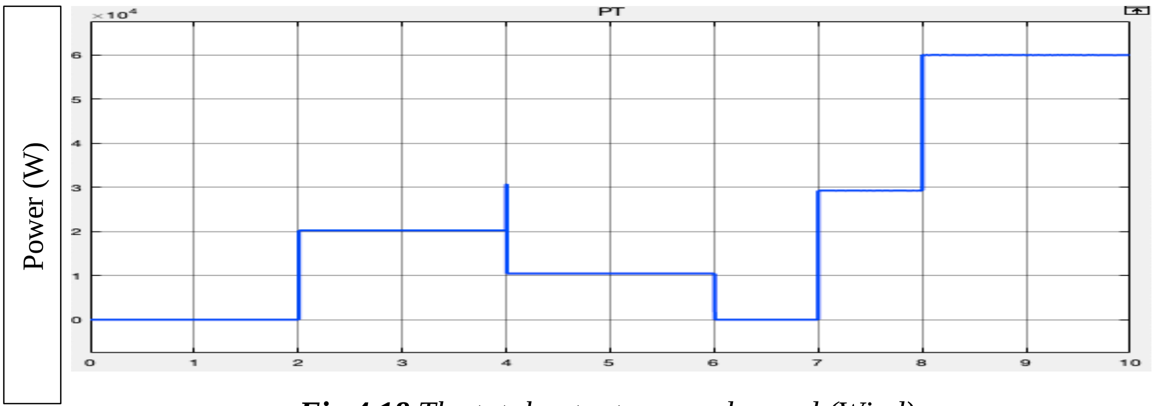


Fig 4.18 *The total output power demand (Wind).*

Discussion and results

We can summarize four main periods :

[2s-4s]: Switch two is on , load 2 is not satisfied with 20KW as the power output of the wind turbine in the same periode on wind speed of 4m/s is 10KW. Deficient energy of 10KW is absorbed from the grid.

[4s-6s]: Switch one is on , load 1 is satisfied with 10KW as the power output of the wind turbine in the same periode on wind speed of 6m/s is 20KW. The additional energy of 10KW is absorbed by the grid.

[7s-8s]: Switch three is on , load 3 is satisfied with 30KW as the power output of the wind turbine in the same periode on wind speed of 7m/s is 30KW.

[8s-10s]: All switches are on , load 1 and load 2 are satisfied with 10KW and20 KW recpectively unlike load 3 witch absorbes only 20KW as the power output of the wind turbine in the same periode on wind speed of 12m/s is 50KW. Deficient energy of 10KW is absorbed from the grid.

4.3.3 Simulation results (Exictance of solar and wind)

We simulate our system presented in Fig 4.19 under the condition of exictance of the sun and wind with the same variable solar irradiance in Fig 4.9 and wind speed profile in Fig 4.14. Also the same output power generated by PV in Fig 4.10 and output power of wind turbine Fig 4..15.

