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Praise be to Allah for his blessings and for the power he gives me to finish this work, there is no power nor strength save in Allah, only by Allah's blessing this where possible.

{Say, "Are those who know equal to those who do not know?" Only they will remember [who are] people of understanding} sūrat l-zumar (39:9)

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Finally, I wish to thank enough my parents, my brothers, my sister, my friends who helped me and all of my family members whom contributed in immeasurable ways that are too difficult to enumerate here.

Dedication

This work is dedicated

to my mother my first person in life,

to my father without him I am nothing.

to my brother Alae, my sister Sanae,

For their endless love, support and encouragement.

To all of my family members whom courage me to keep

following my dreams.

To my friends who helped me in multiple ways.

Dedicated for everyone wonders, if ill dedicate this to theme.

Yes, I am.

ملخص

سنرى في هذا العمل الالة الهجينة تقوم بحساب سرعة الرياح و الاشعاع القادم من الشمس من خلال هذه العملية تختار الالة اي منهما ينتج طاقة اكبر وحسب النتيجة تختار الوضعية المناسبة فإذا كانت سرعة الرياح مناسبة تأخذ الالة وضعية عنفة الرياح (سافونيوس) حيث تقوم الرياح بتدويرها و هكذا يدور مولد الكهرباء و هذا ما ينتج الطاقة الكهربائية اما اذا كانت الطاقة الشمسية هي الأنسب فتختار الالة وضعية الألواح الشمسية و تقوم بتتبع الشمس منتجة اكبر قدر ممكن من الطاقة الكهربائية و هذه الطاقة الناتجة إما تستهلك مباشرة او تخزن في بطاريات للاستعمال في وقت لاحق.

الكلمات الدالة : الالة الهجينة - سرعة الرياح - الاشعاع القادم من الشمس - سافونيوس - الألواح الشمسية - تتبع الشمس - الطاقة الشمسية - الطاقة الكهربائية.

Abstract

We will see in this work a hybrid machine that calculates the speed of winds and the radiation coming from the Sun, Through this procedure, the machine chooses which one produces the most energy and according to the result it chooses the appropriate position, If the wind speed is appropriate, the machine will take the wind turbine position (Savonius) where the wind rotates it, the generator produces electric energy, but if the solar energy is the most appropriate, the machine chooses the position of the solar panel and tracks the sun. tracking the Sun will Produce the largest possible amount of electrical energy, and this resulting energy is either consumed directly or stored in batteries for later usage.

Keywords: hybrid machine - the speed of winds - the radiation coming from the Sun – Savonius - the solar panel - tracks the sun - the solar energy - electrical energy.

Résumé

Nous verrons dans ce travail une machine hybride qui calcule la vitesse des vents et le rayonnement provenant du Soleil, Grâce à cette procédure, la machine choisit celle qui produit le plus d'énergie et en fonction du résultat elle choisit la position appropriée, Si le vent la vitesse est appropriée, la machine prendra la position de l'éolienne (Savonius) où le vent la fait tourner pour que le générateur produise de l'énergie électrique, mais si l'énergie solaire est la plus appropriée, la machine choisit la position du panneau solaire et suit le soleil. Le suivi du soleil produira la plus grande quantité d'énergie électrique possible, et cette énergie résultante est soit consommée directement, soit stockée dans des batteries pour une utilisation ultérieure.

Mots Clés : machine hybride - la vitesse des vents - le rayonnement provenant du Soleil - Savonius - panneau solaire - suivi du soleil - l'énergie solaire - l’énergie électrique.

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General introduction

The limited reserves of fossil fuels in addition to their leftovers and emissions paved the way to a promising alternative that is the renewable energy sources such as solar energy sources and wind energy sources. They are freely available and environmentally friendly. However, renewable energy sources are intermittent in nature. Therefore, the smoothing of power fluctuations (a regular change in voltage that happens when devices or equipment is require a higher load) by storing the energy during periods of oversupply and restore it to the grid when demand becomes necessary. Accordingly, Energy Storage Systems (ESSs) can be appropriately used for this purpose.

Wind energy has become one of the fastest emerging renewable energy technologies, with the total capacity by the end of 2016 reaching 487 GW (*about 4% of global electricity).* Furthermore, the technology and manufacturing infrastructure of wind turbines have advanced enough for further rapid deployment. As per the 2013 IEA roadmap, about 18% of global electricity needs will be met by wind energy by 2050. Most of the progress was anticipated on large onshore and offshore projects (*MW capacity)* far from urban areas, where the wind is most intense, consistent and unperturbed. On the other hand, there is considerable wind in the urban areas with a significant potential for power, road dividers, side of railway tracks, top and around the high-rise buildings. The development of an efficient wind energy system closer to the point of use meets the local power demand, minimizes the use of diesel/gas-based electricity generation, reduces the strain on the existing grid infrastructure, incorporates the sustainability in the cities, supports the local economy, and addresses the environmental concerns.

This technology aims at solving the intermittence problem of renewable energy sources, Hybrid Power System reconsidered. Obviously, several renewable energy sources are considered to be combined with both energy storage systems and Back-up power units or one of them only. Accordingly, possibilities of power sources can be obtained by hybridization of primary renewable energy sources such as solar energy sources and wind energy sources.

In this case, Solar Energy Sources provide their power in the daytime and wind energy sources produce usually more power with stronger wind in the night. hybridization of renewable energy sources and energy storage systems ensures both reliability and security of power generation systems. Henceforth, the produced and stored energies can be optimized to increase the yield energy of hybrid power systems using several energy sources for constructing hybrid

power system alongside with energy storage that would require an energy management strategy to achieve minimum hybrid power system cost and optimal balance between energy generation and energy consumption. This energy management method is a mechanism used in order to achieve an ideal energy production and to conveniently satisfy the load demand with alternative high efficiency.

Photovoltaic panels are one of the main hybrid power system elements. They have several operational problems especially shading problems. Numerous solutions have been presented until now. However, the high cost is still the hallmark of these solutions. Therefore, a new solution, making the equilibrium between the cost and the reliability, have been searched. In addition, the relatively PV panel flow efficiency has been enhanced by cooling the PV panels.

In this thesis, we will see a definition of renewable energy and its impact on the climate and the economy as a whole. Furthermore, we will also see the way solar panels function, its various types of which are different, and how to convert solar radiation into solar energy. We will also explain ways to increase efficiency to the highest percentage.

In chapter N°2, we will tackle the wind turbine, its types, its history and how it works. We will also see a definition of savonius, how it functions, and a calculation of the energy it produces.

In chapter N°3, we will go through the definition of Hybridization and also see some hybrid systems on the ground and also tackle the Storage Systems, how each system runs as well as their pros and what is needed.

In chapter N°4, we would go through the developing of a Smart Hybrid system that generates electric power from the Sun and Wind energy. Hence, we will see how it functions, electronically and electrically, and the parts that constitute form it.

CHAPTER ONE

INTRODUCTION & PHOTOVOLTAIC SYSTEMS

1.1. Introduction

The sun is one of RESs. It delivers 100,000 TW of energy to the earth. Whereas, the world energy consumption in 2012 was 12,476.6 million tons of oil equivalent of 145,103 TWh. Consequently, it is dazzling that the global energy consumption by the world can be produced by solar energy in every 88 minutes. In other words, 6000 times' annual energy consumption can be produced by received solar energy at the earth surface [34] [35].

This chapter is developed as follow. First Renewable energy production and its benefits, the photovoltaic technologies are presented, and particular attention is given to describe influence of by-pass and blocking diodes under non-uniform irradiation condition. Secondly, Maximum power point tracking are reviewed, since it optimizes the functioning of the photovoltaic panels.

1.2. Renewable energy production:

RESs refer to the sustainable natural energy sources, such as the sun and the wind. RESs convert these natural energy sources into consumable energy forms (electricity and heat), which are easy to transport and to use. According to the European directive on RES for production of electricity [01], RESs include: (ii) solar (photovoltaic, thermal electric); (iii) wind; (iv) geothermal; (v) wave and tidal energy; (vi) biodegradable waste; (vii) biomass (solids, biofuels, landfill gas, sewage treatment plant gas and biogas).

1.2.1. Benefits of renewable energy:

The potential contribution of renewable energies to IEA member countries (United Kingdom, Germany, France, United States, Japan…) is growing, as the technologies mature and there is an increasing awareness about the full contribution that renewable energies can make. Renewable energy sources contribute to the diversity of the energy supply portfolio and reduce the risks of continued (or expanded) use of fossil fuels and nuclear power. Distributed renewable energies provide options to consumers because of their deployment close to use. Renewable energy is also the most environmentally benign energy supply option available in current and near-term markets. Finally, renewable energies contribute to a healthy economy, both in their contribution to the efficiency of the energy system, and in the employment and investment opportunities that arise from continued rapid market growth [2]. The primary benefits to us are the energy security, the environment protection, and the economic growth.

a. Energy security

Faced with the energy challenges, the demand for primary energy in the world wide is evolving, particularly in fast developing countries like China. However, the stock of oil in our planet will soon be exhausted. Such dependency over an extended period is unsustainable. Renewable energy can relieve some of that increasing need for imported fossil fuels and reduce dependence on foreign sources. The distributed capability of renewable energies brings the electrical production closer to the end-use, thus minimizing energy transport concerns and costs. The Renewable Energy Working Party also believes that a greater use of renewables in the energy portfolio can minimize overall generation costs relative to the risk [3]. Energy policies should focus on developing efficient generating portfolios that do not solely rely on stand-alone costs but also on expected portfolio risk, including year-to-year cost fluctuations.

b. Environment protection

Moreover, today global warming becomes more serious due to the greenhouse effect. Some emissions of greenhouse gases come from the human activity. The production and processing of electrical energy is one of the main sources of greenhouse gases. Directly or indirectly, environmental concerns dominate the thrust for an expanded deployment of renewable energy technologies. Climate change concerns, which arose during the late 1980s, have created a new input for clean, low-carbon energy technologies, such as renewable energy technologies. In December 1997, the Kyoto protocol has been established in order to reduce global emissions of greenhouse gases. In the area of power generation, this protocol promotes renewable energy sources [4].

c. Economic growth

Renewable energy has several important economic benefits. In IEA (International Energy Agency) countries, the main economic benefits are employment creation and increased trade of technologies and services.

1.3. Solar Power Potential:

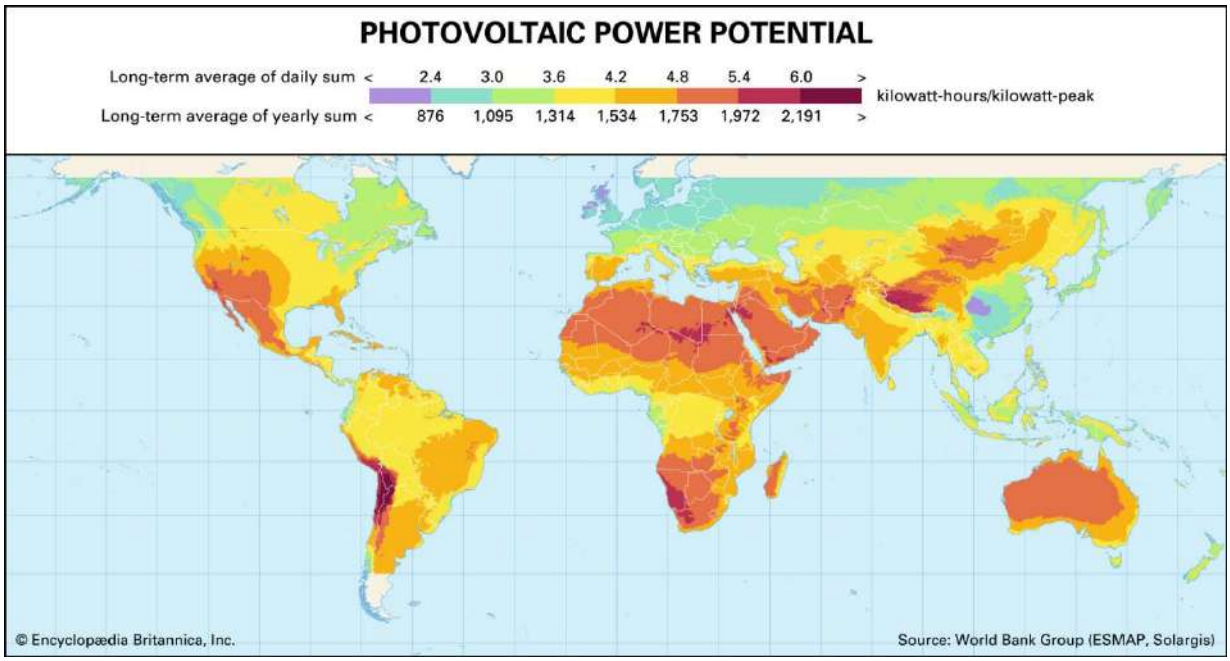


Figure 1.1 solar energy potential

Earth's photovoltaic power potential.

Solar power is energy from the sun that is converted into thermal or electrical energy. Solar energy is the cleanest and most abundant renewable energy source available, solar technologies can harness this energy for a variety of uses, including generating electricity, providing light or a comfortable interior environment, and heating water for domestic, commercial, or industrial use. [5]

Average daily insolation changes from 150 to 300 W/m^2 or 3.5 to 7.0 kWh/m^2 day. There are two main types of technologies for converting solar energy to electricity: Photovoltaic (PV) and solar–thermal electric [6].

• PV conversion produces electricity directly from sunlight via a solar cell. There are many types of PV cells, such as thin film, mono-crystalline silicon, polycrystalline silicon, and amorphous cells, as well as multiple types of concentrating solar power. PV power can be used either in small- or in medium-sized applications.

· Solar–thermal electric production based on concentrating solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. The concentrated solar energy heat is used for producing steam to drive turbines and produce

electricity. A parabolic trough consists of a linear parabolic reflector that concentrates light onto a receiver positioned along the reflector's focal line. The receiver is a tube positioned right above the middle of the parabolic mirror and is filled with a working fluid. The reflector is made to follow the sun during the daylight hours by tracking along a single axis [7]

Recently, solar installations are expanded into residential areas, with governments offering incentive programs to make renewable green energy sources more economic options [8].

1.4. Photovoltaic energy conversion:

Photovoltaic phenomenon is an intrinsic propriety of some material giving them the ability to convert sun light energy into electricity. It has been discovered by physicist Alexander Edmond Becquerel who originally presented it to the French science academy in 1839. Through the last decades, emergence of large-scale photovoltaic sourced system combined with public subventions enabled important decrease of the photovoltaic KWh costs. In the same time, efficiencies grown making possible competitiveness face to other energy production solutions for some applications. [9]

The photovoltaic conversion efficiency, η, is the most important comparative measure for a photovoltaic device. It is defined as the maximum power produced by the photovoltaic panel divided by the incident light power under standard light conditions. Our Simulators provide repeatable light conditions.

$$\eta = \frac{Pout}{p} = \frac{Voc\ Jsc\ FF}{P} \qquad 1.1$$

Where:

Pout = output power density produced by the panel

P = the incident power density

Voc = the open circuit voltage

Jsc = the short circuit current

FF = the fill factor

The definitions assume illumination with the standard irradiation.

1.4.1. Existing technologies:

In the literature, several documents review existing technologies for photovoltaic cells as for example [10, 11]. In [12], technological industries linked to cells manufacturing are presented. There, a brief review of existing technologies is proposed. Nowadays, two main technologies shared most of the market. First comes technologies based on crystalline silicon with around 90% of the sales. Second is thin-film technologies with nearly the left. Recent developed technologies are also briefly presented. Researches on the subject are making very fast progress resulting in improved efficiency for every type of existing technologies and appearance of newer and promising solutions. **Figure 1.2** shows improvement on the maximum efficiencies (i.e. electrical power vs irradiating sun power) obtained with research cells from 1975 for different technologies as detailed in the next paragraphs.

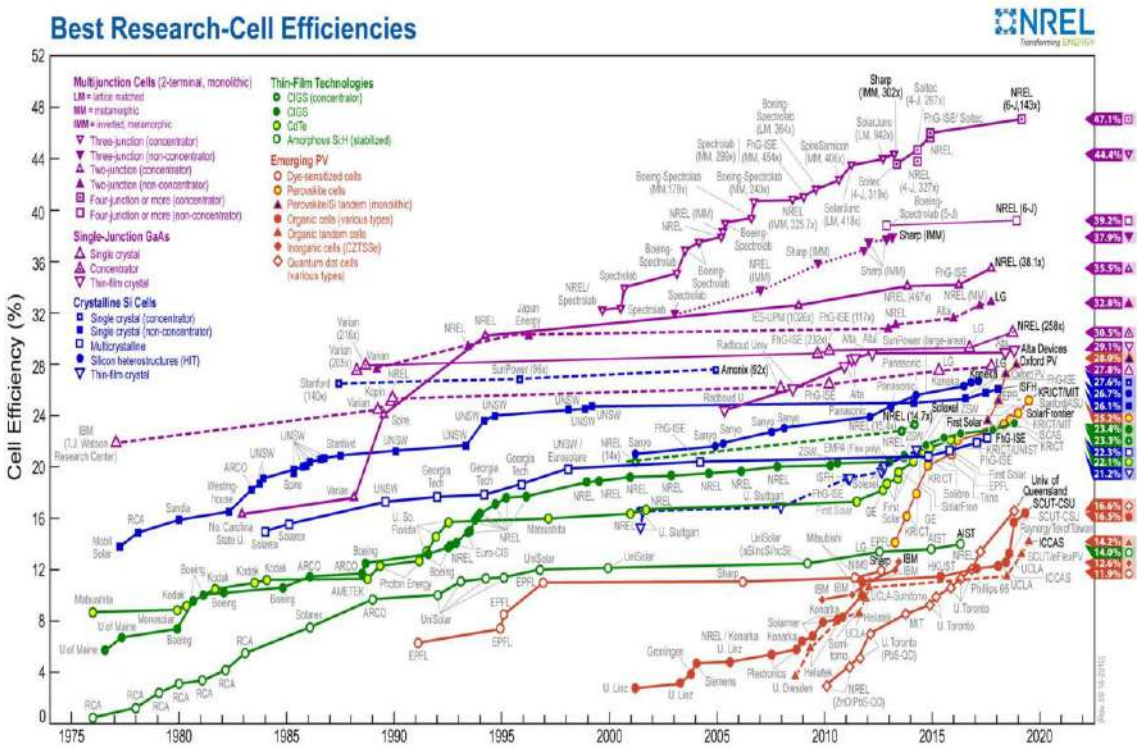


Figure 1.2 PV research-cell efficiencies [13]

Crystalline silicon based technologies:

Crystalline silicon based technologies (in blue in Fig02) are the most present on the market. Silicon is very frequently used in industry in view of its semiconductor proprieties and its abundance. Indeed, silicon is the second most abundant element in the Earth's crust (about 28% by mass) after oxygen [14]. Those technologies can be separated in two, face to crystallization techniques utilized.

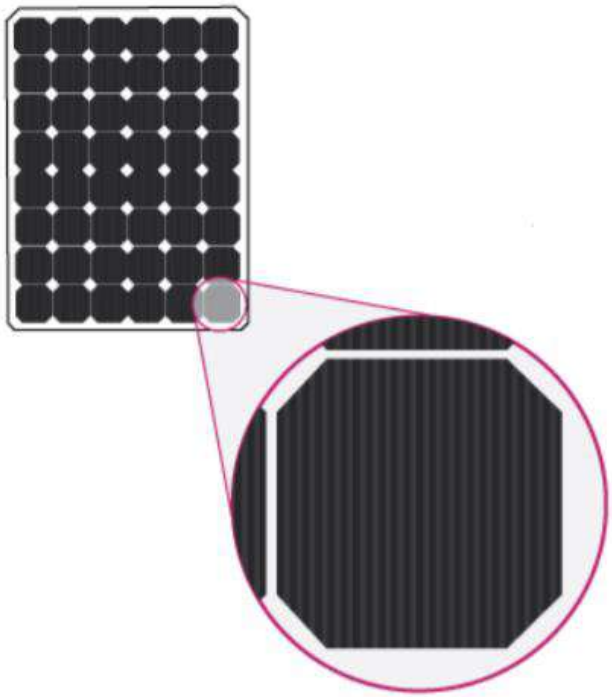


Figure 1.3 Mono-crystalline.

• **Mono-crystalline (or single crystal) silicon:**

It represents nowadays most common technology with a round of the market [10]. This technology is the one used for experimental verification of this thesis purpose. With actual knowledges, efficiency of this kind of technologies are around 18% to 25%. **Figure 1.3**

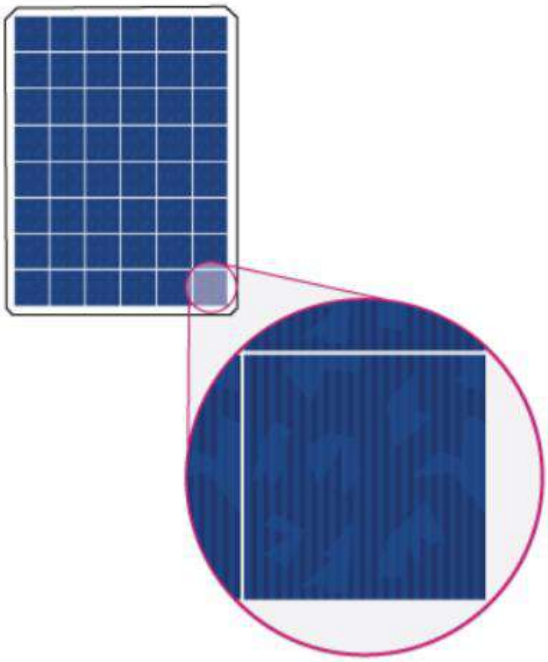


Figure 1.4 Poly-crystalline.

• **Poly-crystalline (or multi-crystalline) silicon:**

Under cost reduction objectives, new crystallization processes have been developed. Then, poly crystalline silicon technologies follower], with production costs reduced. However, compared with mono-crystalline solutions, efficiencies are still lower as they stay between 12% and 20% maximum.



Figure 1.5 Thin-film Amorphous.

- **Thin-film technologies:**

Thin-film photovoltaic technologies are also called second-generation technologies as they appeared later on the marked than crystalline silicon-based one. Under thin-film, it is supposed structures with a thickness lower than 5 µm [12]. Even if thin-film solutions present lower efficiency than silicon-based technologies, they have been developed because of a much lower production cost. Thin-film technologies have been widely studied until now as for example in the review detailed in [15] and [16] for modelling purpose. Among every thin-film possibilities, two different solutions distinguished because of their performances and simplicity of production [12], namely CdS/CdTe and Cu (In, Ga) Se2 technologies. Amorphous variations are also well represented on the market.

- **CdS and CdTe:**

Among thin-film technology possibilities, CdS and CdTe presents the better efficiency with commercial solutions between 10% and 16%. The use of CdTe comes from the long-time knowledge that this material present an ideal gap (1.45eV) with a high direct sun light absorption coefficient [10]

- **Cu (In, Ga) Se2:**

This technology and its variations such as CulnSe2 also named CIGS allow efficiencies around 9% to 15%. As underline in [12], CIS is a very promising material for photovoltaic modules mass production.

- **Amorphous silicon:**

Amorphous silicon (a: Si) is the most present technology among thin-film possibilities [11] However, it only enabled efficiencies around 6% to 10%, staying lower than other results.

1.4.2. Third generation technologies:

Since a couple of years, new photovoltaic technologies appears on the market. As examples, it can be notice some solutions based on organic cells or painting with solar energy conversion capabilities. Even if those technologies are competitive in term of cost, they are few represented on the market because of their efficiency rarely higher than 5 — 8%

Other more promising solutions are multi-junctions and GaAs cells. Their main disadvantage is their production complexity, leading to a far too high cost in most of the applications. However, those technologies shown the better efficiency of every photovoltaic

solutions with some up to 40%. For this reason, those technologies are widely used for space applications (where budgets are huge) as for example on every satellites recently orbited.

1.5. Resulting characteristic:

Whatever the used technology is, resulting characteristics present the same behavior as they are based on the same physical principle (photovoltaic phenomenon). Two main parameters have to be taken into account since they modified the characteristic, namely the solar irradiation level (S in W/m2), and the photovoltaic cell temperature (T in K). Figure 06 presents characteristic typical behaviors, and its evolution with respect to irradiation and temperature.

It has to be notice that the behavior of the characteristic is similar indifferently while thinking in one cell, one array or one module composed of several arrays long as they are uniformly irradiated and supposed strictly identical. Only scales will change as photovoltaic arrays or modules are PV cells series / parallel associations.

Series associations of PV cells is motivated from the fact that cells only deliver very small voltage (< IV). Indeed, cell voltage comes from nature of the used material. Then in order to realize module with voltage easily usable, cells are always connected in series to form an array. As small surface cells production is easier, current is usually quite small. Parallel association is then necessary to obtain the required power, depending on the application.

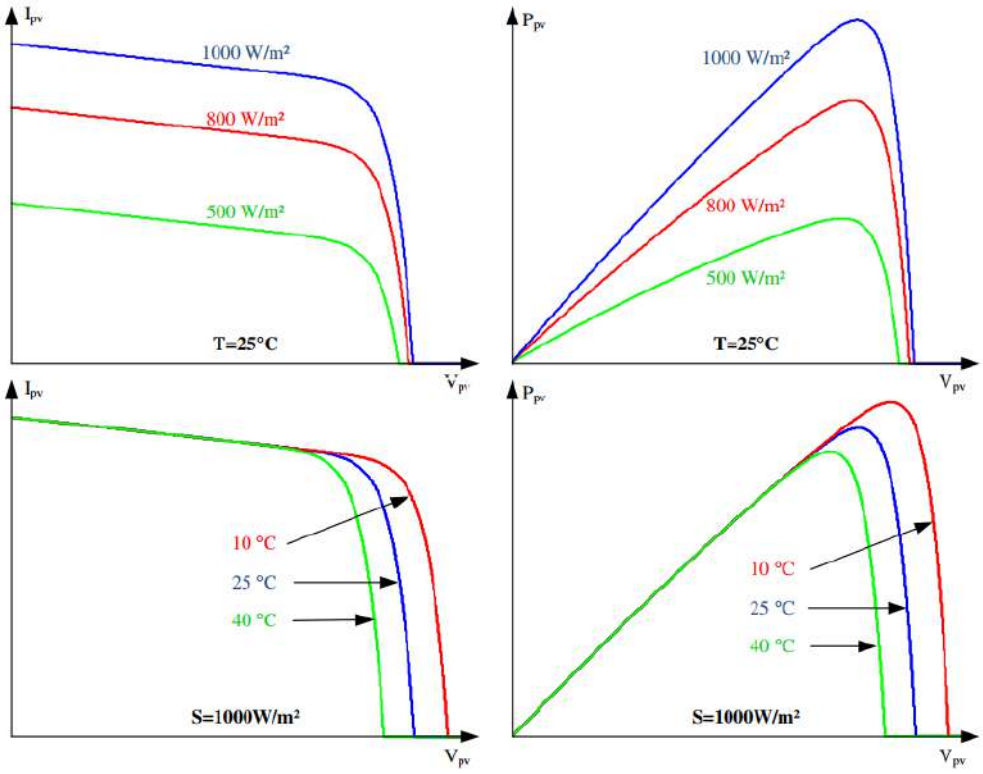


Figure 1.6 Photovoltaic cell typical characteristics.

1.6. Non-uniform irradiation behavior - Protection diodes influence:

Series and parallel connection of photovoltaic cells is often required to obtain desired voltage and current. Supposing strictly identical cells under uniform conditions of irradiation and temperature, it result of an array with voltage increase by number of cells in series and current multiplied by number of parallel associations. However, uniform condition among every associated connected cells cannot be guaranteed (partial shadow, various orientations …). Non-uniform conditions among an array can be very impacting since it can even lead to cell destruction if thermal constraint is high or falling voltage reach [17].

By pass diodes usefulness is illustrated in **Figure** 1.7 In this figure, the static characteristic resulting from the interconnection of two differently irradiated cell groups without by-pass diodes is represented (in orange). It appears indeed that there is a part of the resulting characteristic without by-pass diodes where the shaded cells group can work as receptor instead of generator. As an example, for a functioning of the global array on point B of the characteristic, it will result on a shaded group of cells working on point A, i.e. viewing a negative voltage.

Such receptor functioning of the cell as to be proscribe as it leads to it degradation. In the literature, non-uniform conditions are also called "mis-match" phenomenon, and associated degradation is mainly caused by "hot-spot" phenomenon. To overcome this problem, by pass diodes are connected in parallel with cells. Then, lower irradiated cell will be by-pass when trying to work as a generator. Resulting characteristic is also represented in **Figure** 1.7 (red dash-line). Practically there is not one by-pass diode per cell. Indeed, this would increase far too much cost of the module and will not be efficient especially because of the natural voltage drop of the diode. Classically, diodes are added per groups of 8 to 24 series connected cells, most common solution being 18 [18]. Notice that those diodes are generally directly added by photovoltaic modules manufacturers, with commercial solutions composed of several cells in series (typically 72 cells for a 48V array, with usually 4 by-pass diodes).

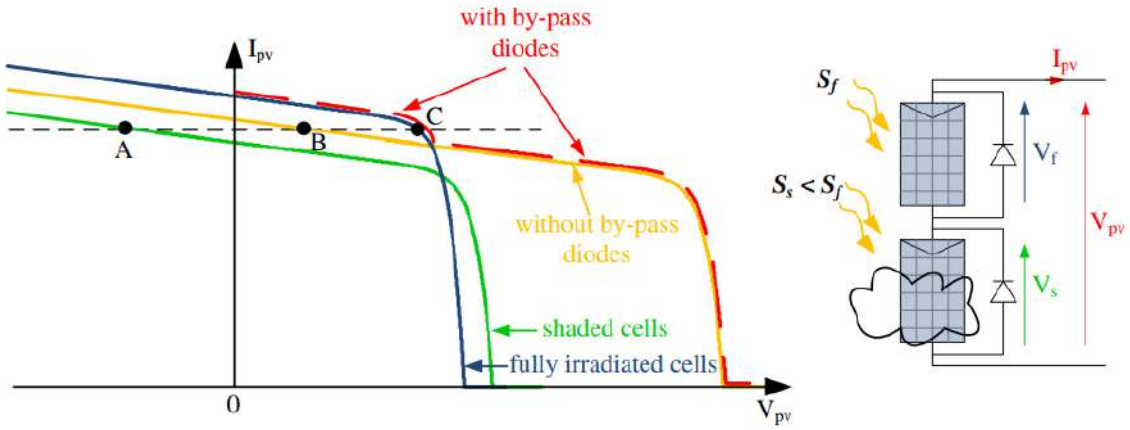


Figure 1.7 Series association of photovoltaic cells-By-pass diodes influence under non-uniform conditions.

For parallel interconnection problems are similar. This time, diode in series with each parallel module has to be added to avoid degradation. Unless by-pass diodes, they are not present on commercial module, and user has to add them when realizing parallel association. Influence of those diodes on the resulting characteristic under different levels of irradiation and temperature is similar to by-pass diodes behavior.

The presence of protection diodes is not without influence on the global behavior as shown in **Figure 1.7** This is even more visible when looking at power characteristic under non-uniform conditions as presented in **Figure 1.8** In this figures, multiple local maxima are visible. This behavior represents one challenging problem in the use of photovoltaic sources. Indeed,

classical MPPT techniques are able to find a maximum in power, but may felt under such conditions by converging to any local one instead of the global maximum power.

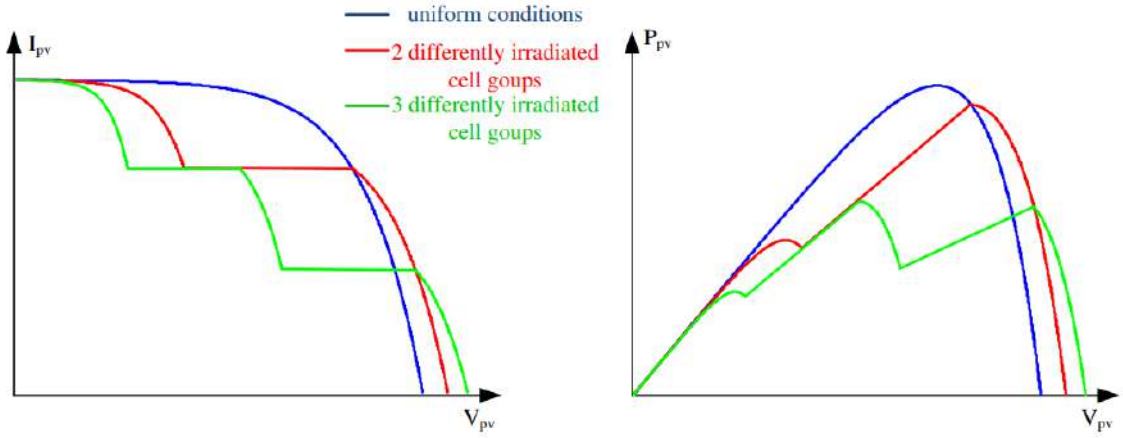


Figure 1.8 Static characteristic under different uniform and non-uniform conditions.

1.7. Blocking Diodes:

It is often recommended that a diode be fitted to prevent reverse current flow back through a solar panel at nighttime. This occurs because in battery charging systems, the module potential drops to zero at night, and the battery could discharge all night backwards through the module. This would not be harmful to the module but would result in loss of precious energy from the battery bank.

A blocking diode is not necessary if a charge controller is being used in the system.

1.8. Maximum Power Point Tracking:

From the behavior of the photovoltaic source characteristics **Figure 1.6** and 1.8 respectively under uniform and non-uniform irradiation conditions, one important problematic of the use of photovoltaic sources is easily understandable. This problematic comes from the presence of a maximum of power on the characteristic. To optimize the functioning, the global power optimum must be followed, which is not trivial since the characteristic curve is not known during time as it varies with respect to irradiation and temperature. The optimum power research is often called Maximum Power Point Tracking (MPPT). Maximum Power Point Tracking thematic has been largely studied and many solutions have been proposed. Number of papers on the subject has grown considerably through the last decades and remains strong. A non-exhaustive review of MP PT technique is proposed in [19] In this paper, the authors

listed more than 90 paper published from 1968 to 2005 among which at least 19 distinct methods have been introduced. There, the two most commonly used MPPT algorithm are presented and some solution for non-uniform irradiation conditions are reviewed.

1.8.1. Classical MPPT solutions:

Among hundreds of MP PT algorithm which can be found through the literature, two particular techniques largely distinguish especially because of their simplicity of implementation:

- **Perturbation and Observation (P&O):**

This first method is the most used, especially on industrial applications. It works by applying perturbation on the PV operating voltage or current in order to increase the power. The perturbation can also directly been applied on the associated converter duty cycle (this method being also called Hill-climbing in the literature). Flowchart of the P&O algorithm is shown in **Figure 09** where X is the perturbed variable. One of the main particularities of this technique is that even when converged it stays oscillations around the maximum. Among articles discussing on this technique, reference [20] can be distinguished. In this paper, the authors gives mathematical analysis enabling to optimize the two parameters of the P&O algorithm, i.e. its time and perturbation steps (duty cycle [20]). When optimized following the method proposed of an associated boost converter in [20], the P&O MPPT converges precisely on the maximum with good behavior under in 15 transient conditions (verified for fast variation on the irradiation).

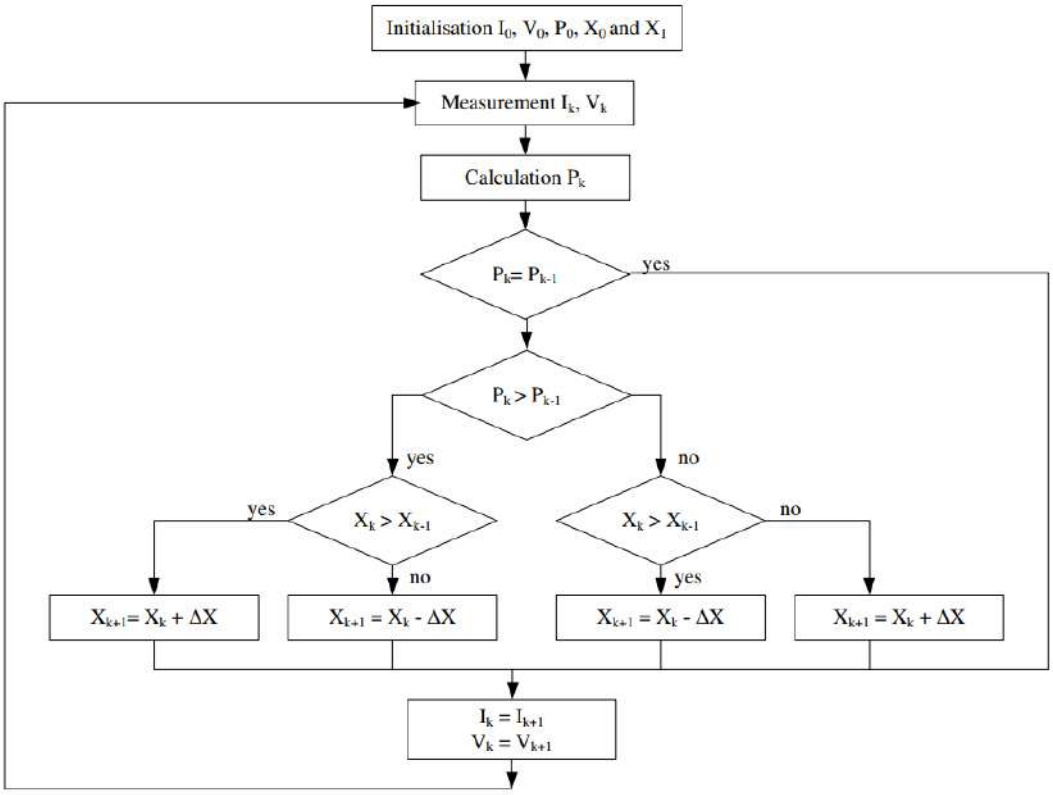


Figure 1.9 Algorithm MPPT P&O.

- **Incremental Conductance (IncCond):**

This second technique is based on the observation of the power derivative and uses the fact that the PV characteristic slope is zero at the maximum. Flowchart of the IncCond algorithm is shown in **Figure 1.10**. Even if this technique is known to be more efficient than the P&O under fast variations on the conditions and has the advantage to stabilize without residual oscillations, this second technique remains less used than the P&O.

Many improvements on those two techniques can be found through the literature as for example in [21], [22], [23], [24], and so forth... Some can also found more advanced methods as proposed in [25], [26] or [27] presenting better results under fast variations on the irradiation and temperature condition. However, every of those methods may felt under non-uniform conditions when power characteristic present multiple maxima.

1.8.2. MPPT under non-uniform conditions:

Classical methods and their variations show limited efficiency while the PV array operates under non-uniform conditions since those techniques can stabilize on a local power maximum

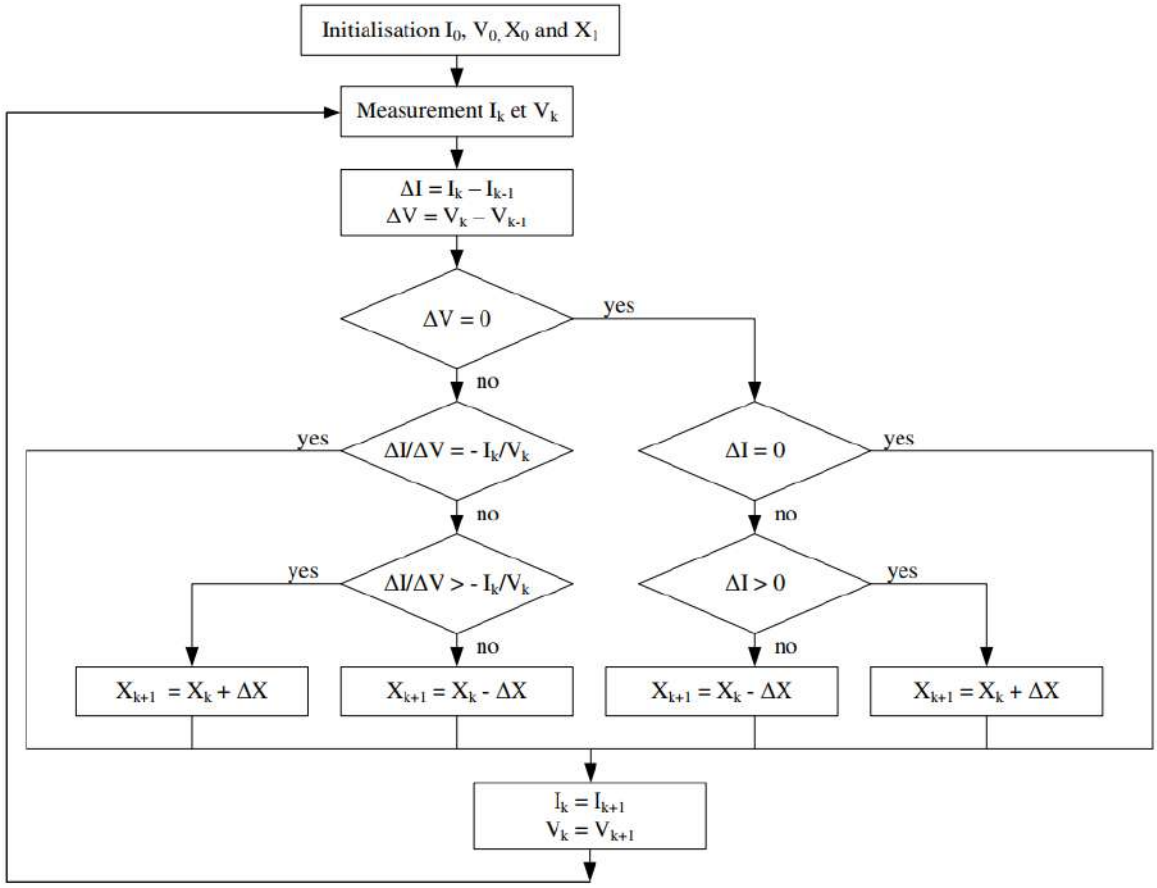


Figure 1.10 Algorithm MPPT IncCond.

Different from the global one (also on local minima for some IncCond-based techniques). Such configurations can happen several times a day leading to large deficit on the produced energy with one of those MPPT algorithms.

In the literature on the subject, several MPPT techniques are described solving partially shaded problems. However, those methods are often complex and no specific one stands out to be more adapted than others. As briefly review in [28], among possibilities ones can find:

- The "improved Fibonacci" MPPT propose by Ahmed and Miyatake in [29]. It is a P&O based MP PT with variable perturbation steps following the Fibonacci sequence. It uses an empirical function-condition enabling to know whether the reach maximum is local or global.

- On the same principle, in [30] proposed a variable step IncCond-based MPPT with partial shading condition detected from two empirical conditions on the PV current and voltage. In [30], authors shown that their proposed technique is around 10% more efficient than a conventional IncCond MPPT under non-uniform conditions.
- In [31], Koboayashi et al. proposed a two-step MPPT working under non-uniform conditions. Second step of their MPPT is a classical algorithm, which starts close to the global maximum. To ensure this, an additional circuit is required to access measurements of the PV short-circuit current and open-circuit voltage which are used to approximately located the global maximum. Even if showing satisfying results even under partial shadow, this method requires additional circuit increasing cost of the global structure.
- Chowdhury et al. proposed an MP PT based on a Particle Swarm Optimization (PSO) algorithm in [32]. They show that their techniques allows reaching the global maximum for more than 98% of shaded scenarios.
- Some studies also solve the MP PT problem under non-uniform condition by periodically scanning the PV characteristic to detect the global maximum. This solution is used in [33] with discussion on the scanning possibility.

1.9. Conclusions:

This chapter uncover the Renewable energy production and the benefits of it**,** also the Solar Power Potential, the photovoltaic energy conversion its existing technologies and third generation technologies, Non-uniform irradiation behavior Protection diodes influence are addressed, Furthermore Blocking Diodes, finely the Maximum Power Point Tracking techniques and its benefits.

CHAPTER TOW

WIND TURBINE POWER GENERATOR

2.1. Introduction

Wind Energy (WE) is a promising source of Removable energy widely used and considered to be the cleanest RE with no environment impact [59]. The European Wind Energy Association (EWEA) has adopted an energy production policy. This strategy aims at 20% of RE production percentage of total produced energy. In addition, an installed capacity of WE at 80000 MW in EU-27 by 2020 should be reached. Obviously, this Wind Energy capacity represents 5% of total produced energy [60]

This chapter addresses the state of the art of wind turbine power system. Thus, presents a definition of the system with its fundamental principles of operation. Subsequently, studying energy resource; history of wind turbines, construction of wind turbines, sizing of power units and configuration, Savonius Wind turbine and future trends of wind power and its contribution in global energy system, also advantages and disadvantages of wind power generation systems.

2.2 Wind Resource

a) Definition of Wind

Wind can be defined as the movement of the air. It yields from the variation of atmospheric pressure from place to another on the earth‘s surface, because of the non-homogenous of the earth surface and the difference in temperature according to time _seasons‘ and the place, all this will cause the wind flow from regions of higher pressure to low pressure regions[36]

b) Wind Characteristics

The wind is characterized by the following main parameters:

- **Variation of height.**
- **Its direction.**
- **Its speed.**
- **Its statistics properties.**

c) Wind Variation with Height:

The speed variation of wind in the vertical position is called vertical wind profile; this is caused by the air convection in the atmospheric layer around the earth. Actually, wind data at various speeds are not accessible by measurement devices. Thus, mathematical equations are used to estimate the wind velocity, at a certain height, which is 10 meters above the surface of the earth.

The wind speed variation can be function of the height, which can be mathematically expressed as following. [36]

$$\frac{V}{Vrf} = \left(\frac{H}{Href}\right)^{\alpha} \qquad \textbf{2.1}$$

Where:

Href: it is the height of the reference point which is generally taken at a height of 10 meters.

Vref: it is the wind speed corresponding to that height;

H: it is the point, at which the wind speeds need to be estimated;

α: is the coefficient that must be chosen.

The coefficient α vary according to the altitude, time season and, nature of the terrain, wind velocity and temperature. Usually it is taken between 0, 1 and 0, 4

d) Wind Direction:

A specific diagram called wind rose is implemented to study the wind direction, as well as to find the best and more power wind direction.

The wind rose is a circle shape diagram which indicates wind distribution, and wind direction during measurement time, using this diagram; it is possible to determine direction of the wind, and its orientation mostly. The wind rose can be used to trace the wind in multi directions and sectors. The figure shown below is an example of the wind rose for 16 sectors:

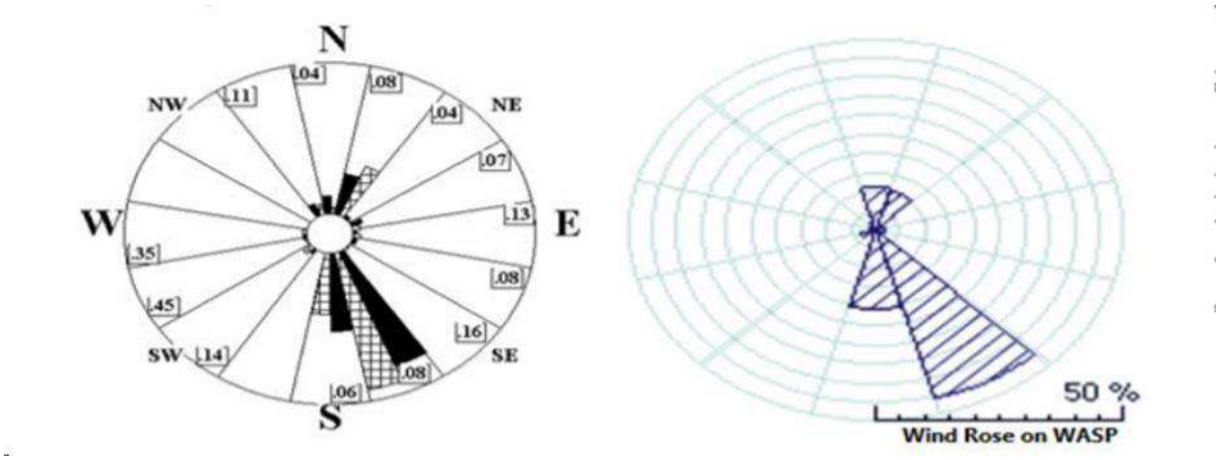


Figure 2.1 Wind Rose.