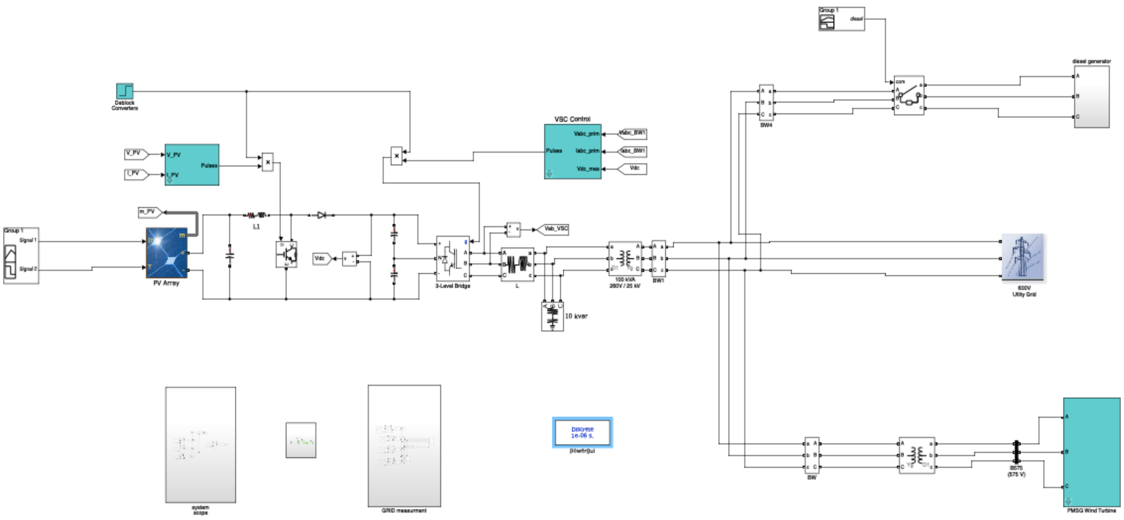


Fig 4.19: *SIMULINK model for overall System (PV+Wind).*

Other results are shown in the figures below:

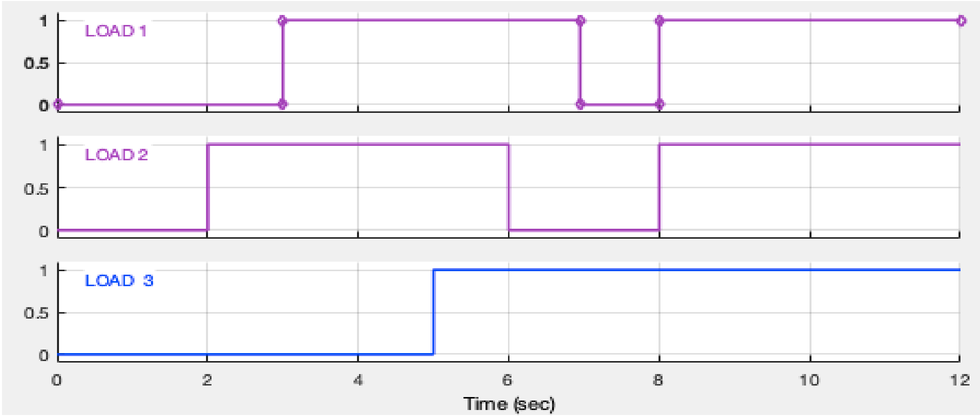


Fig 4.20 *Switch condition of each load (PV+Wind).*

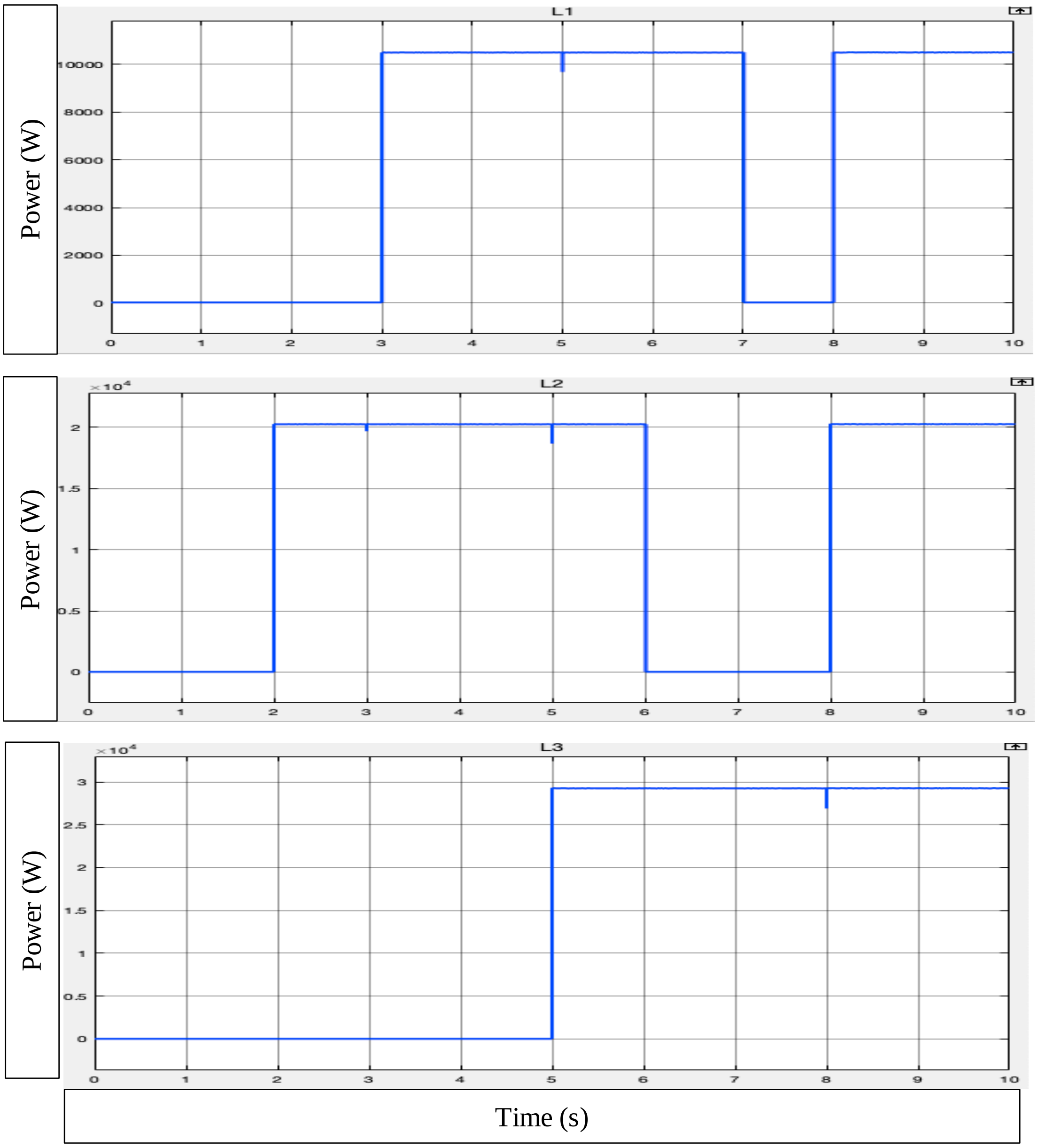


Fig 4.21 *Output power demand of each load (PV+Wind).*

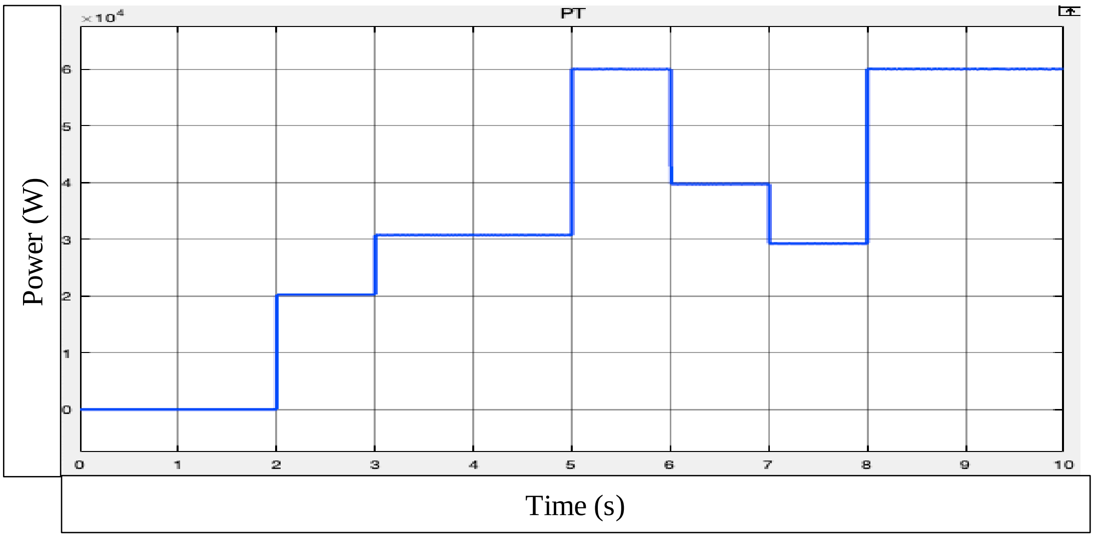


***Fig 4.22** The total output power demand (PV+Wind).*

Discussion and results

We can summarize five main periods :

[2s-3s]: Switch two is on , load 2 is not satisfied with 20KW as the power output of the wind turbine and the PV in the same periode on solar irradiation of 200W/m^2 and wind speed of 4m/s is 10KW. Deficient energy of 10KW is absorbed from the grid.

[3s-5s]: Switch one and two are on , load 1 and load 2 are not satisfied with 10KW and 20 KW recpectively as the power output of the wind turbine and the PV in the same periode on solar irradiation of 200W/m^2 and wind speed of 4m/s is 10KW from 3s to 4s and the power output of the wind turbine and the PV in the same periode on solar irradiation of 500W/m^2 and wind speed of 6m/s is 20KW from 4s to 5s. Deficient energy of 20KW in the first sub-range and 10KW in the second is absorbed from the grid.

[5s-6s]: All switches are on , load 1 is satisfied with 10KW unlike load 2 and load 3 witch absorbe only 10KW as the power output of PV the wind turbine in the same periode on solar irradiation of 500W/m^2 and wind speed of 6m/s is 20KW. Deficient energy of 30KW is absorbed from the grid.The same for sub- range **[8s-12s]** .

[6s-7s]:]: Switch one and three are on ,load 1 and load 3 are not satisfied with 10KW and 30 KW recpectively as the power output of the wind turbine and the PV in the same periode on solar irradiation of 800W/m^2 and wind speed of 7m/s is 30KW. .Deficient energy of 10KW is absorbed from the grid.

[7s-8s]: Switch three is on , load 3 is satisfied with 30KW as the power output of the wind turbine and the PV in the same periode on solar irradiation of 800W/m^2 and wind speed of 7m/s is 30KW.

4.3.4 Discussion the exictance of only diesel generator (buck-up)