Frequency of the wind speed represents the percentage of wind speed intervals for 1m /s registered in a given period of time in a certain site. Generally, it is represented by a diagram as the one shown in figure 2.2:

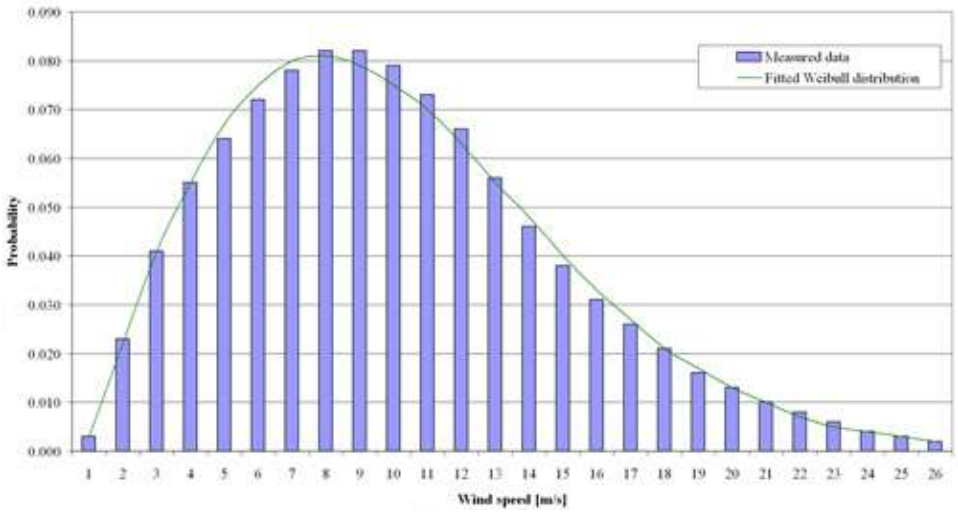


Figure 2.2 Wind Distribution Curve.

2.3 History of Wind Turbines:

Since the time began, human being researched for power resources, wind was one of the early discovered power resources, it is used in navigation transport thousands of years ago by Egyptians [37], later it is developed to be used in day to day life as mills for grinding grain. The first windmills were conceived 2000 years ago by the Persians; and for water lift [38]. In [1846-1908] Paul La COUR - Danish meteorologist experimented wind turbine to rotate DC generator

to generate electrical power [39]. During winter of [1887-1888] the American Charles Francis Brush constructed first wind turbine and electrical generator (12 kW) to supply his house by electric power using a battery as storage unite [40].

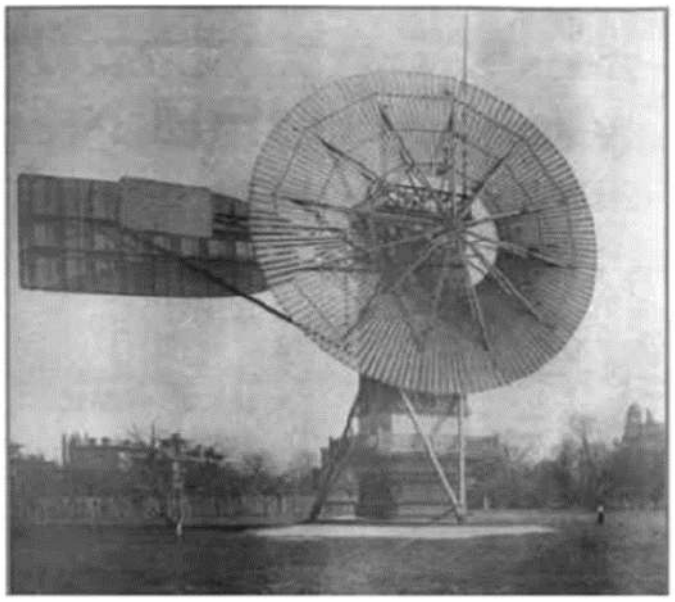


Figure 2.3 First Aerodynamic Generator Constructed by Charles F.Bruch. [37]

In 1957, one of La COUR students _Johannes JUUL', created the first wind turbine generates alternative current 200 kW (Gedser Turbine) [41-42].



Figure 2.4 Wind Turbines Classification. [43]

2.4 Classifications of wind turbines:

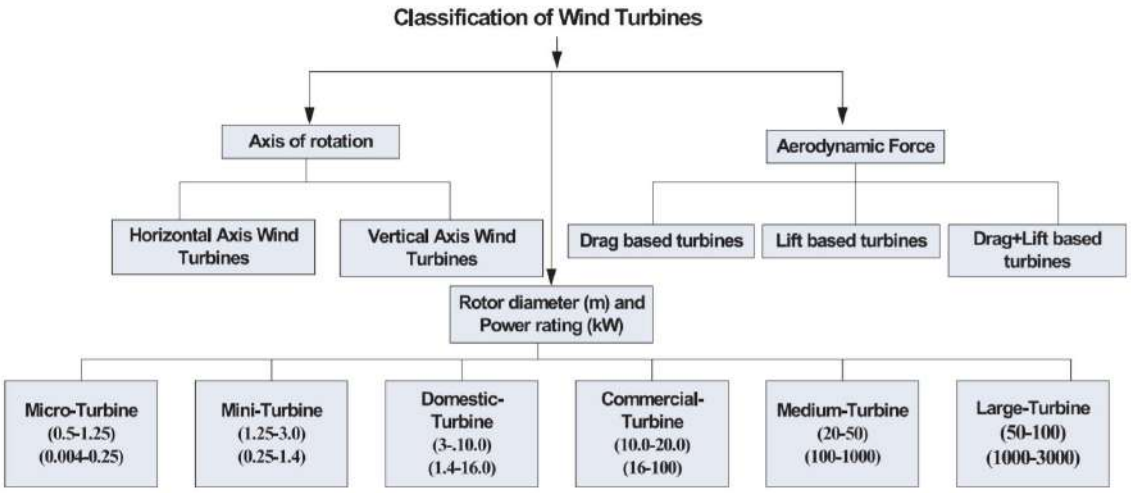


Figure 2.5 Classifications of wind turbines. [44]

Wind turbines are classified regarding to the point of view of the research area, for example in control point of view they are classified into two main categories:

- Fixed speed-controlled wind and/or turbines

- Variable speed-controlled wind and/or turbines

Whereas, in the position point of view turbines are classified into two main types:

- Horizontal Axis Wind Turbines.

- Vertical Axis Wind Turbines.

Wind turbines are classified into three categories in aerodynamic force:

- Drag based turbines.
- Lift based turbines.
- Drag + Lift based turbines.

Also, wind turbines are classified into three main categories according to mechanical power being generated:

1. Micro-Turbine (0.5-1.25) m , (0.004-0.25) Kw.
2. Mini-Turbine (1.25-3.0) m , (0.25-1.4) Kw.

3. Domestic-Turbine (3-10) m , (1.4-16) Kw.
4. Commercial-Turbine (10-20) m , (16-100) Kw.
5. Medium-Turbine (20-50) m , (100-1000) Kw.
6. Large-Turbine (50-100) m , (1000-3000)Kw. [44,45]

2.4.1 Horizontal Axis Turbines (HAT)

Horizontal turbines are the most commonly used type; it is composed of three blades usually, gear box, shaft and, electrical generator, all these elements are installed in the nacelle on the top of the tower.

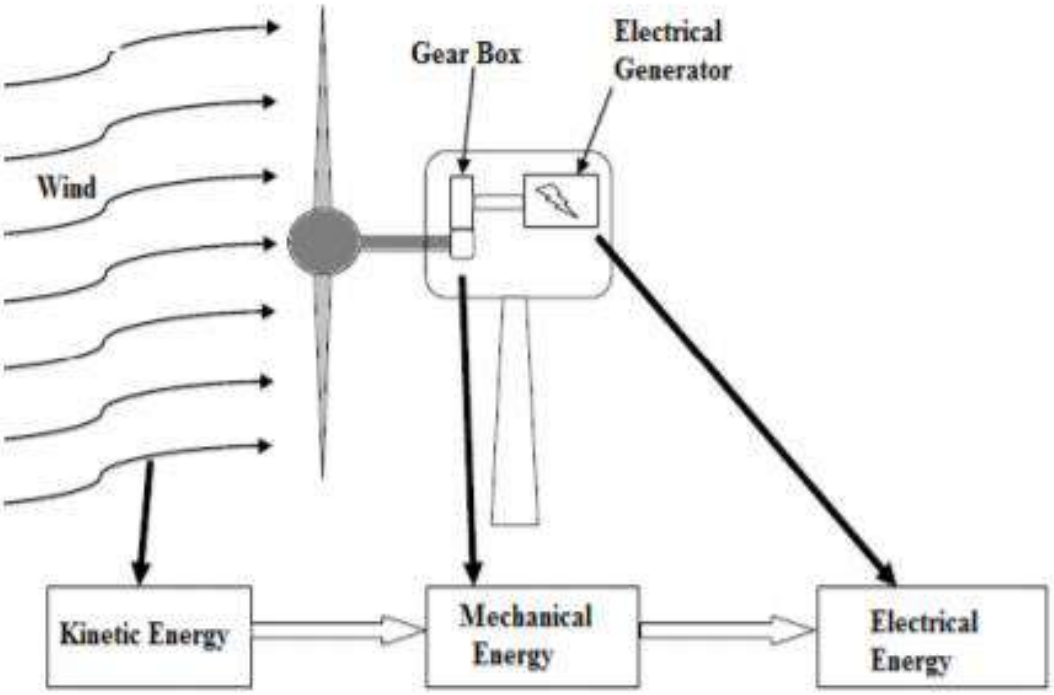


Figure 2.6 Wind Turbine Power System. [45]

2.4.2 Vertical Axis Turbines (VAWTT):

The most commonly used types are Darrieus and Savonius turbines. Darrieus Wind Turbine the Darrieus wind turbine is commonly called "Eggbeater" turbines because it looks like a giant eggbeater. It is one of the most successful vertical axis wind turbines. The most attractive feature of this type, that generator and transmission devices are located at ground level. In addition, it is able to capture winds from any direction. However, these advantages are counteracted by reducing energy capture since winds intercepted by the rotor have less energy.

Moreover, despite the fact that the generator and the transmission are located at ground level, the maintenance is not simply because it generally requires the removal of the rotor. Mainly for these reasons, the use of vertical axis wind turbines has declined considerably in recent decades.[46]



Figure 2.7 Darrieus Wind Turbine at GREAH.

2.5. Wind turbines Parts

2.5.1 Mechanical Parts

1. Foundation: It is a large, heavy concrete immersed in the ground in order to hold up the tower and the other parts of the turbine figure 1.8.

2. Tower: It is used to supports and holds turbine‘s blades, rotor, gear box, and generator in the air (off the ground), see figure 1.8.

3. Nacelle: it is the chamber which contains and protects the electrical generator, high and low speed shaft, orientation control system Yaw, and control system, figure 1.8.

4. Rotor: It is the connection part between the blades and generator, in some types of turbines when gear box is used there are two sides high speed side and low speed side rotor.

5. Blades: It is the main part responsible on transforming wind energy into mechanical energy, it represents the area of energy transformation, its length has a direct relationship with power generation, denoted in mathematical modeling by R2, see figure 1.8 [47] [36].

6. Gear box: It is used to step up the rotation speed of the electric generator‘s shaft, when the wind speed is not quite high enough to generate electrical power.

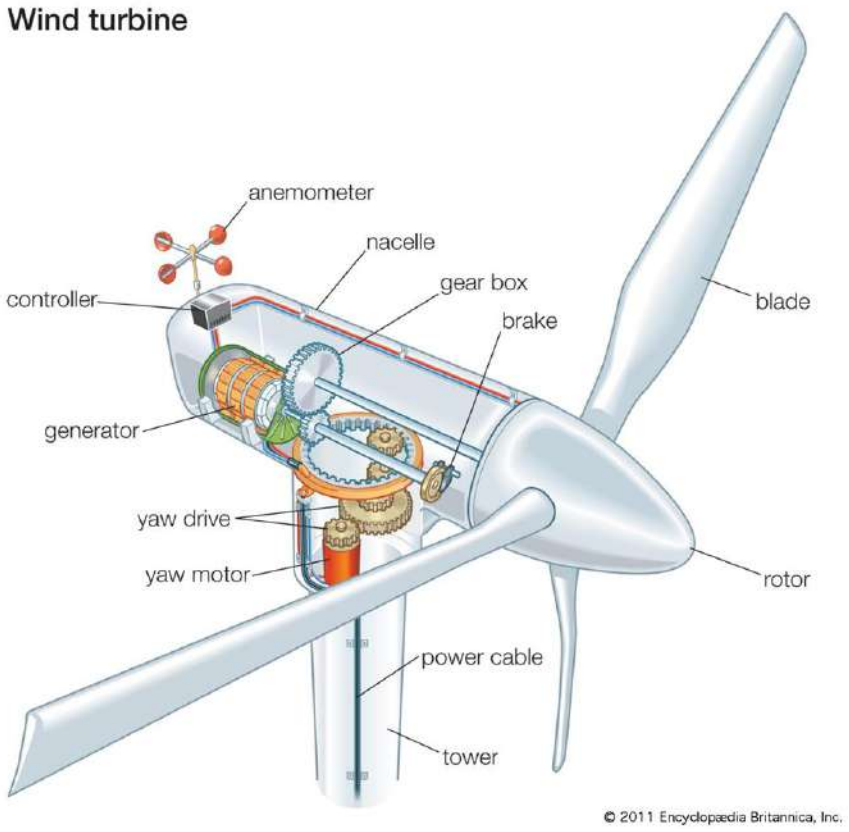


Figure 2.8 Wind Turbine Foundation. [47] [48]

2.5.2 Electrical Parts

1. Electrical Generator: It is used to convert mechanical energy into electrical energy; electrical generators usually used are synchronous or asynchronous machines.

2. Power Converter: It has two function to control the rotation speed of the generator, via pulse width modulation PMW, thus by altering the frequency of the rotor side, also to stabilize the output power by converting AC to DC and vice versa (rectifier and inverter) respectively.

3. Transformer: Transformers are used to adapt the generated tension to the gird side.

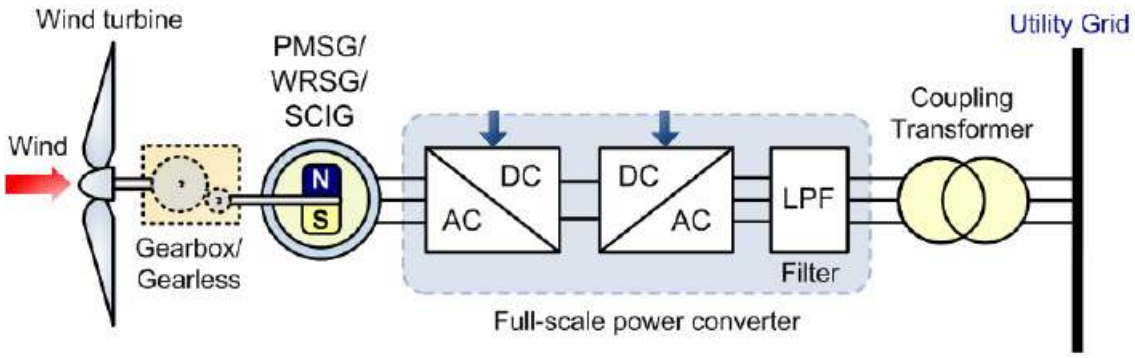


Figure 2.9 Turbine Construction. [50]

2.6 Operation Principle

The operating principle of an aero generator is practically the same as a windmill, the kinetic energy of the wind currents strike the surface of the blades, which turns the blades of the aero generator, blades are fixed on the rotor and coupled to an electrical generator that converts mechanical energy into electrical energy [45].

So, power generated by wind turbine depends up on certain factors that can be used to determine the power that can be extracted from the wind, these factors are expressed in the following mathematical expression:

$$Pw = \frac{1}{2}\rho\pi r^2 V^3 Cp \qquad \textbf{0.2}$$

Where:

ρ: air density,

πr^2: swept area.

V^3: wind speed.

Cp: power coefficient.

Turbine efficiency is determined by how much power can be extracted by the turbine blades from the moving wind currents. Therefore, the power coefficient is a function of the turbine efficiency.

Energy produced by wind turbines is called wind energy; it is a clean energy, distributed geographically. Furthermore, it does not emit CO2 or waste nuclear materials. The captured and converted wind energy remains quite complex, because it alters with time and seasons [51].

2.7 Savonius

2.7.1 Historical background

Savonius wind turbines were invented by the Finnish engineer Sigurd J. Savonius in 1922, but Johann Ernst Elias Bessler (born 1680) was the first to attempt to build a horizontal windmill of the Savonius type in the town of Furstenburg in Germany in 1745. Nowadays they are not usually connected to electric power grids.

2.7.2 The concept of the Savonius rotor

The concept of the Savonius rotor was based on the principle developed by Flettner [Modi and Roth, 1985]. Savonius used a rotor that was formed by cutting the Flettner cylinder into two halves along the central plane and then moving the two semi cylindrical surfaces sideways along the cutting plane so that the cross-section resembled the letter ‘S’ [Savonius, 1931].

There are two ways a Savonius turbine can extract power from a flow. In Figure12 , imagine the flow is moving upwards from below. Such a flow would produce a wake load top of left bucket and stagnation pressure load below right bucket. There would also be impulse load where a sheet of water moves first along left bucket and then along right bucket. One can imagine the turbine absorbs momentum when it hits the left bucket and expels momentum where it leaves the right bucket. So there is a drag mechanism and a momentum mechanism. A Savonius rotor cannot exceed the speed of the water and operates at a lower RPM range than would a horizontal axis turbine.

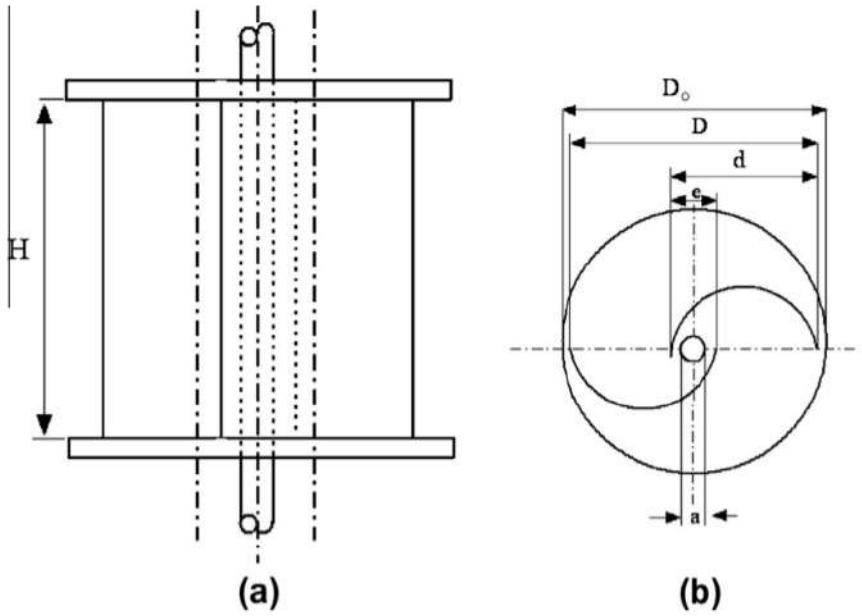


Figure 2.10 Scheme of a single-stage Savonius rotor: (a) elevation view; (b) plan view.

2.7.3 Use and operation

The Savonius is a drag-type VAWT, so it cannot rotate faster than the wind speed. This means that the tip speed ratio is equal to 1 or smaller, the efficiency is lower compared to other types, so it can be employed for other uses, such as pumping water or grinding grain. Much of the swept area of near the ground, making the overall energy extraction less effective due to lower wind speed at lower heights.

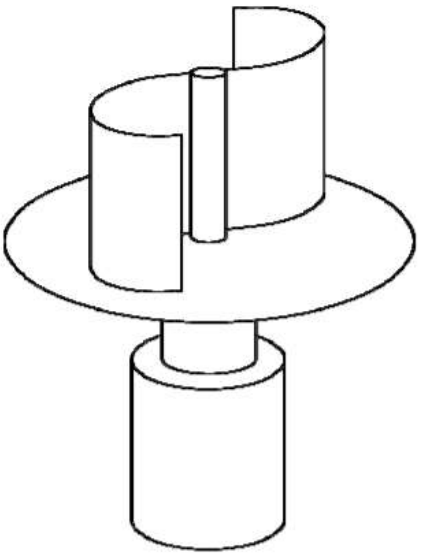


Figure 2.11 Savonius Rotor.

Its best qualities are the simplicity, the reliability, and the very low noise production. It can operate well also at low wind speed because the torque is very high especially in these conditions. However, the torque is not constant, so often some improvements like helical shape are used.



Figure 2.12 Savonius wind turbine.

Examples

The Savonius can be used where reliability is more important than efficiency:

- small application such as deep-water buoys.
- most of the anemometers are Savonius-type.
- used as advertising signs where the rotation helps to draw attention.

2.7.4 Savonius Wind turbine theory

As a simplest turbine, Savonius wind turbine works due to the difference of forces exert on each blade. The concave part to the wind direction caught the air wind and forces the blade to rotate around its central vertical shaft.

Otherwise, the convex part hits the air wind and causes the blade to be deflected sideway around the shaft. The blades curvature has less drag force when moving against the wind or Fconvex than the blades moving with the wind or Fconcave as seen in Figure 12 [53]. Hence, concave blades with more drag force than the other half cylinder will force the rotor to rotate.

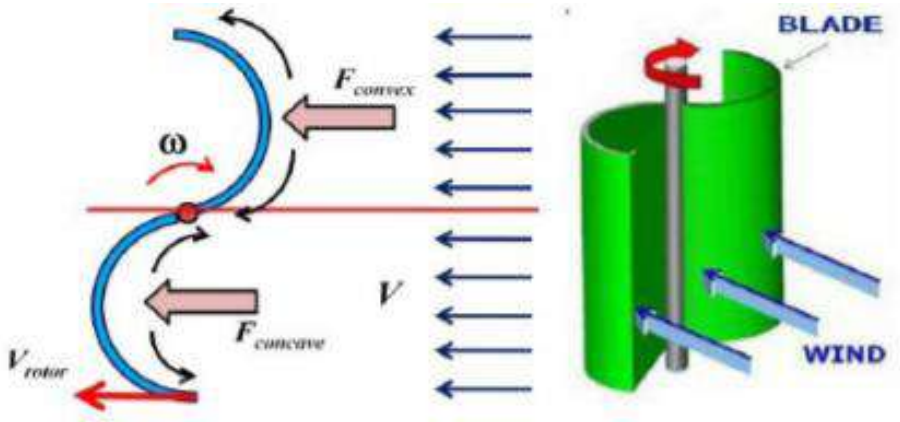


Figure 2.13 Two blades Savonius wind turbine with the drag forces [53].

2.7.5 Measurements the mechanical power

The mechanical power for the tested Savonius rotor is determined by measuring the mechanical torque on the rotating shaft and rotational speed at different values of wind speed [52].

While the shaft rotational speed is measured using a digital dc tachometer.

From the measured values of mechanical torque and rotational speed, the mechanical power can be estimated at each wind speed as:

$$Pm = T\omega\ (W) \qquad \textbf{2.3}$$

Where T is the mechanical torque and ω is the angular speed the angular speed is defined in rad/s as:

$$\omega = \frac{2\pi n}{60} \quad \textbf{0.4}$$

where n is the shaft rotational speed in rpm.

The mechanical torque is obtained in (N m) by:

$$T = Fr \quad \textbf{0.5}$$

Where r is the pulley radius.

The force acting on the rotor shaft obtained in (N) by:

$$F = (m - s)g \quad \textbf{0.6}$$

Where m is the mass loaded on the pan in kg, s is the spring balance reading in kg and g is the gravitational acceleration.

The power coefficient Cp and static torque coefficient Cts can be determined from the following equations:

$$Cp = \frac{Pm}{Pw} \quad \textbf{0.7}$$

Where Pw is calculated from the following equation:

$$Pw = \frac{1}{2}\rho A V^3 \quad \textbf{0.8}$$

Where ρ is air density, kg/m3

, A is the projected area for the rotor (HD), V is the wind speed, m/s

Finally, the power coefficient can be formulated as:

$$Cp = \frac{gr\pi n(m-s)}{15\rho AV^3} \quad \textbf{0.9}$$

The static torque coefficient is calculated from

$$Cts = \frac{4T}{\rho D^2 V^2 H} \quad \textbf{0.10}$$

2.7.6. The performance of Savonius

The performance of Savonius wind turbine can be expressed in the form of torque coefficient (Ct) and the coefficient of power (Cp) in comparison with the tip speed ratio or TSR (λ). TSR is a parameter related with rated wind speed and rotor diameter. As the ratio between the speed of tip blade and wind speed through the blade, TSR can be determined as [54].

$$TSR = \lambda = \frac{Vrotor}{V} = \frac{\omega . d}{V} \quad \textbf{0.11}$$

where Vrotor is the tip speed or the peripheral velocity of rotor (m/s) ; ω is the angular velocity of rotor (1/s) ; d is the diameter of the halves cylinder of rotor (m), and V is the wind speed (m/s).

The coefficient of torque or Ct is defined as the ratio between the actual torque develop by the rotor (T) and the theoretical torque available in the wind (Tw) as,

$$Ct = \frac{T}{Tw} = \frac{4T}{\rho\ As\ d\ V^2} \quad \textbf{0.12}$$

where ρ is the density of air (ρ = 1.225 kg/m3); T is the torque (Nm), and as is the swept area of blades = the rotor height x the rotor diameter (m2).

The coefficient of power of a wind turbine (Cp) is the ratio between the maximum power obtained from the wind (Pt) and the total power available from the wind (Pa) as,

$$Cp = \frac{Pt}{Pa} = \frac{Pt}{\frac{1}{2}\rho A V^3} \quad \textbf{0.13}$$

where the maximum power of wind turbine is determined as

$$Pm = T\omega\ (W) \quad \textbf{0.14}$$

The relationship between the power coefficient Cp and the tip speed ratio TSR or λ as an effect of solidity of the wind turbine performance is shown in Figure 13 [55]. The curve shows that single blade of wind turbine has smaller solidity and the shape of curve Cp relatively flat which caused by higher drag force. The three blades wind turbine gave optimal solidity with Cp maximum and the result it produces more energy.

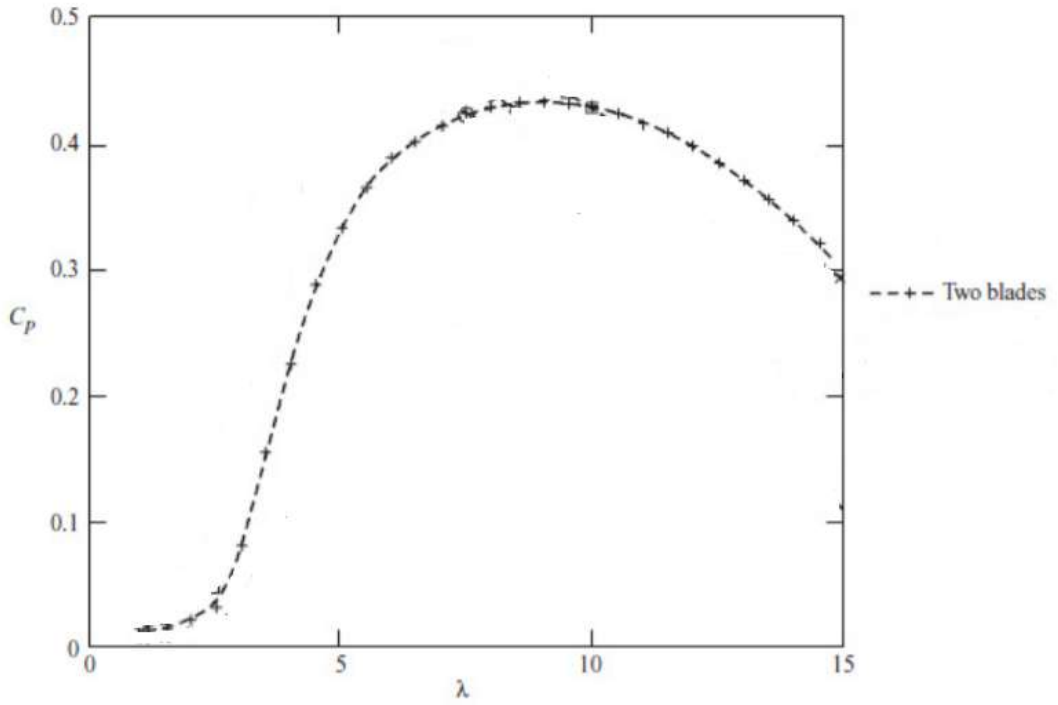


Figure 2.14 The curve of power coefficient Cp and tip speed ratio λ of wind turbine.

2.7.8 Pressure distribution

The deviation of drag forces caused by pressure differences on the blades of Savonius wind turbine will be shown using ANSYS 13.0 software. The simulation was assumed on steady flow with the wind speed of 10 m/s. Figure 14 shows pressure distribution for wind turbine rotor with two blades (a), Pressure on concave blades is higher than pressure on convex blades with result that the deviation of drag forces will rotate the rotor. As shown in Figure 14, pressure in front of blades is higher than that at the back and wind turbine rotor will rotate. The more blade surfaces with higher pressure is found in four blades wind turbine. It makes that four blades wind rotor has highest torque compared with other wind turbine rotor. Pressure differences between the area in front and at the back of wind turbine blades are determined as in Table 1. [56]

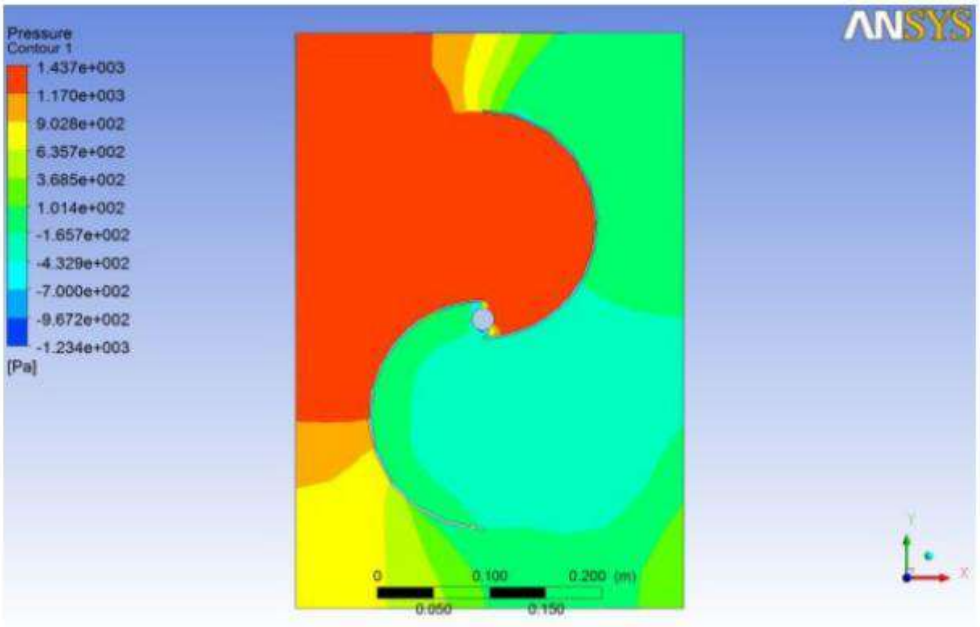


Figure 2.15 Pressure distribution on two blades.

Table 2.1. Pressure differences between area in front and back of rotor.

2 blades	
Wind speed (m/s)	**Pressure differences (Pa)**
1	**12,808**
5	**328,375**
10	**1335,7**

2.7.9 Flow pattern around a single Savonius rotor

Strong unsteady and nonlinearity including separation and vortex shedding are observed for the flow on a Savonius rotor as a drag type wind turbine and due to continuous variation of flow angle with respect to blades, The velocity vectors and the flow patterns occurring around the rotor from the numerical solution shown in Figure 15(c) are identified and found comparable to the experimentally extracted data [56]. in Figure 15(b). Flow (I): coanda like flow (attached flow along the advancing blade convex side). Flow (II): dragging flow (from advancing blade convex side to returning blade concave side). Flow (III): Overlap flow though the overlapping area. Flow (IV): stagnation flow from upstream to the returning blade convex side. Flow (V): shedding vortex at the advancing blade tip. Flow (VI): shedding vortex from the returning blade tip[57] [58].

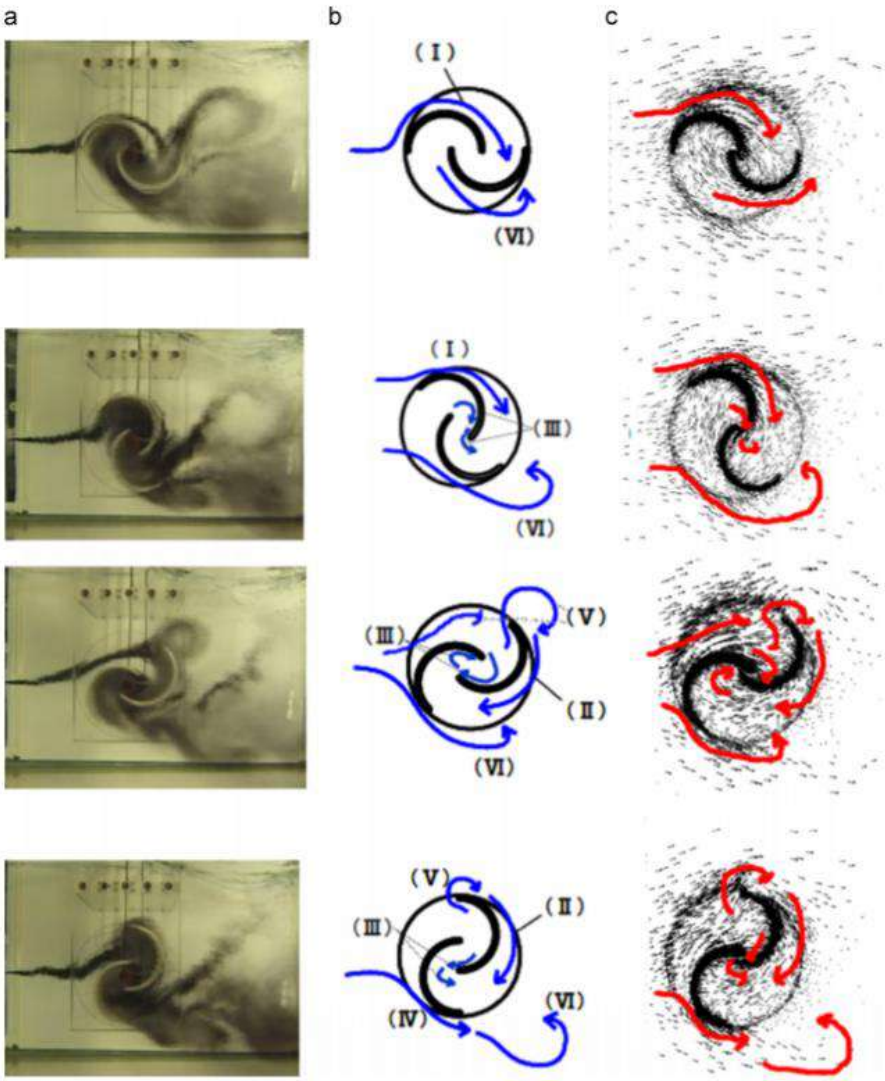


Figure 2.16 Flow pattern around single Savonius rotor. [56]

2.8Advantages & Disadvantages of Wind turbine

2.8.1 Horizontal Axis Turbines

a) Advantages

1. High rotation speed comparing to vertical axis turbines.
2. Can be oriented to track wind direction using Yaw control system.
3. Angle of attack can be remotely adjusted to extract maximum power available in the wind.
4. Horizontal axis turbines are Self-starting turbines.
5. Damage is minimized because of pitch system that can stop in high-speed wind.
6. High efficiency of power generation the rotor blades [48].

b) Disadvantages

1. Complex control system is needed to achieve high performance.
2. Mechanical stress due to its perpendicular to the wind flow direction.
3. It needs to be at sufficient height.
4. Consuming large area of land and can be obstacle to navigation in offshore sites.
5. Vision and noise pollution.
6. Dangerous; kill birds [49].

2.8.2 Vertical Axis Turbines

a) Advantages

1. It bi-direction.
2. Generator, gearbox and other components are placed on the ground.
3. Low production cost compared to horizontal axis wind turbine.
4. It does not need to be oriented, so yaw drive and pitch mechanism is not needed.
5. Easy to install.
6. Low maintenance cost.
7. Low risk to human and birds, because blades moves at relatively low speed.

b) Disadvantages

1. Low efficiency compared to HAWTS.
2. Initial push to start is needed.
3. They have relative high vibration.
4. Because of vibration, bearing wear increases therefore increase of maintenance costs.
5. Pollution of noise.
6. Needs a guy wires to hold it up [50].

2.9. Conclusion

This chapter included: wind energy (speed and distribution), history of wind turbines, as well as, classifications of wind turbines, operation principle and construction of wind/ conversion chain, the Savonius Historical background and its operation theory and measurements of the mechanical power, the fundamental of performance comprehensive study of the pressure distribution on the blades and the rotor, at the end the advantages & Disadvantages of horizontal and vertical Wind turbine.

CHAPTER THREE

HYBRID ENERGY SYSTEMS & STORAGE TECHNOLOGIES

3.1 Introduction

Variety is the spice of life, so why limit ourselves to just one energy source or storage option. In these cases, hybrid energy systems are an ideal solution since they can offer substantial improvements in performance and cost reduction and can be tailored to varying end user requirements.

Configurations could include renewable or non-renewable energy sources, electrical and chemical energy storage and fuel cells, often connected via a smart grid.

They have the potential to dramatically reduce cost and emissions from energy generation and distribution for households but can be held back by the limitations of individual power generation or storage technologies.

This means there is substantial demand for hybrid energy solutions to lower cost and improve efficiency, while still meeting performance requirements.

Here's an example hybrid energy system whereby solar, wind and a fuel cell provide the energy for your house and/or car.

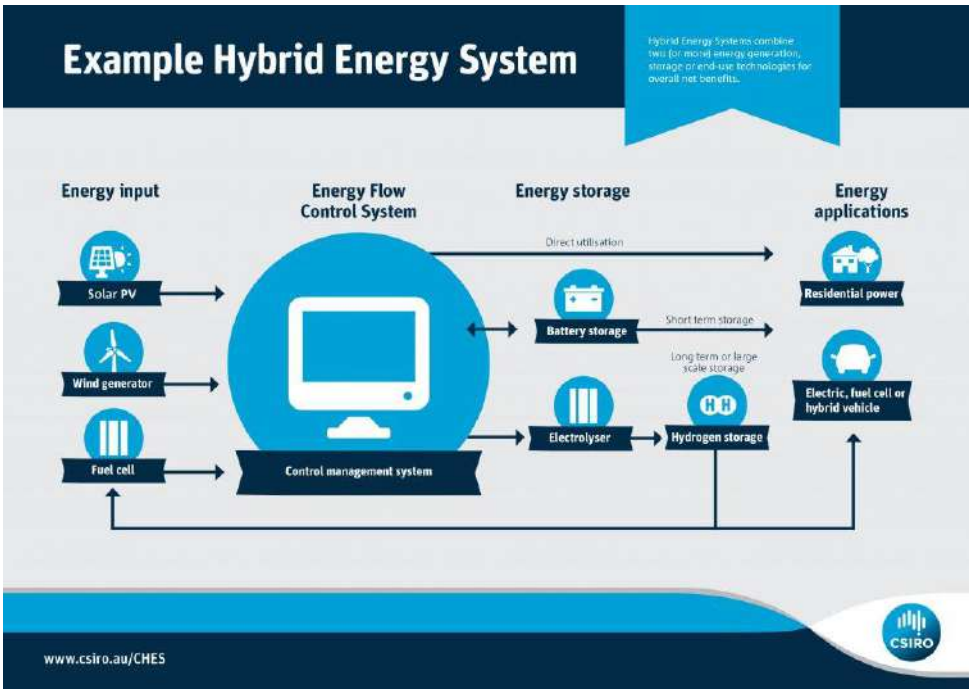


Figure 3.1 Hybrid energy system. [72]

According to Dr Sukhvinder Badwal, there is now an increased availability of renewable

and modular power generation and storage technologies such as batteries, fuel cells, and household solar.

"These technologies are becoming cost competitive, but the key to greater use is to combine them in connected hybrid systems," Dr Badwal said. [72] [73]

"By doing this, we can offer substantial improvements in performance and cost."

In this chapter, the energy production from different renewable energy sources will be presented. The hybridization among the different sources will be studied. Then, the energy storage technologies will be highlighted. Therefore, the different existing energy management control approaches for hybrid systems will be discussed.

A comprehensive literature review presenting the recent studies on hybrid systems including hydrogen storage technologies will be presented.

3.2 Hybrid Energy Systems components and structure

From a structural point of view, renewable energy systems can be classified into two main classes: isolated and grid connected [61, 62].

- Isolated systems provide an energetic independence with less geographical constraints, they are less fault tolerant and require a reliable local power storage. Such systems need to be wisely designed and sized in order to satisfy a high reliability condition and avoid the power shortages.

- Grid connected systems are more reliable less dependent on the storage but they can be more expensive. The environmental footprints of such systems still depend partially on the electrical sources of the grid.

3.2.1Renewable sources in the Hybrid Energy Systems

As the most abundant renewable energy forms, solar energy and wind energy are worldwide available. They receive an increasing interest in the research and development.

- **Biomass-wind-fuel cell**

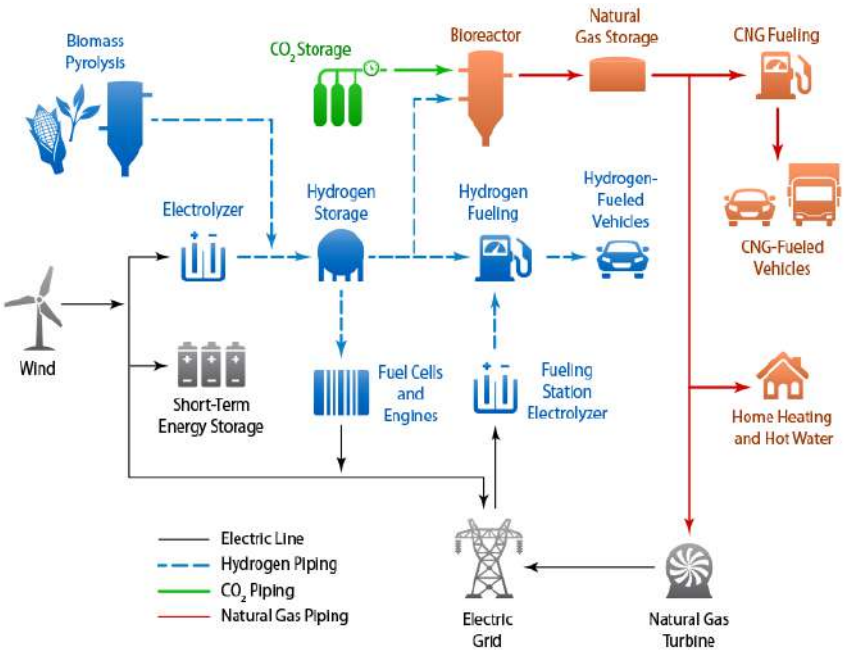


Figure 3.2 Biomass-wind-fuel cell.

For example, consider a load of 100% power supply and there is no renewable system to fulfill this need, so two or more renewable energy system can be combined. For example, 60% from a biomass system, 20% from wind system and the remainder from fuel cells. Thus combining all these renewable energy systems may provide 100% of the power and energy requirements for the load, such as a home or business.

- **Solar thermal hybrid systems**

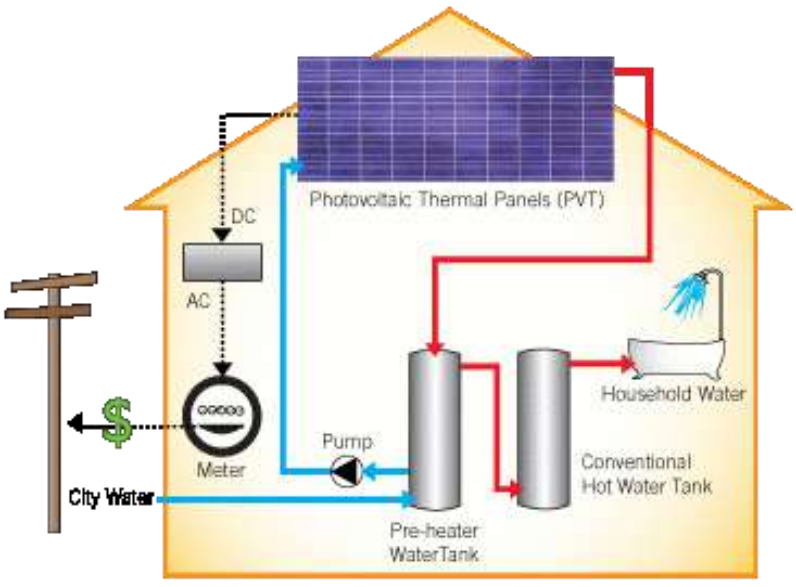


Figure 3.3 Solar thermal hybrid systems.

Though Solar PV generates cheaper intermittent power during the day light time, it needs the support of sustainable power generation sources to provide round the clock power. Solar thermal plants with thermal storage are clean sustainable power generation to supply electricity round the clock.[63][64] They can cater the load demand perfectly and work as base load power plants when the extracted solar energy is found excess in a day.[65] Proper mix of solar thermal (thermal storage type) and solar PV can fully match the load fluctuations without the need of costly battery storage.[66][67]

During the day time, the additional auxiliary power consumption of a solar thermal storage power plant is nearly 10% of its rated capacity for the process of extracting solar energy in the form of thermal energy.[65] This auxiliary power requirement can be made available from cheaper solar PV plant by envisaging hybrid solar plant with a mix of solar thermal and solar PV plants at a site. Also to optimise the cost of power, generation can be from the cheaper solar PV plant (33% generation) during the day light whereas the rest of the time in a day is from the solar thermal storage plant (67% generation from Solar power tower and parabolic trough types) for meeting 24 hours base load operation.[68] When solar thermal storage plant is forced to idle due to lack of sunlight locally during cloudy days in monsoon season, it is also possible to consume (similar to a lesser efficient, huge capacity and low cost battery storage system) the cheap surplus / infirm power from solar PV, wind and hydro power plants by heating the hot molten salt to higher temperature for converting stored thermal energy in to electricity during the peak demand hours when the electricity sale price is profitable.[69][70]

- **wind-diesel hybrid**

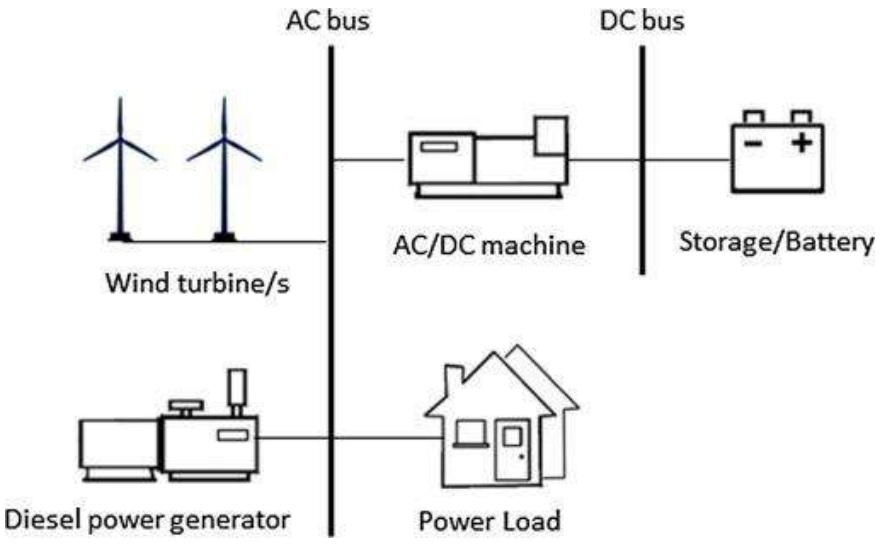


Figure 3.4 Wind-diesel hybrid.

A wind-diesel hybrid power system combines diesel generators and wind turbines,[71] usually alongside ancillary equipment such as energy storage, power converters, and various control components, to generate electricity. They are designed to increase capacity and reduce the cost and environmental impact of electrical generation in remote communities and facilities that are not linked to a power grid [71]. Wind-diesel hybrid systems reduce reliance on diesel fuel, which creates pollution and is costly to transport [71].

Technology

The successful integration of wind energy with diesel generating sets relies on complex controls to ensure correct sharing of intermittent wind energy and controllable diesel generation to meet the demand of the usually variable load. The common measure of performance for wind diesel systems is Wind Penetration which is the ratio between Wind Power and Total Power delivered, e.g. 60% wind penetration implies that 60% of the system

power comes from the wind. Wind Penetration figures can be either peak or long term. Sites such as Mawson Station, Antarctica, as well as Coral Bay and Bremer Bay in Australia have peak wind penetrations of around 90%. Technical solutions to the varying wind output include controlling wind output using variable speed wind turbines (e.g. Enercon, Denham, Western Australia), controlling demand such as the heating load (e.g. Mawson), storing energy in a flywheel (e.g. Powercorp, Coral Bay). Some installations are now being converted to wind hydrogen systems such as on Ramea in Canada which is due for completion in 2010.