When we have the case of night and no windnwe lose our renewable energy sources for loads and grid so we activate the diesel generator with 50KW stable power to feed the loads and to keep the power stored on the grid earlier from PV and wind turbine saved after . So the diesel generator work as buck-up system.

4.4 Conclusion

In this chapter, simulation and control of a Micro-grid system consisting of photovoltaic array ,wind turbine , Grid and diesel generator (buck-up source) are implemented under Matlab/Simulink environment. Different situations are tested and discussed. The aim of this system is to extract the produced power by (PV) system and wind turbine to the electrical network (load), and manage the system without errors of power or any electrical errors. And in case of luck of renewable energies the system satisfied by the diesel generator DG.

General Conclusion

Nowadays, modern nations produce the majority of their power using conventional energy generation technology, based on fossil fuel, nuclear or waterfall. These power plants generate power at large scale and dominate power systems almost all around the world.

However there is trend everywhere to turn to clean, renewable and sustainable energy sources. So far their utilization is somehow limited to micro-grids, islanded hybrid power systems or grid-connected small power plants.Our project aimed to design and optimize an grid hybrid renewable energy system (HRES) for a remote island load, where a grid extension is available. The study considered two type of renewable energy resources , and diesel generator witch works as a buck-up , we study this situation and try to inecrease the use of renewable energies over the conventional one and see it’s effect on the general system , especially the microgrid.

As further work, we propose the following:

1. Introducing storage element and considering greenhouse emission in the energy management
2. Optimal sizing of DGs for a given load profile and specified location using metheuristic algorithms;
3. Considering incertenty of weather parameters in the design of such microgrid .

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Appendix E