- **Photovoltaic and wind**

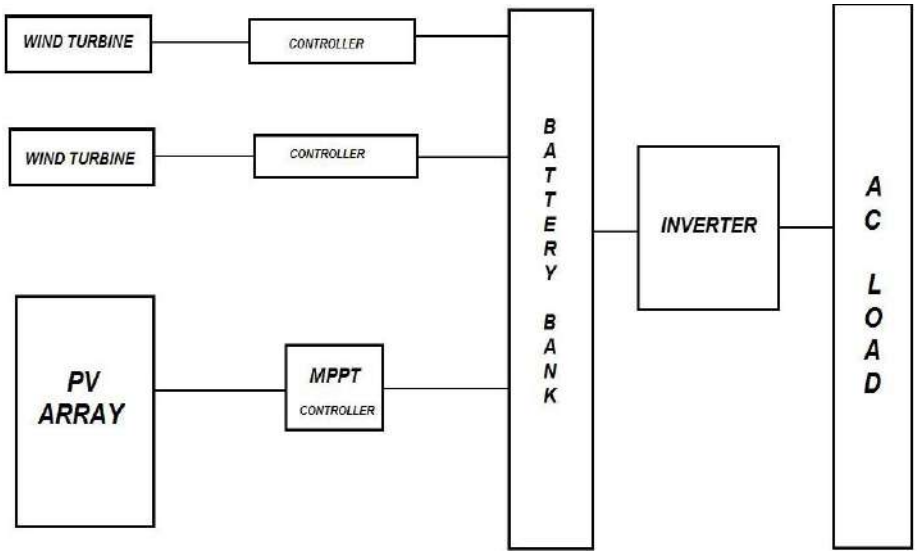


Figure 3.5 Block diagram of a SUV/wind hybrid energy system.

Another example of a hybrid energy system is a photovoltaic array coupled with a wind turbine.[62] This would create more output from the wind turbine during the winter, whereas during the summer, the solar panels would produce their peak output. Hybrid energy systems often yield greater economic and environmental returns than wind, solar, geothermal or trigeneration stand-alone systems by themselves [107].

- **Completely Renewable Idea**

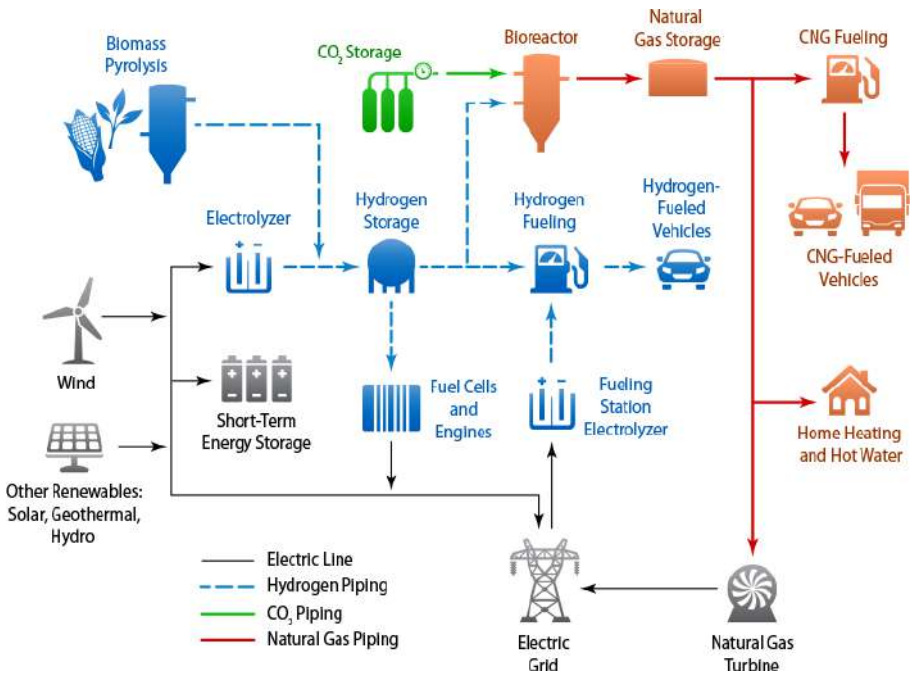


Figure 3.6 Completely Renewable Idea.

Completely Renewable Hybrid Power Plant (solar, wind, biomass, hydrogen) A hybrid power plant consisting of these four renewable energy sources can be made into operation by proper utilization of these resources in a completely controlled manner. Hybrid Energy Europe-USA. Caffese in Europe introduce hybridizing HVDC transmission with Marine hydro pumped Energy Storage via elpipes. The project of Caffese is 3 marine big lakes producing 1800 GW and transmission with elpipes. A part 1200 GW produce water fuels-wind fuels-solar fuels 210 billion liter year. (IEEE Power and Engineering Society-General Meeting Feb.9.2011,Arpa-E,Doe USA,MSE Italy, European Commission-Energy-Caffese plan and Consortium Hybrid renewable energy systems (HRES) are becoming popular as stand-alone power systems for providing electricity in remote areas due to advances in renewable energy technologies and subsequent rise in prices of petroleum products. A hybrid energy system, or hybrid power, usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply.

3.2.2 Drawbacks of Standalone Renewable Energy Sources

Most of us already know how a solar/wind/biomass power generating system works, but, all these generating systems have drawbacks of some kind. Solar panels, for example, are expensive to set up, and are peak output is not obtained during the night or cloudy days. Similarly, Wind turbines can't operate safely in high wind speeds, and low wind speeds produce little power. Biomass plants collapse at low temperatures.

3.3 Advantages and Disadvantages of Hybrid Energy Systems

3.3.1 Advantages of Hybrid Systems

1. Some of power units can be installed very close to the end user without high risk issues, such as PV panels.

2. Reduce power cost.

3. Endless resources.

4. It is possible to be installed as a part of industrial process to exploit their wastes and used for power generation.

5. Reduce GHG emission.

6. Safe to environment.

7. It is possible to be installed as a part of industrial process to exploit their wastes and used for power generation.

8. Reduce GHG emission.

9. Safe to environment.

3.3.2Disadvantages of Hybrid Systems

Despite their significant benefits to the environment and great long-term potential for sustainable energy development, hybrid RE systems have some disadvantages, which make barriers to employ this source of energy; some inconvenient points are listed hereafter:

1. Not all resources available in everywhere, i.e. (in the north sun resources not available as in the south while wind resources available more in the north).

2. More complex to be controlled.

3. Generated unstable power according to the resources situation.

4. A storage system is essential for overcoming the problem of power fluctuation in the grid.

5. Sometimes one power unit is not sufficient to provide the required power so hybrid system is needed.

6. It is not easy to be integrated with the general electrical network

3.4 Power Management Strategies Based on Energy Storage Technologies

3.4.1 History of Energy Storage Systems

Thermal energy storage system TESS is one of the oldest forms of energy storage systems in the world where ice is harvested for food preservation and cooling purposes, in China cold water was injected into an aquifer. Subsequently, it was noted that water had maintained it temperature for long period of time [83] Pumped hydro energy storage systems PHS has existed for a long time – the first pumped hydro storage plants were used in Italy and Switzerland in the 1890s.

The Wallace Dam Pumped Hydro Project was placed in full commercial operation in December 1980. In 1999 first seawater pumped hydro plant was built in Japan (Yanbaru, 30 MW) [76].

First fuel cell of about 2000 years old was discovered, near Baghdad, Iraq and it was first described by German archaeologist Wilhelm Koning. Then, the first step began when Emile Alphonse Faure invented and patented the so-called sticky plates in 1880; large scale production of lead-acid batteries was developed.

The next step was to increase storage capacity and electric power in battery. The most common used types of batteries Lead-acid battery invented by Gaston Plante in 1859 at France and it is the oldest and most widely used. Flow Battery FB invented by Lawrence Thaller in 1976 [84]. Hereafter summarized history of batteries in table 4 [85].

The first energy storage program was an integration of batteries with photovoltaic and wind energy systems in 1978, titled ‒Batteries for Specific Solar Applications‖ [86].

Table 3.1: History of Batteries

Developer / Inventor	Country	Year	Invention
Luigi Galvani	Italy	1786	Animal Electricity
Alessandro Volta	Italy	1800	Voltaic Pile

John F. Daniell	Britain	1836	Daniell Cell
Sir William Robert Grove	Britain	1839	Fuel Cell
Robert Bunsen	German	1842	Liquid electrodes to supply electricity
Gaston Plante	France	1859	Lead Acid Battery
Georges Leclanche	France	1868	Leclanche Cell
Thomas Alva Edison	United states	1901	Alkaline/Accumulator
T.A. Edison & Waldemar ungner	U.S.A & Sweden	1895-1905	Nickel-cadmium / nickel-iron
Andre		1930	Silver/oxide zinc cell

3.4.2 Role of Energy Storage Units in Power System

The Energy Storage Systems (ESS) is a key component in the electrical generation and stability, energy storage is one of the features of this century, where the need of energy increasing dramatically. Electrical interruption or its instability is one of the big challenges at all levels of life and may cause a death to a patient in Intensive Care Unit (ICU) or big losses in business. From this point of view, the need for storing energy becomes very essential to save lives and money. Also, using energy storage system will decrease the gas combustion hence the gas emission and reducing the environment pollution. The following sections show the contribution of energy storage systems in power demand and generation for different periods of time during the day [87].

As shown in Figures 07&08, using ESS will improve the performance of power generation system from first step of power generation, power transmission and finally the end user, these attractive vales that can be added by the ESS such as: i) reduce generation cost during peak demand periods, (ii) maintain continuous and flexible supply, (iii) management in power generation, (iv) improving power quality/ reliability, (v) help insertion of smart power grids.

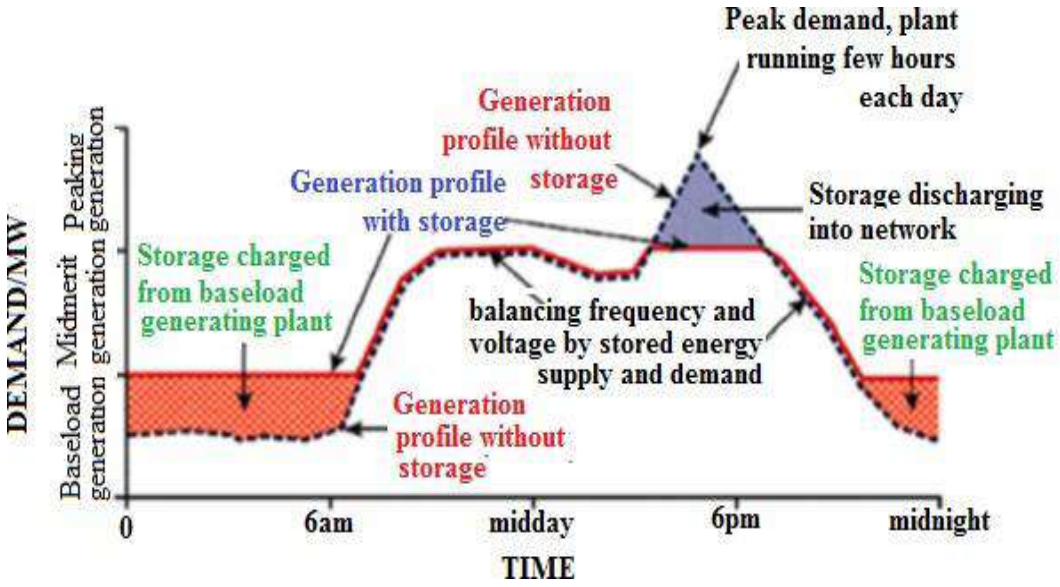


Figure 3.7 Effect of energy storage system in power generation and consumption. [88]

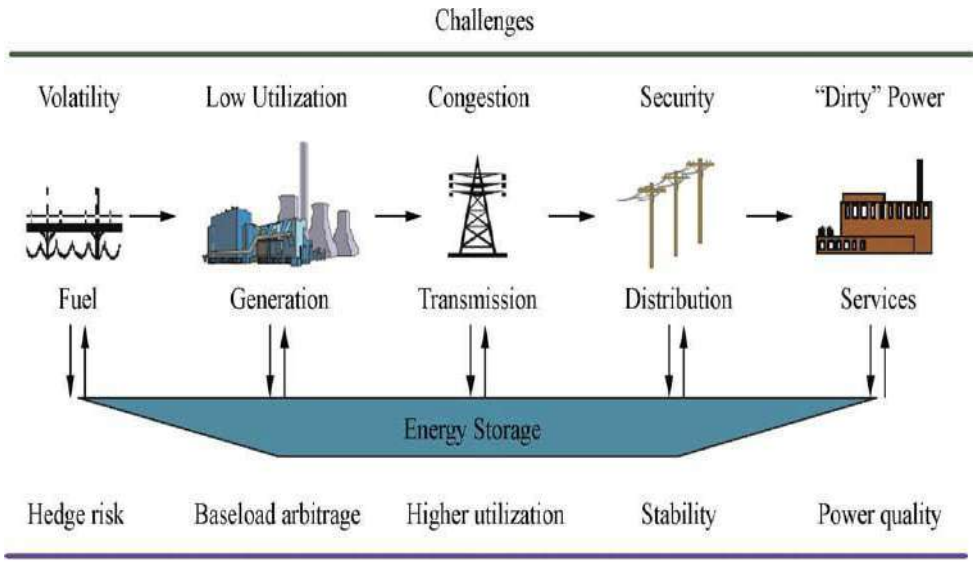


Figure 3.8 Application of ESS in power system. [88]

Batteries are classified as small-scale storage systems in low distribution system. More than 64% of the utilized capacity of batteries is used is take place in the emergency units in the hospitals. Besides that, several battery systems (19%) are located in the office building as show in figure 3.09 With regard to the energy storage market, the high percentage (99%) capacity of installed storage is provided by plants of pumped hydroelectric as in figure 3.10 [89].

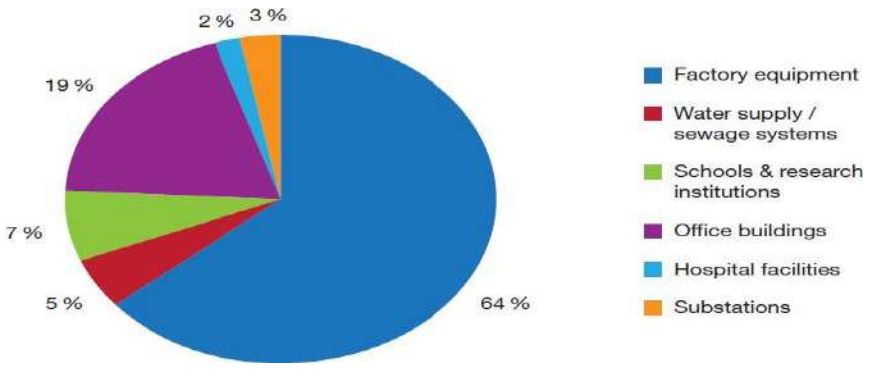


Figure 3.9 Utilization of Battery as ESS. [89]

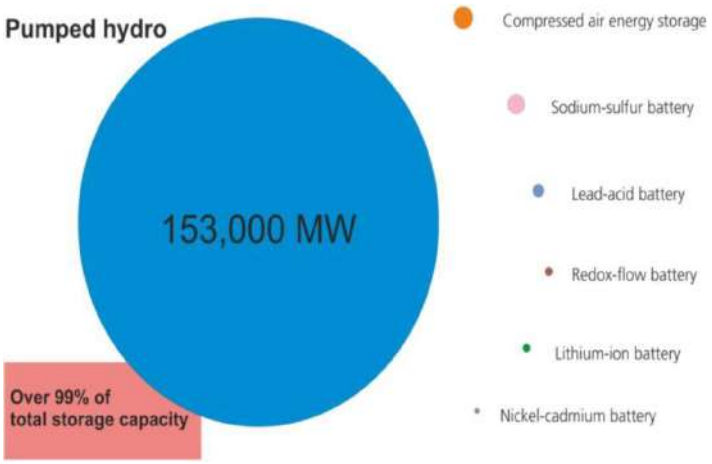


Figure 3.10 Installed Capacity of ESS. [89]

3.5 Basic Theory of Energy Storage Systems

Thermal Energy Storage Systems TES

Thermal energy storage (TES) is process of stocking excessive energy in a form of heat, by heating or cooling a storage medium so that the stored energy can be used later for heating and cooling applications and power generation. TES systems are used particularly in buildings and industrial processes [90], energy can be stored by means of TES depends on two basic principle, sensible heat (e.g. water, rock) and latent (e.g. water/ice, salt hydrates) [91].

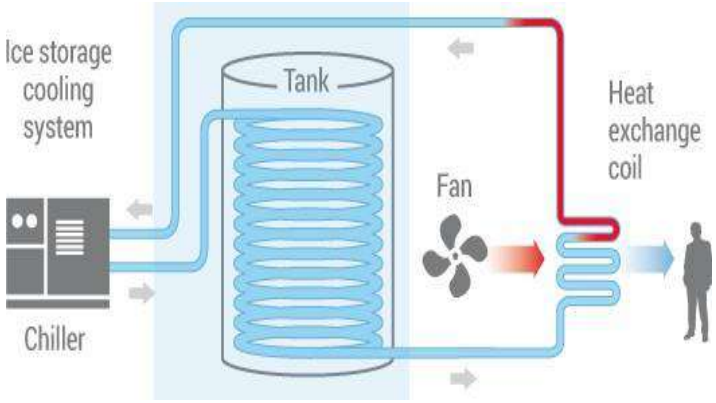


Figure 3.11 Thermal ESS. [92]

Main thermal storage techniques:

- Sensible Thermal Energy Storage
- Underground Thermal Energy Storage (UTES)
- Phase Change Materials for TES
- Thermal Energy Storage via Chemical Reactions [93]

Pumped Hydro Storage System PHESS

The PHS considered as a large-scale storage unite represents about 99% of worldwide storage capacity, the main idea of PHES is to pump and store water at high levels during off-peak periods, and reuse it to operate power generation turbines during peak periods as shown in Figure 3.12.

In another ward, store electric energy in another form of energy "hydraulic potential energy". Pumping and generating generally follow a daily cycle but weekly or even seasonal cycling is also possible with larger PHES plant [93].

The overall efficiency of this type of ESS can be determined by finding out the ratio of the energy used to pump up the water and produced energy. In addition, the period of storing and production is an important factor. The following two expressions used to find out the efficiency of the system [94]:

$$\text{Epumping} = \frac{\rho\, g\, h\, V}{\eta_P} \qquad \textbf{3.1}$$

$$Egenerator = \rho\, g\, h\, V\, \eta_g \qquad \textbf{3.2}$$

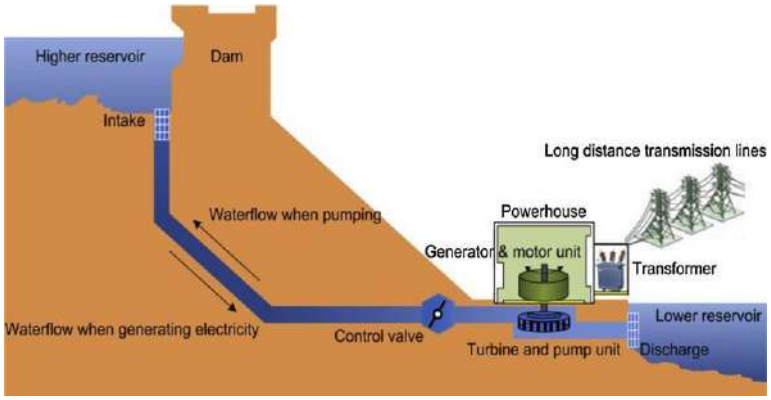


Figure 3.12 Pumped Hydro Storage System.

Flywheel Energy Storage System FESS

In a very simple explanation the flywheel is made of a metal in cylindrical form, supported by magnetic bearing located in vacuum chamber to reduce friction losses and connected to a rotor of generator/motor as in figure 3.13. Kinetic energy can be stored in the flywheel in rotation form [95]. The amount of stored energy depends on the inertia and speed rotation of the flywheel. The energy absorbed and released by a rotating flywheel rotor [96]. The kinetic energy that can be stored in flywheel according to the following equation:

$$E = \frac{1}{2} I\, \omega^2 \qquad \textbf{3.3}$$

Where:

I: inertia momentum of the flywheel

ω: angular speed

There are some factors affect the maximum energy that can be stored in flywheel system, these factors can be expressed in the following relation:

$$Esp = K_s \frac{\sigma_m}{\rho} \quad \textbf{3.3}$$

Where:

Esp: maximum specific energy density; σ_m: Maximum tensile strength of flywheel material ks: Shape factor; ρ: Density of the flywheel materia

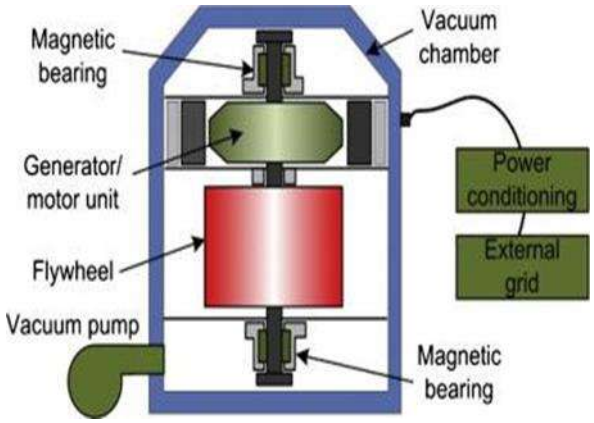


Figure 3.13 Flywheel Energy Storage System FESS. [78]

Compressed Air Energy Storage System (CAES)

The intermittency of wind is main reason to use this technology, the excessive electrical energy used to operate series of air compressors, to store electrical energy in a form of compressed air in reservoirs or over ground tanks, in order to reuse it later in peak demand figure 3.14.

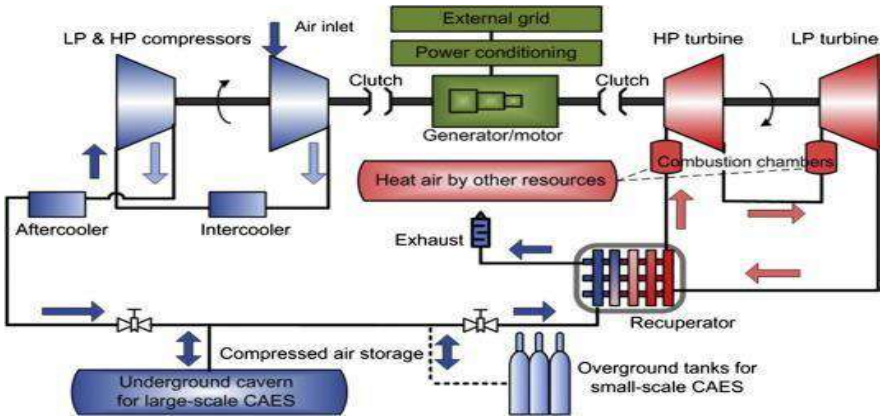


Figure 3.14 Compressed Air Energy Storage System CAES. [78]

Batteries

A battery storage system mainly composed of electrode, anode and electrolyte figure 3.15 which can be at solid, liquid or ropy/viscous states, electrical energy can be stored in a form of controlled chemical reaction which reproduces electricity when it is needed "bi-directional convert of energy". In this category of ESS there are main common types of Batteries namely (Lead-acid battery, Sodium Sulfur battery, Lithium ion battery, Metal air battery, Flow battery) [98] [99].

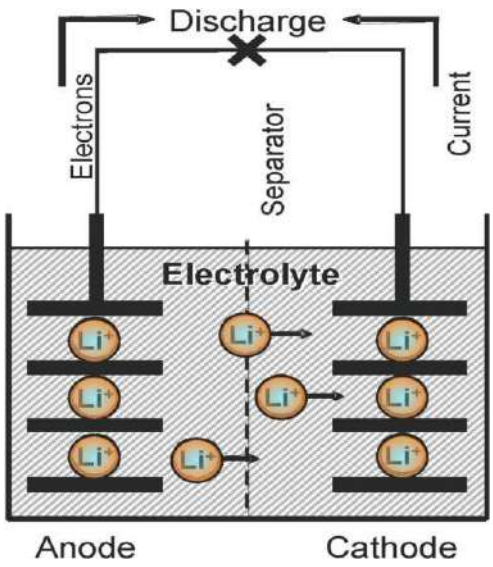


Figure 3.15 Battery Schematic. [78]

Superconducting Magnetic Energy System SMES

An SMES device is a dc current device that stores energy in the magnetic field. The dc current flowing through a superconducting wire in a large magnet creates the magnetic field [100]. The coil is made of Niobiumtitane (NbTi) filaments and cooled below its superconducting critical temperature, one of the attractive properties of SMES that it can be fully charged and discharged in a very short of time, and high value of energy can be stored in figure 16. The energy stored in the coil, E, is given by expression [101].

$$E = \frac{1}{2} L\, I^2 \qquad \textbf{3.5}$$

Where:

E: energy (W)

L: inductance (H), and

I: current (A).

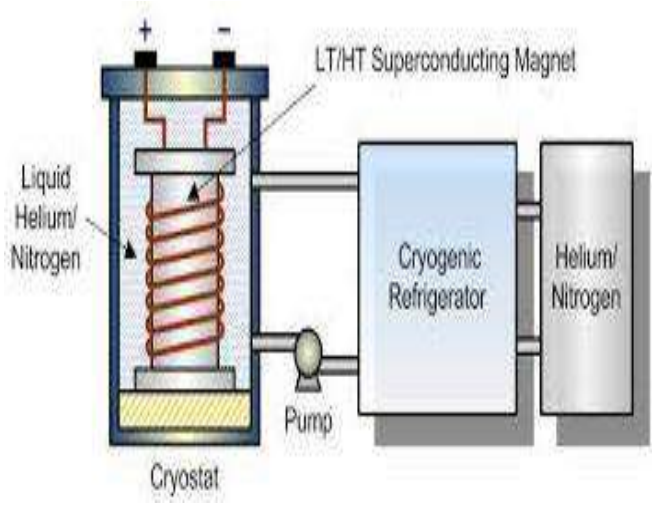


Figure 3.16 Superconducting Magnetic Energy System SMES. [91]

Fuel Cell Energy Storage System FCESS

Fuel cell based on the separation of water into its original components Hydrogen and Oxygen, as shown in figure 3.17. Hydrogen is used to generate electricity; also it can be transported in portable cylinders or tanks and stored for long time [102].

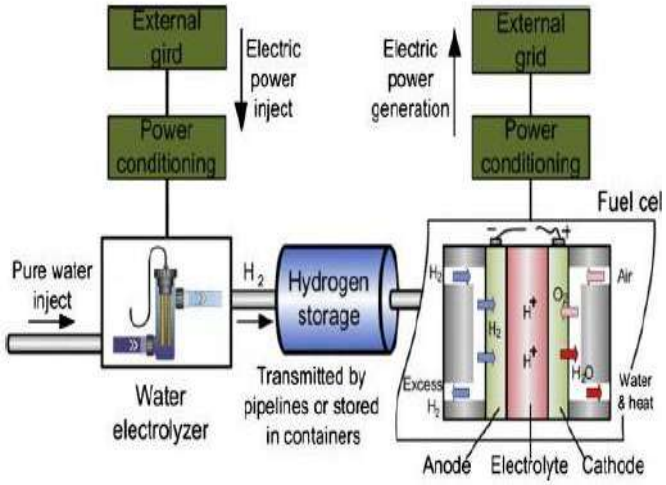


Figure 3.17 Hydrogen Storage and Fuel Cell. [78]

3.6 Classification of Energy Storage Systems

Electrical energy storage systems are classified into five categories according to the energy storage principle as indicated in the following block diagram. Also, storage systems can be classified according to: the period of charging and discharging; long period and short period as high-energy batteries, like sodium sulfur battery, like super-capacitors respectively. In addition, another classification regarding their load capacity (low, medium and high storage capacity).

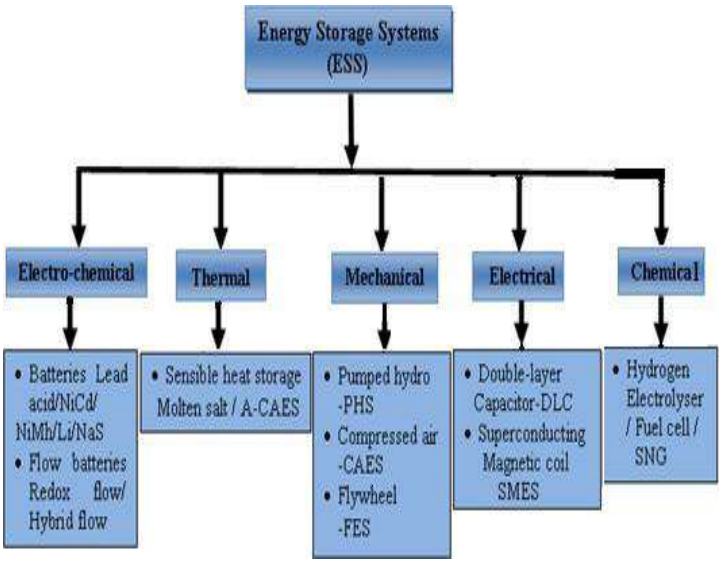


Figure 3.18 Classification of EES.

3.7 Application of Energy Storage Systems

Electro-chemical Energy Storage Systems

Hereafter, review - papers [103-105] focused on types, uses and impact of energy storage systems on renewable energy systems, also addressed and evaluated some of drawbacks, facing the integration of energy storage units with the grid. Furthermore, provide perspectives on future directions. Found that, battery systems can offer a number of high-value opportunities and lower costs can be obtained.

Battery Storage System BSS in figure 3.19, considered as main part, for efficiency improvement of water desalination unite, supplied by renewable resource PV-wind turbine power generation system to eliminate the intermittently of required electrical power.

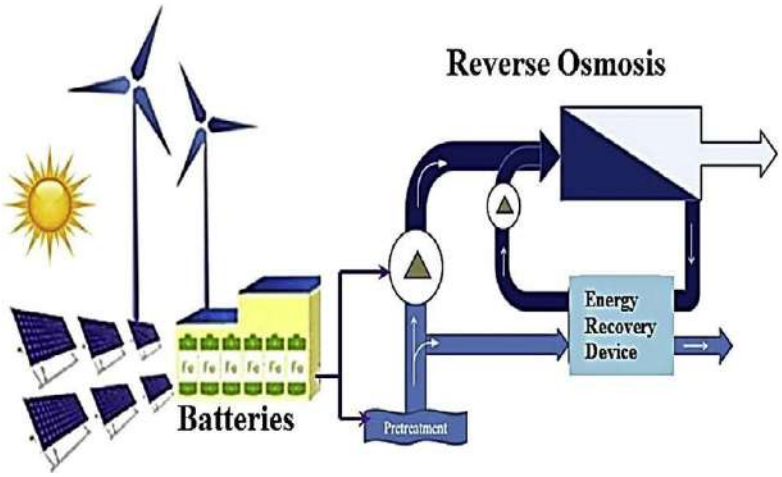


Figure 3.19 Wind and Solar Cells with Batteries. [104]

Thermal Energy Storage Systems

Papers [106-101] devoted to study thermal properties of materials that can be used as storage energy units, i.e. storing energy in a form of heat or cold. Results show that, storing energy in this form is suitable for long-term, more efficient and less expensive than the other forms of energy storage systems. But it is more complex to be implemented and expensive. Figure 3.20 demonstrates thermal energy storage systems in France, used to provide higher storage energy, Phase Changing Materials (PCMs).

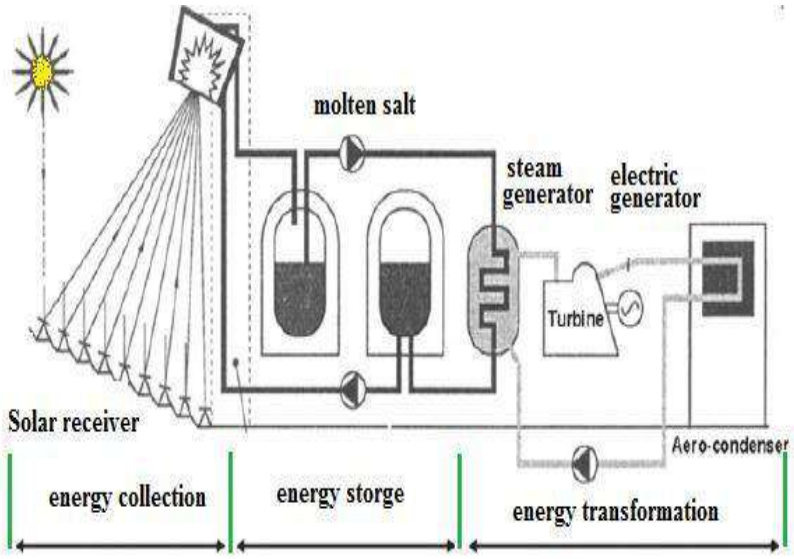


Figure 3.20 Thermal Station in France.

Mechanical Energy Storage System

Energy can be stored in a form of potential or kinetic energy. So, it can be reused later to operate turbines to produce electrical power. However, three main ways are used to store energy in mechanical form namely [102-108];

- Pumped Hydro Storage System (PHSS), used for long periods compensation.
- Flywheel Energy Storage System (FESS), used for short period compensation.

Compressed Air Energy Storage System (CAESS), used for medium period compensation. Cost is the main common disadvantage. Whereas, location and slow of response for pumped hydro storage system, but has long period of compensation.

Electrical Energy Storage Systems

Researches [109-110] provide an overview of Electrical Energy Storage Systems based Superconducting Magnetic Energy Storage and its applications in electrical energy systems. The electrical energy systems are classified into three main groups:

- Thyristor-based SMES,
- Voltage-source converter- based SMES, and
- Current-source-converter-based SMES.

Due to the instability of renewable energy resources, ESS is needed to be used in order to mitigate power fluctuation in power systems.

Chemical Energy Storage Systems

Two types of Chemical Energy Storage Systems (CESS), Fuel Cell (FC) and Ultra-Capacitor (UC) have been the subject of many papers and case studies [111-112]. In General, fuel cells are used as an energy resource hybrid with other resources to overcome the problem of power fluctuation in a micro-grid renewable power system, and to produce hydrogen gas when electrical energy is not demanded, thus store the generated gas in order to operate power units later. Whereas, Ultra-Capacitor used to store electrical energy in chemical reaction form

The common advantage of such an energy storage system it is portable and responds fast to power fluctuation. However, one notable disadvantage for a fuel cell that it is an explosive and flammable.

3.8 General Comparisons of Different Energy Storage Systems

The comparison between energy storage systems depends on the purpose of energy storage, and frequency of use as well as the location. Actually, it is difficult to find storage unit that meet all the power system requirements. Anyway, there are common factors to compare: Costs, density of energy, specific power, recyclability, Accessibility, durability energy efficiency [113].

Summary of advantages and disadvantages of energy storage technologies detailed in table 2.

Table 3.2: Main Advantages and Disadvantages of Electrical Energy Storage Systems

Energy Storage System	Advantages	Disadvantages
Electrochemical	High efficiency	short storage period
Mechanical	High capacity and power	high costs (initial investment) and Special site requirement
Chemical	Long storage period	Low efficiency
Thermal	High efficiency and long lifetime	High production cost, Requires special charging circuit
Electrical	High efficiency and long lifetime	Low Energy Density

The intensive technical comparison for several EES systems has shown in table3.3.

Table 3.3: Comparison of Technical Characteristics of Electrical Energy Storage Systems

ESS	Wh/kg	Power rating	Discharge time	Suitable storage duration	Life time (years)	Capital cost
PHES	0.5–1.5	100–5000 MW	1–24 h+	Hours–months	40–60	600–2000
CAES	30–60	5–300 MW	1–24 h+	Hours–months	20–40	400–800
Lead-acid	30–50	0–20 MW	Seconds – hours	Minutes–days	5–15	300–600
Fuel cell	800–10,000	0–50 MW	Seconds –24 h+	Hours–months	5–15	10,000+
Solar fuel	800–100,000	0–10 MW	1–24 h+	Hours–months	–	–
SMES	0.5–5	100 kW–10 MW	1 ms– 8 s	Minutes–hours	20+	200–300
Flywheel	10–30	0–250 kW	1 ms–15 min	Seconds–minutes	~15	250–350
Super capacitor	2.5–15	0–300 kW	1 ms – 60 min	Seconds–hours	20+	100–300

3.10 Conclusion

Finally, this chapter included: an intensive and comprehensive study of state of the art of hybrid power generation systems. Moreover, unit sizing, configuration are addressed and advantages and disadvantages of hybrid energy systems. Energy storage systems and its impact on power generation, and how it can be integrated in power generation systems. Furthermore, the advantages and disadvantages of the hybrid power system, in addition to a comparison between energy storage systems.

CHAPTER FOUR

SMART SOLAR WIND PANEL

4.1. Introduction

In this chapter, we will see the design of smart hybrid machine which will produce electricity from wind power and solar radiation, the mechanical functioning and electrical behave will be presented, also how does it function as solar panel stand-alone, how it acts as wind turbine stand-alone how it can generate electricity and how it functions as hybrid Machin. Finely, the energy production from different renewable energy sources will be presented. The hybridization among both sources will be studied.

4.2. Methodology and system design

The project was designed and implemented using the top to bottom design method. This approach involves breaking down a system into smaller units to enable the designer get more insight into the system.

Solar Part's design: The design of the Solar Part was not easily done, because it is unlike an ordinary solar panel. Therefore, this panel must be from hard matter and solid enough in order for it to resist the natural factors and to be able to bear the weight of Solar Cells installed on it and at the same time being foldable to be used in the winds part.

The major components of this system are as follows.

- Input Light Sensors (Photoresistor).
- Microcontroller.
- Stepper motor driver.
- Tracking software.
- Output mechanical transducer (stepper motor).

How can a solar panel be foldable?

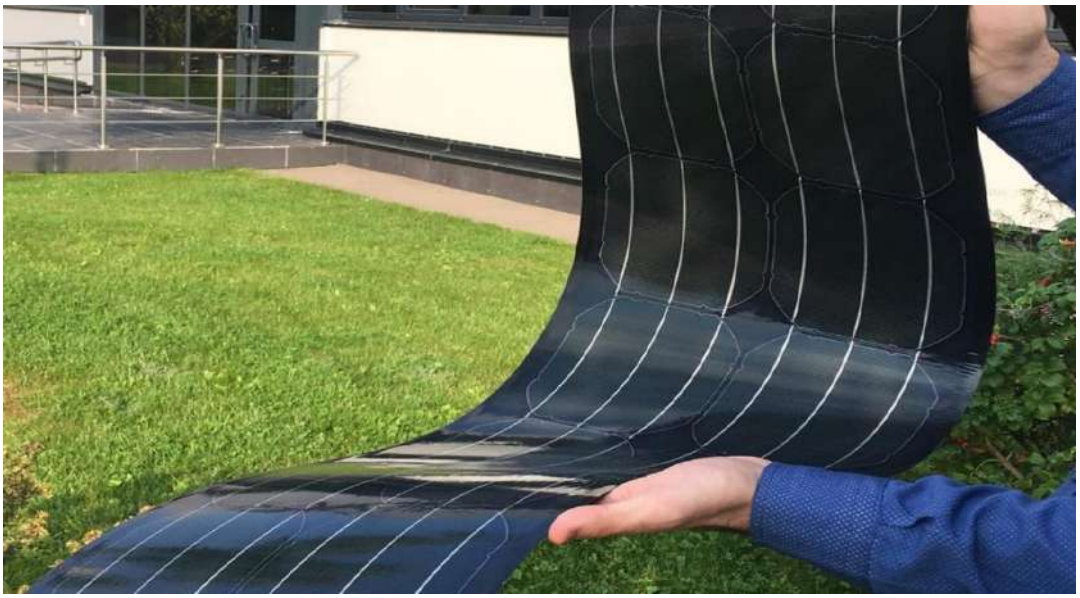


Figure 4.1 Thin-Filmed Solar Cells/Panels. [114]

First, we can use the collapsible panels known as Thin-Filmed Solar Cells/Panels Figure 4.1. These films would play the role and function as solar panels. In addition, they are more flexible to a certain degree, which enable it to absorb shocks, as, we can also install it on surfaces of whichever shape, a characteristic that facilitates the process of transformation and resorting to solar energy.

The Downsides of this technique:

- The price of the panels is high, compared to the regular ones.
- The efficiency is less than 9%.
- Life rate is lower than normal panels.

The second solution applied in this design is to use ordinary mono crystal solar panels, but with a smaller size of 4.8x2.1cm, so that there is flexibility and the panels would be able to move easily and smoothly. It may also be installed in series or parallel circuit as needed and shall become shock resistant. Its disadvantages are the same as the ones of the normal panels

4.3. The Stand-Alone Photovoltaic Systems

4.3.1The Method of Alignment

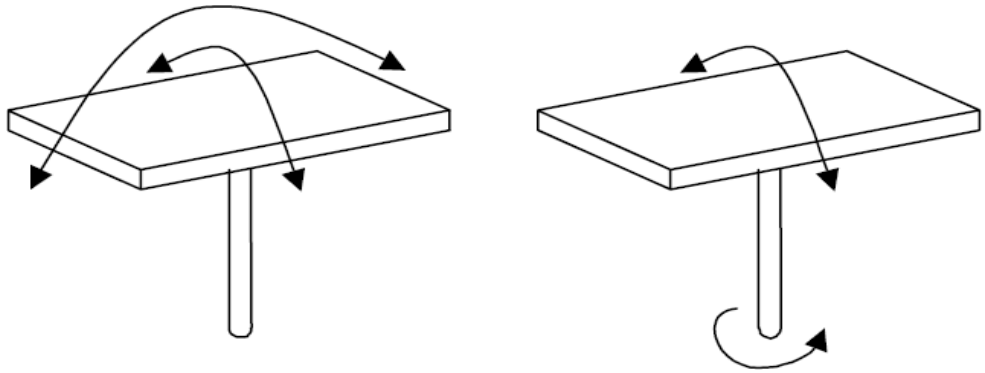
Before the design of the sensing circuit can be considered, it is necessary to choose an appropriate method of alignment for the solar panel.

There are two ways of aligning the arrays viz:

a. Two Axis Tilt: This involves tilting the array in two axes to maintain the required position as shown in Figure 4.3 (a).

b. Rotate and Tilt: This involves rotating and tilting the array to maintain the same position as shown in Figure 4.3 (b).

In this work, the Rotate and Tilt method was adopted because it is flexible less complicated in terms of mechanical construction as stated earlier [115], Figure 4.3



(a) Two axis tilt (b) rotate and tilt

Figure 4.2 Methods of Alignment of Solar Panel [115].

4.3.2. The Photovoltaic Panel Mechanical Operation

Mechanically, the solar panels follow the Sun during the whole day time, which is done by using the Tracking System, in order to achieve the largest amount of collected energy in a day.

The tracking is done using two engines from the "Stepper Motor" type. The first engine is installed on the holder of the solar panels and rotates vertically from 0° to 90° with the possibility of stopping and maintain the position at any angle between 0° and 90°.

The second engine though, is attached to the gearbox installed at the base of the pole (we used the gearbox for producing more torque.) Thus is the case, the motor works to rotate the plates at an angle of 360° horizontally with maintaining and stopping at any angle as well.

Moreover, we used the tracking system with two parameters, so that the panels could be positioned freely and at any angle, this would make the efficiency become maximal, Figure 4.4.



Figure 4.3 3D design of the solar panels tracking sun in different positions.

4.3.3The Photovoltaic Panel Electronic Mode of Operation:

Figure 4.5 shows the complete circuit diagram of a microcontroller based dual axis solar radiation tracker. This system is used to tracker the radiation of the sun and face it directly such as it been 90 degrees the solar rays for high contact of the solar panel since energy converted by the solar panel is higher when it is directly 90degrees to the sun radiation.

The system makes use of voltage regulators but one battery source. When a DC voltage of 9v coming from the battery, the regulators LM7805 produce 5v, the 5v goes to the light dependent resistors and also to the microcontrollers.

At night the LDR's detect no solar ray and are idle, but once solar radiation increases the four LDR's which work in pairs convert the solar radiation into analog signals and send them the microcontroller through pins A0, A1, A2 and A3 which do the comparison.

The microcontroller does its comparison and sends signal to the stepper Motors's drivers through pin 5 and 2 to stepper motor X's driver and through pin 6 and 3 to stepper motor Y's driver, to carry out adjustments, when necessary, so as to make the solar panel to face the direction with the highest intensity of solar radiation.

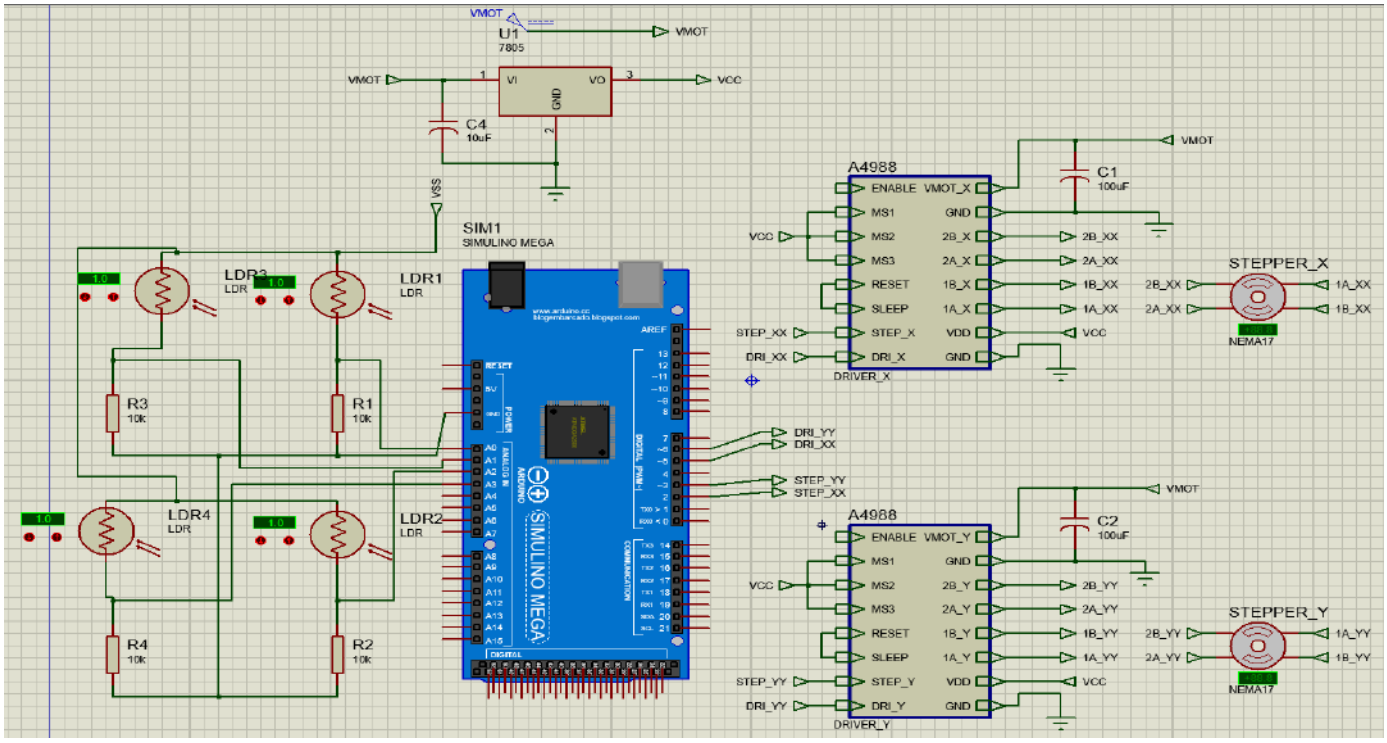


Figure 4.4 the solar panels tracking system circuit Simulation on Proteus 8.

4.3.4 The Photovoltaic Panel Algorithm

Microcontroller (Arduino) acts as brain of the whole solar tracking system. It will receive the desired light radiation through the CDS sensors. The input radiation to the sensors can then be compared to determine the position of the sun or the light source. The microcontroller then sends the output signal to the stepper motor's driver for the desired angle of altitude and elevation angle.

An algorithm has to be developed to make the microcontroller to read the input and respond accordingly. Therefore, the algorithm is established and represented by a flowchart in Figure 4.6 These flowcharts are then translated into C language and compiled using the Arduino IDE. The program in C language can be referred in Appendix.

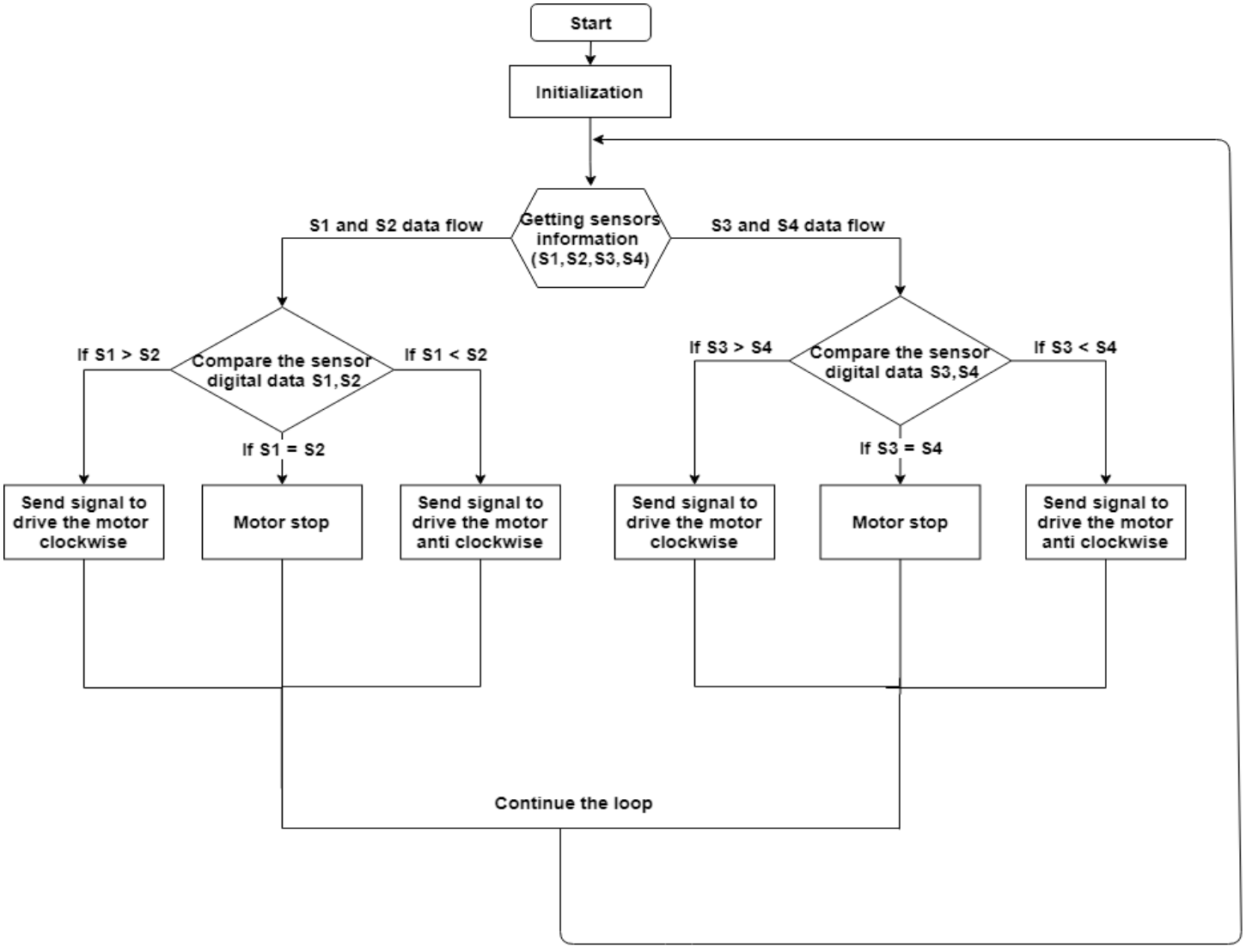


Figure 4.5 The solar panels tracking system Algorithm.

4.3.5 The Photovoltaic Panel Charging Circuit

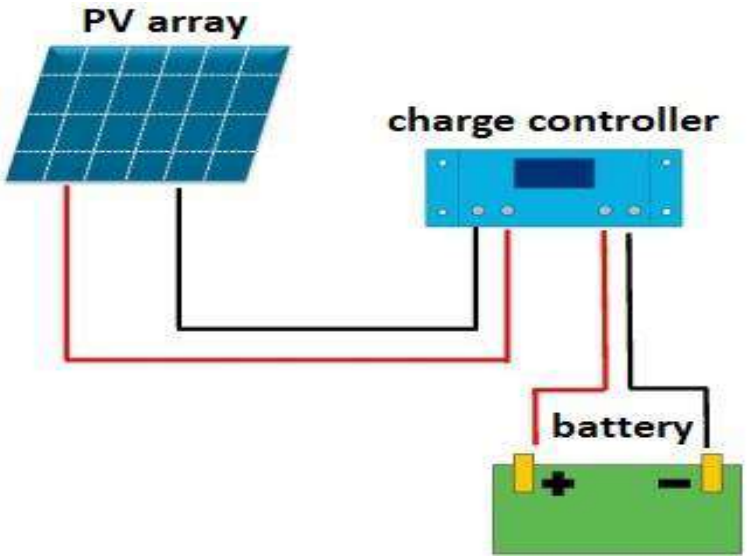


Figure 4.6 Charging circuit. [116]

In our design meant for the solar panels, we find 4 of them, and each one is composed out of 45 solar cells linked in series; therefore, giving us, each of these solar cells, an output of: 0.5V and 185mA. This makes the output of the solar panel equal to 22.5V and 185mA.

Hence, this result is enough to connect every two panels in **series**. As this gives us two groups, where each one is consisted out of two panels and the output is 45V and 185mA.

Furthermore, we connect the first group to the second in parallel, resulting in a solar array output of: 45V and 370mA. Then, the Solar Array is linked with the Charger Controller which controller and regulate the charge and discharge process in the solar power system. the main role of the charge controller is to control the charge current flowing from the PV panels to the battery, keep the current flowing not too large to prevent the battery pack from overcharge, Figure 4.9.

There are 2 kinds of the solar regulator on the market:

- MPPT Solar Charge Controller
- PWM Solar Charge Controller

4.3.6 Comparison between Stationary Panel and Tracking Solar Panel:

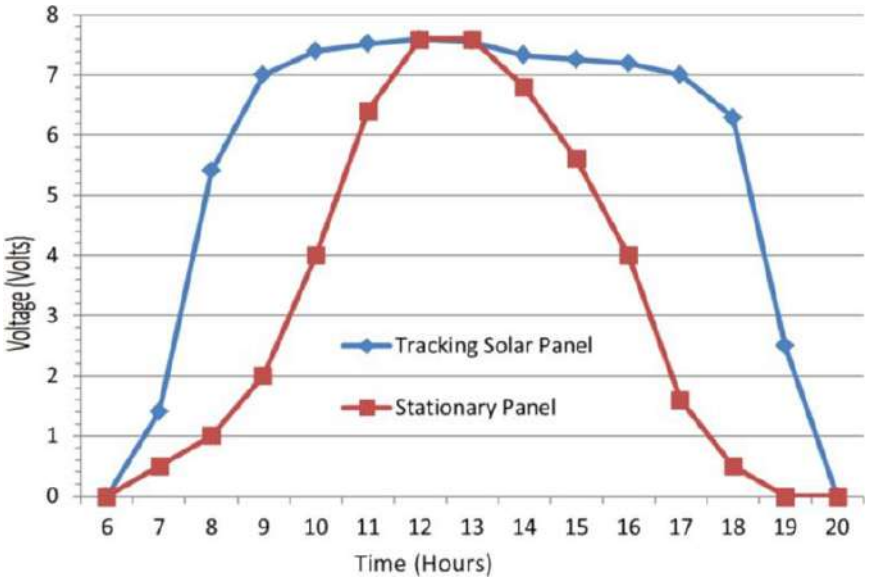


Figure 4.7 Plot of Output Voltage with Fixed Panel vs Dual Axis Control [117].

Table4.1: Comparison between Stationary Panel and Tracking Solar Panel in Volts [117].

Time	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00
SSP	0	0.50	1.00	2.00	4.00	6.40	7.60	7.60
TSP	0	1.40	5.40	7.00	7.40	7.52	7.60	7.56
TIME	14.00	15.00	16.00	17.00	18.00	19.00	20.00	
SSP	6.80	5.60	4.00	1.60	0.50	0	0	
TSP	7.32	7.26	7.20	7.00	6.30	2.50	0	

SSP = Stationary Panel; TSP = Tracking Solar Panel

This experiment involved a solar panel with four (4) solar cells, which was mounted at the top of a platform where shade interfered. Table 1 represents the voltage values received from both the static and tracking solar panels at different times of the day, while Figure 4.10

shows the curve. From Table 1 it can be seen that there is much improvement in voltage level in the tracking solar panel system compared the static panel at 9.00 am/9.00 hrs. However, as the time goes on the difference decreases up to 12.00pm/ 12.00hrs. Thereafter, it increases as the sun rotates more towards the west **[117].**

4.4 The Stand-Alone wind turbine

4.4.1 The Wind Turbine Mechanical Operation

The concept of harnessing wind energy to generate mechanical power goes back for millennia. As early as 5000 B.C., Egyptians used wind energy to propel boats along the Nile River. American colonists relied on windmills to grind grain, pump water and cut wood at sawmills. Today's wind turbines are the windmill's modern equivalent, converting the kinetic energy in wind into clean renewable electricity.[118]

In our case, we got The Motor "Y" at rest position, i.e. 0°. After that, The Motor "Z" spins, and this leads to the pulling of the panels for them to bend and give each panel a shape of a half-cylinder.

That shape creates a savonius, and the machine works based on the performance nature of The Normal savonius, meaning it converts wind energy into mechanical energy by means/through The Spinning Blades which rotate the shaft installed on the gearbox that runs The Motor "X", whereby the latter works as a generator that converts mechanical energy into electrical energy.

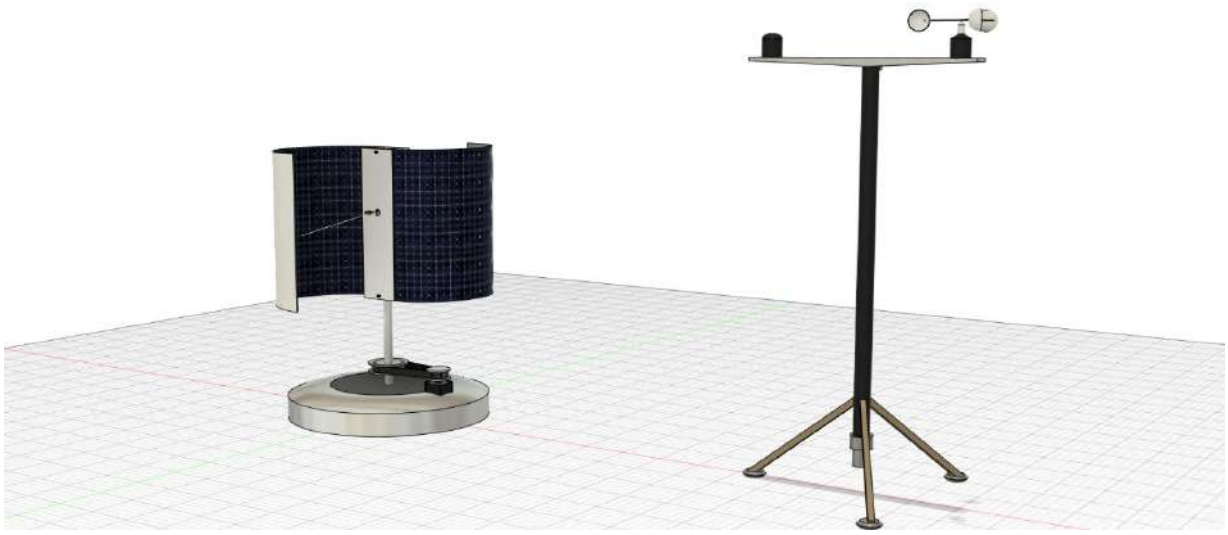


Figure 4.8 3D design of the wind turbine.

4.4.2 The Wind Turbine Electronic Mode of Operation

Figure 4.12, Represents the Circuit Meant to Run the Wind Part In the circuit, we have The Wind Speed Sensor that calculates the wind speed according to "Table 02"; then, sends the results to the Microcontrollers via pin A4 that does the comparison

This system is used to generate electricity from wind using stepper motor as generator, it changes the shape of the panels to be more reliable to rotate by the wind's power and give us high energy quantity.

When the wind speed is low the wind sensor will give us low result so the machine is active as solar panel, but once the wind speed increases the wind sensor convert the speed into analog signals and send them to the microcontroller through pins A4, which do the right operation.

The microcontroller sends signal to the stepper Motors's drivers through pin 5 and 2 to stepper motor X's driver, through pin 6 and 3 to stepper motor Y's driver and through pin 6 and 3 to stepper motor Z's driver, to adjustments, when necessary, so as to change the panel's shape to the savonius shape.

Table 4.2: Relationship between Speed and Output value

WS (m/s)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Value (v)	**0.17**	**0.33**	**0.5**	**0.67**	**0.83**	**1**	**1.17**	**1.33**	**1.5**	**1.67**
WS (m/s)	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Value (v)	**1.83**	**2**	**2.17**	**2.33**	**2.5**	**2.67**	**2.83**	**3**	**3.17**	**3.33**
WS (m/s)	**21**	**22**	**23**	**24**	**2.5**	**26**	**27**	**28**	**29**	**30**
Value (v)	**3.5**	**3.67**	**3.83**	**4**	**4.17**	**4.33**	**4.5**	**4.67**	**4.83**	**5**

Ws = Wind speed

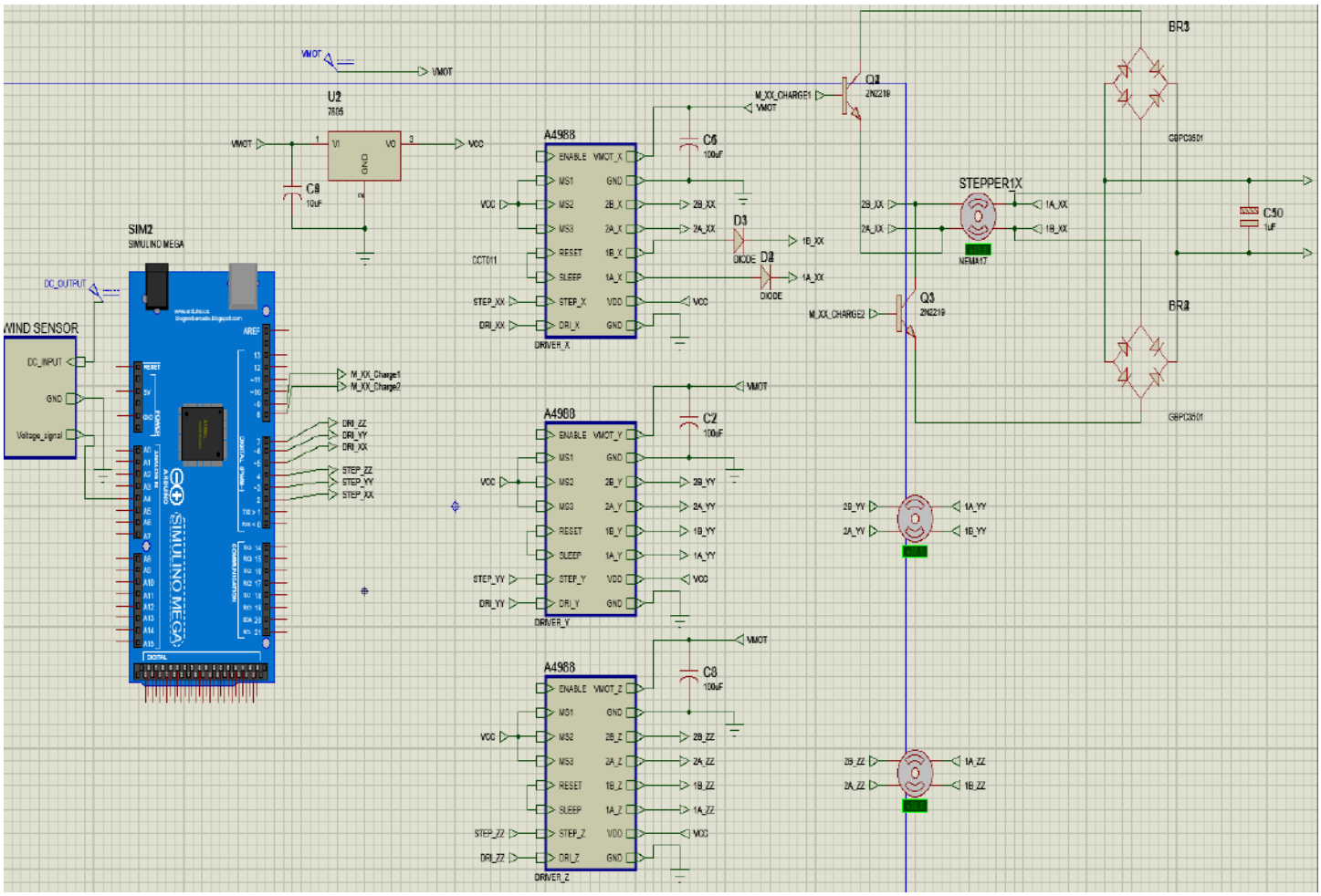


Figure 4.9 The wind turbine circuit Simulation on Proteus 8.

4.4.3 The Wind Turbine Algorithm

Microcontroller (Arduino) will receive the voltage signal from the wind sensor. The input of the sensors can then tell the wind speed. The microcontroller then sends the output signal to the stepper motor's driver for the desired actions and send signal to open the motor X's charging circuit.

An algorithm has to be developed to make the microcontroller to read the input and respond accordingly. Therefore, the algorithm is established and represented by a flowchart in Figure 4.13 These flowcharts are then translated into C language and compiled using the Arduino IDE.

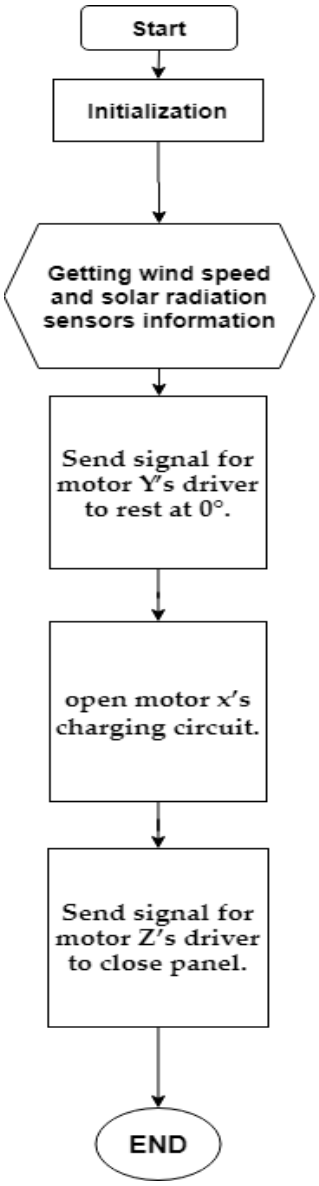


Figure 4.10 The wind turbine Algorithm.

4.4.4 The wind turbine charging circuit

The stepper motor is ideal to be used as a generator. In contrast to other generators, a stepper motor produces a large induced voltage even at low rotational speeds. The stepper motor type used here, can generate more than 20 V when turned by hand, without any gearing. The circuit diagram for a wind turbine charging circuit Figure 4.14, shows how we can use a stepper motor as a generator. A supplementary circuit stores the energy. Two bridge rectifiers, each made up of four 1N4148 diodes, charge the 4700µF capacitor.

Using the bridge rectifiers to convert the ac output of the stepper motor to Dc so we can store it, we can connect the bridges to each other's in parallel for more Amperes and same

voltage or in series for more voltage and same Ampers. Using the capacitor to smooth the output and also it does store some of the energy. This circuit is been control by the microcontroller witch dose open the charging circuit when the stepper motor act as generator by sending signal to the thyristor Q1 and Q2 from pin 8 and 9 and close it when we use it as a motor we also use the diode to protect the stepper motor's driver and the microcontroller from the load of energy the stepper motor generate.

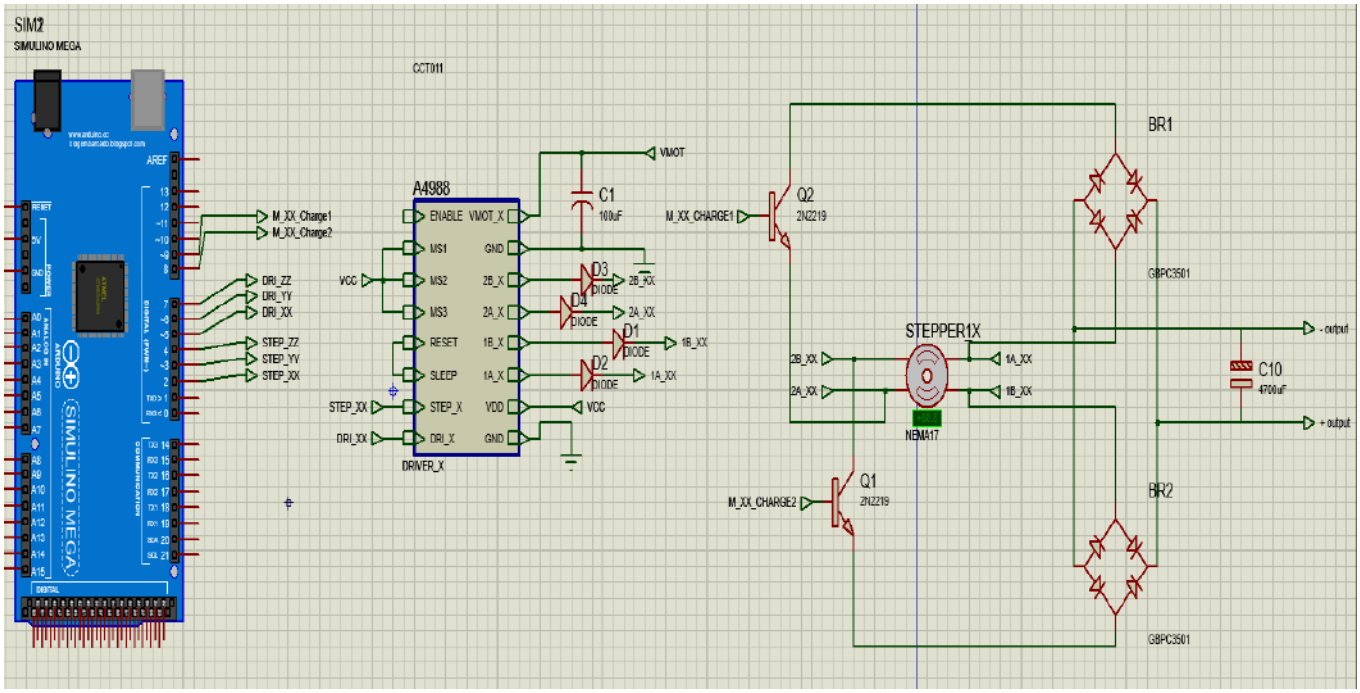


Figure 4.11 the wind turbine charging circuit Simulation on Proteus 8.

4.5. The Smart Wind Solar Panel

4.5.1 The Hybrid Mechanical Operation

As a hybrid Machin all the mechanical action will be the same as we have seen in the solar and wind part individually, but the only difference here is that the machine will act as solar panel and wind turbine by commend, so we will have all the mechanical movement Gidden by the microcontroller who will calculate compere and possession the machine at the chosen shape, Figure 4.15.

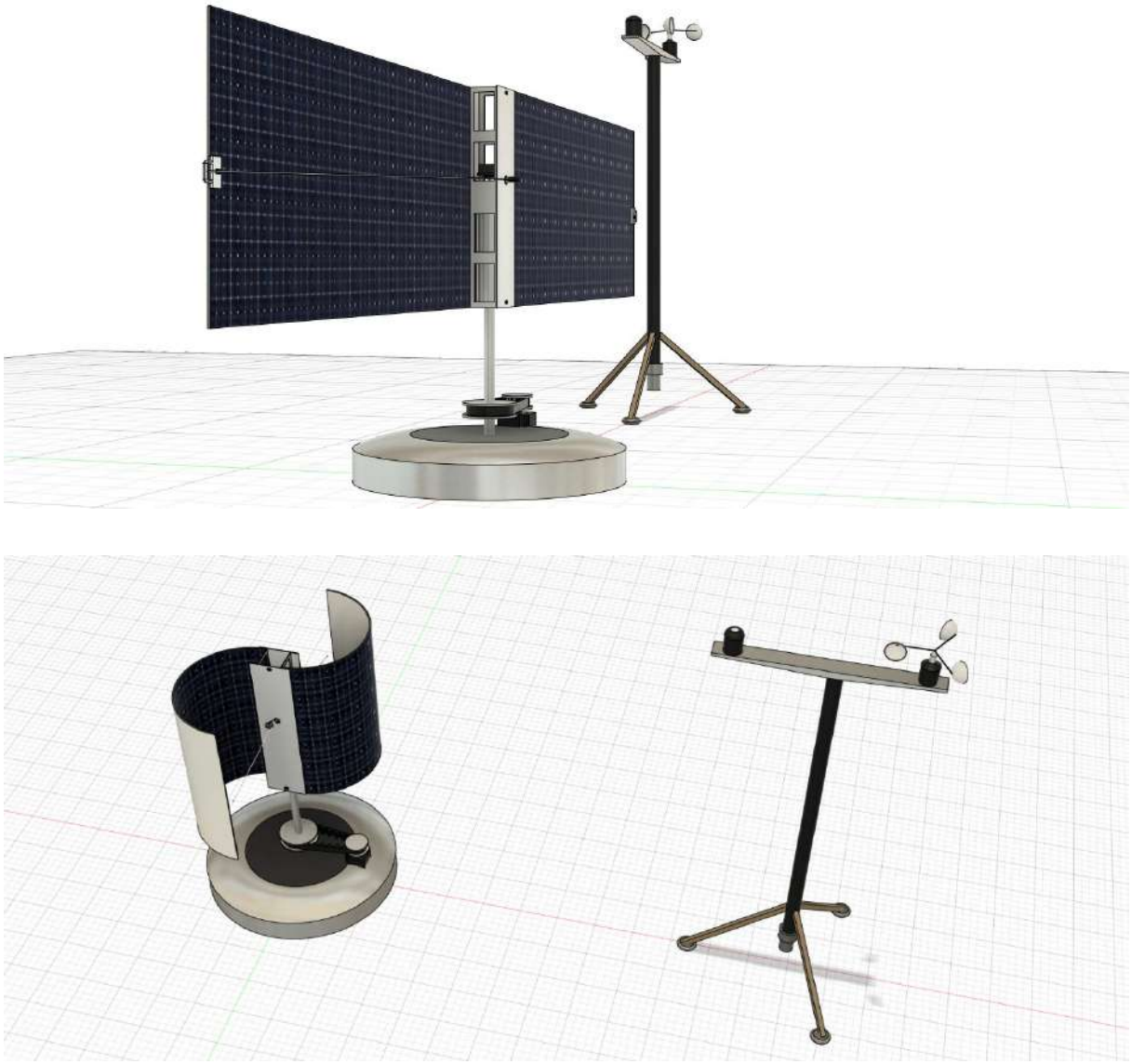


Figure 4.12 3D design of the Photovoltaic Wind Hybrid Machin.

4.5.2 The Hybrid Electronic Mode of Operation

Figure 4.16 Represents the Circuit of the hybrid part witch combine both of the solar panel and the wind turbine circuits plus an additional sensor witch is the solar radiation sensor; after getting both of the sensors is output signals (wind sensor and solar radiation sensor), the microcontroller will calculate the possible power generated from both sources supported on "Table 4.2"and "Table 4.3" and figure 4.17; and choose the greatest one, so the machine will follow and take the chosen position, as we have seen in (**4.4.2The Photovoltaic Panel Mechanical Operation)** and **(4.5.2The Wind Turbine Electronic Mode of Operation).**

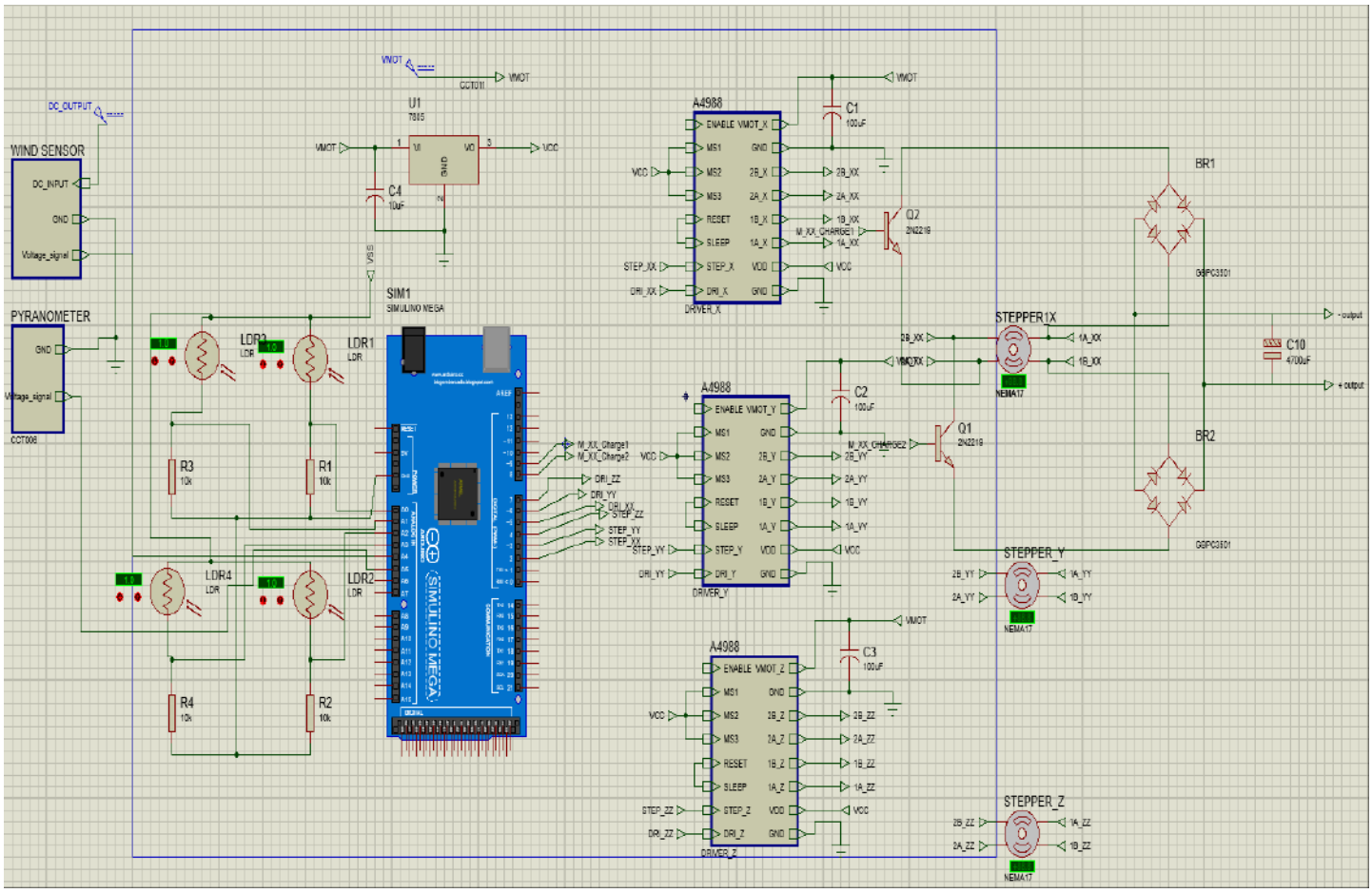


Figure 4.13 Photovoltaic Wind Hybrid Circuit Simulation on Proteus 8.

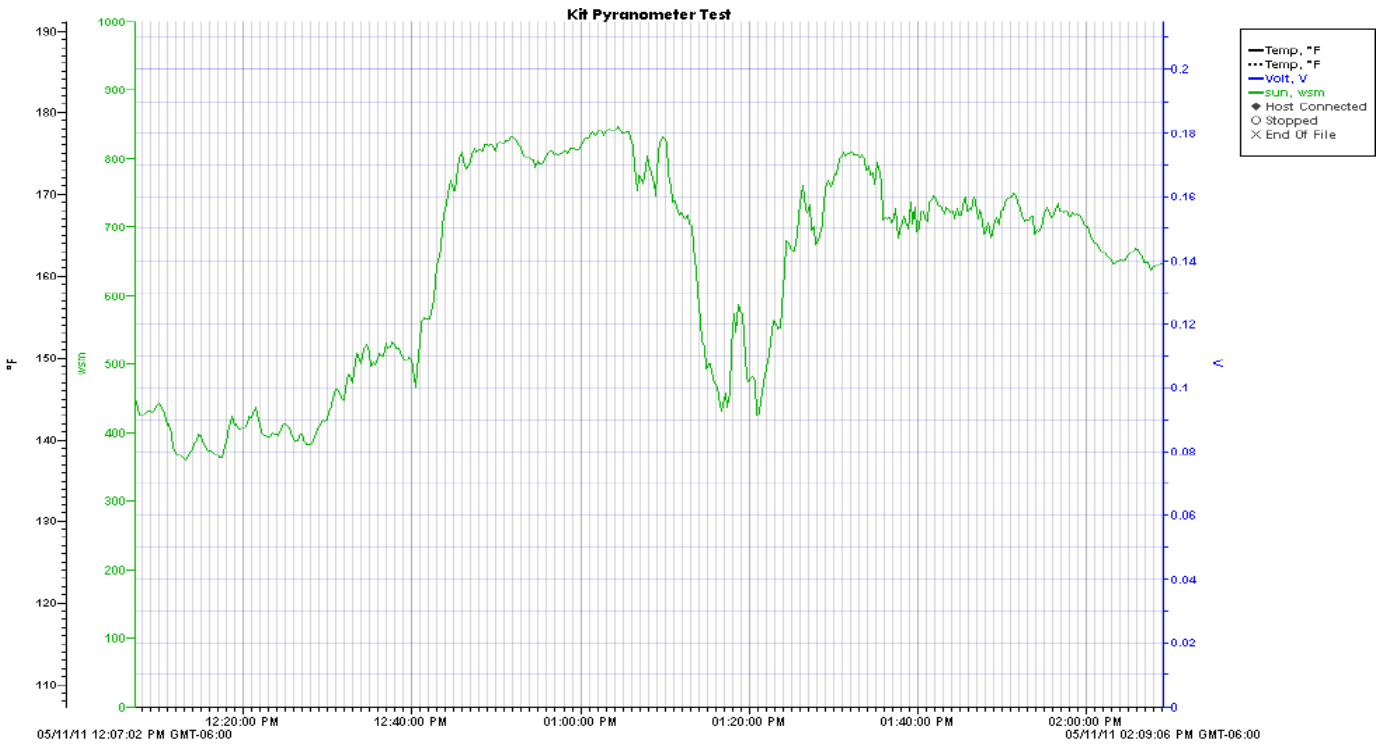


Figure 4.14 Shows the output of the Apogee pyranometer in watt/cm /v [119].

Table 4.3: Relationship between solar radiation and Output value

SR (watt/cm)	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
Value (v)	0.065	0.075	0.085	0.095	0.107	0.115	0.128	0.140	0.145	0.158	0.172	0.182	0.192	0.205	0.215

4.5.3 Photovoltaic Wind Hybrid Algorithm:

Microcontroller (Arduino) will receive the voltage signals from both the solar radiation sensor and the wind speed sensor. Then it will calculate the possible generated energy from both ways, after getting the results from both sources it will choose the greatest one, then the machine will follow and change its shape to the Selected Position and function as it is explained in **(4.4.4The Photovoltaic Panel Algorithm)** and (**4.5.3the Wind Turbine Algorithm)** Figure 4.18.

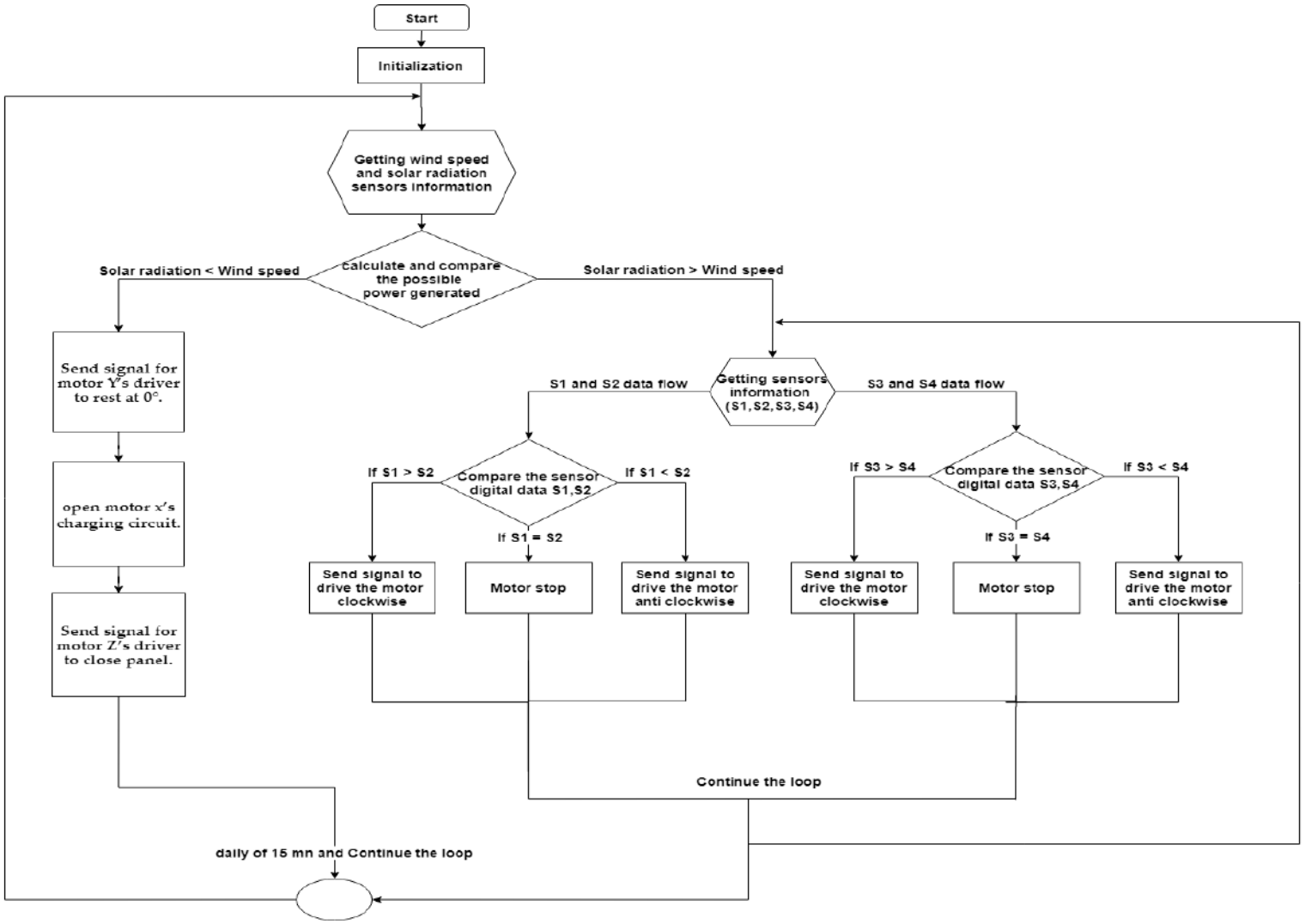


Figure 4. 15 Photovoltaic Wind Hybrid Algorithm.

4.5.4 The calculation of the generated power

The microcontroller will do the calculation of the generated power; this will be achieved by following two of the roles to calculate the generated power from the sun will apply the global formula to estimate the electricity generated in output of a photovoltaic system is:

$$E = A.r.H.PR \text{ (Watt)} \qquad 4.1$$

Where:

E = Energy (W);
A = Total solar panel Area (m^2);
r = solar panel yield or efficiency (%);
H = average solar radiation on tilted panels (Watt/m²);
PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9, default value 0.75).

In our design, the total solar panel area is (0.021 * 0.048) * 190 = 0.19152 m^ 2. The solar panel efficiency is 12% because the model we used is polycrystalline solar cells. The solar radiation will be determined by reading the pyranometer at the outlet and the compartment in "Table 03" and the loss coefficient is of the order of 0.75.

The formula will be:

$$E = 0{,}19152.0{,}12.H.0{,}75 \text{ (Watt)}$$

Where:

H = the rotor height (m).

D = the rotor diameter (m).

For calculate possible generated Energy from savounies wind turbine we will use this formula:

$$\mathrm{P} = \frac{1}{2}\rho \,.\, \mathrm{A_s} \,.\, \mathrm{V}^3 . \mathrm{Cp} \text{ (Watt)} \qquad \textbf{4.2}$$

Where:

$\boldsymbol{\rho}$: the air density (kg/m3)

$\boldsymbol{A_S}$: The swept area = As = H * D

V: Wind speed

Cp: The power coefficient (Cp).

In our design the swept area is A_s = 0.2 * 0.3 = 0.6m^2, the air density 1.225 kg/m³

The Wind speed will Determined using Table 02, the power coefficient (Cp) will be specified using Table 04 (because we did not do an experiment due to the covid-19 pandemic, we used the result from Figure 2.14 chapter02**).**

Table 4.4: Relationship between power coefficient and the wind speed.

WS (m/s)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Cp	**0,01**	**0,02**	**0,1**	**0,24**	**0,32**	**0,38**	**0,41**	**0,42**	**0,43**	**0,42**	**0,41**	**0,4**	**0,36**	**0,34**	**0,32**

The formula will be:

$$P = \frac{1}{2} \cdot 1{,}225 \cdot 0{,}6 \cdot V^3 \cdot Cp$$

4.6 Solar, Wind and Hybrid Generated Power:

For the test I have chosen Aïn El Ibel to be a reference of simulation, because there is Solar Photovoltaic Power Plant Stationed in there, and for our lack of testing, I have taken the information from PVsyst for the sun radiation and wind speed of the chosen site.

Aïn El Ibel is a town and commune in Djelfa Province of Algeria., GPS details are Latitude: 34.3438°, Longitude: 3.2247°, Elevation: 1008m.

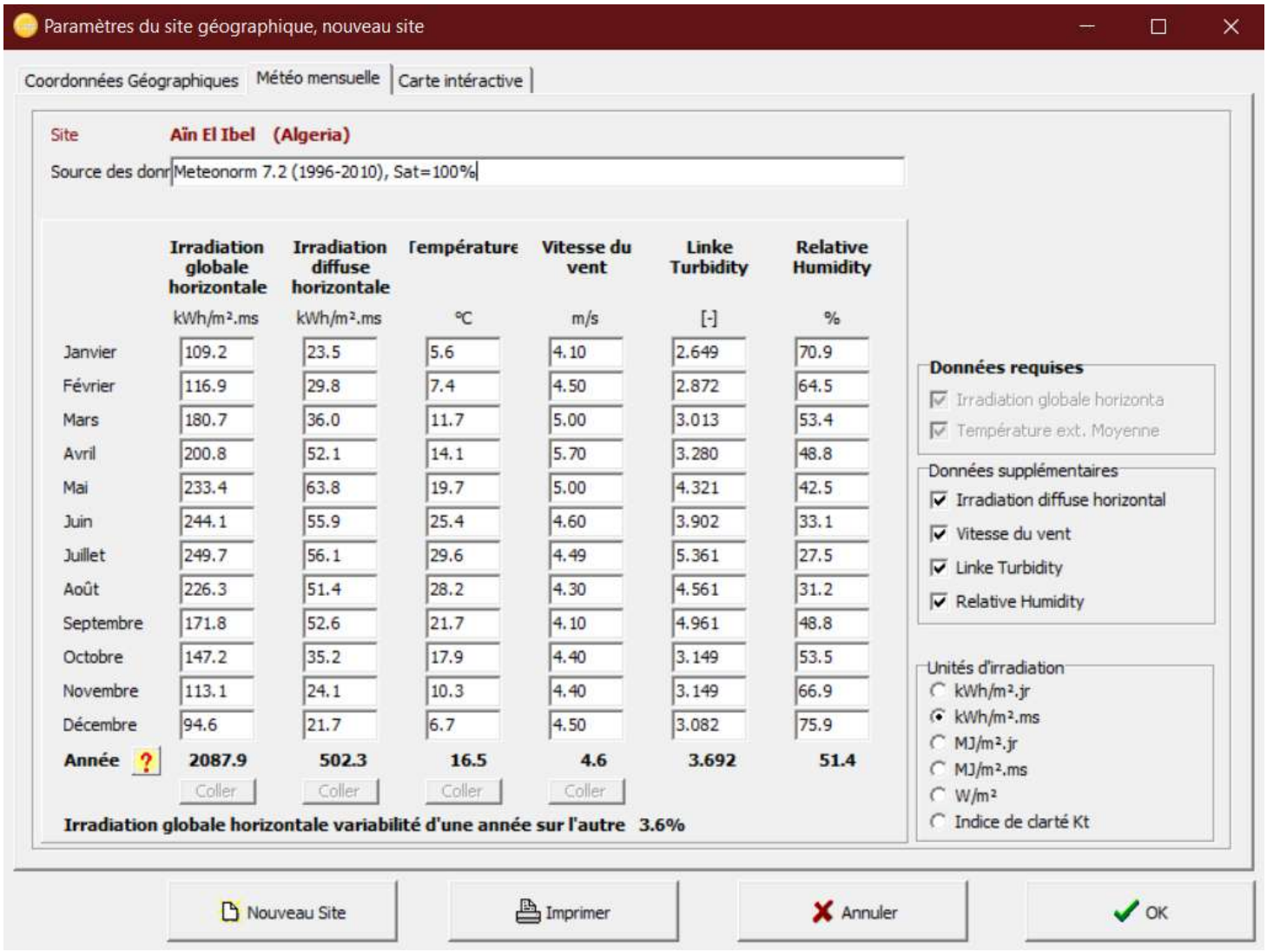


Figure 4.16 Aïn El Ibel's solar radiation and wind speed by PVsyst program.

Table 4.5: solar radiation and wind speed for the chosen site

months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Solar radiation ($kw/m^2.ms$)	109.2	116.9	180.7	200.8	233.4	244.1	249.7	226.3	171.8	147.2	113.1	94.6
Wind speed (m/s)	4.1	4.5	5.0	5.7	5.00	4.6	4.49	4.3	4.1	4.4	4.4	4.5

Figure 4.19 showing the results solar radiation wind speed and some more details of the chosen site (Aïn El Ibel) using PVsyst programme.

Table 4.5 show the solar radiation and wind speed for the chosen site.

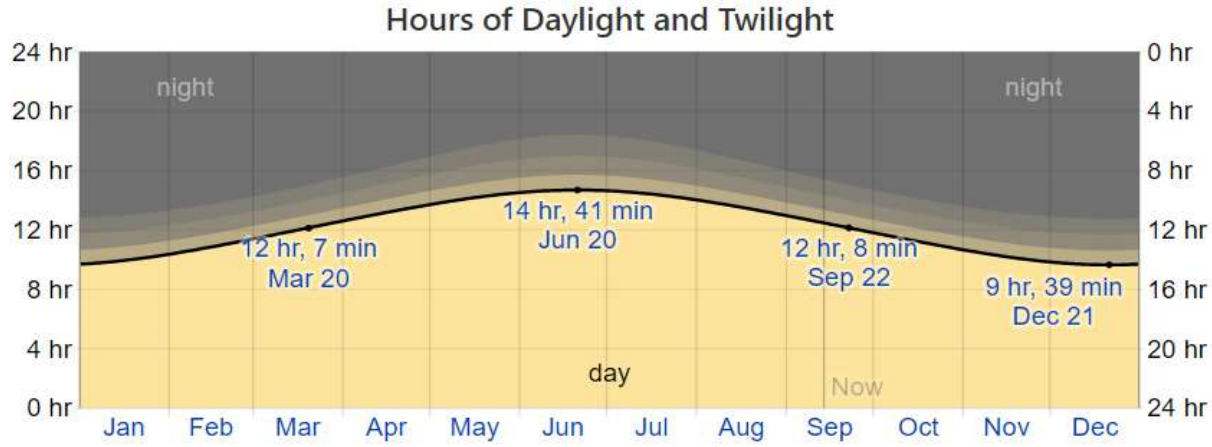


Figure 4.17 The number of hours during daylight and twilight.

Table 4.6: The number of hours during daylight and twilight

months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daylight Time (h)	15	13	12	11	10	9.5	10	11	12	13	14	14.5
Twilight Time(h)	9	11	12	13	14	14.5	14	13	12	11	10	9.5

Figure 4.20 and Table 4.6 show the number of hours during daylight and twilight in Algeria during all the year for each month.

The following formula calculates the power produced by the sun:

$$E = A.r.H.PR \text{ (Watt)} \qquad = 0.19152 \,.\, 0.12 \,.\, \mathrm{H} \,.\, 0.75 \qquad = 0.0172368 \,.\, \mathrm{H}$$

Where:

H: is the solar radiation

Table 4.7: The energy generated by solar radiation.

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
The generated power from the sun (kw. ms)	**1,88**	**2,01**	**3,11**	**3,46**	**4,02**	**4,30**	**3,90**	**3,84**	**2,96**	**2,53**	**1,94**	**1,63**

The following formula calculate the generated power from the wind:

$$P = \frac{1}{2} \cdot 1{,}225 \cdot 0{,}6 \cdot V^3 \cdot Cp \cdot h \cdot ms \ (kw.ms) \qquad = 0.3675 \cdot V^3 \cdot Cp \cdot h \cdot ms$$

Where:

V: the wind speed

Cp: power coefficient from **Table 4.4.**

h/day: time of functioning per day from **Table 4.5.**

ms: number of days per month**.**

Table 4.8: The energy generated by wind.

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
The generated power from the Wind (kw. ms)	**1,767**	**2,889**	**5,468**	**9,873**	**6,174**	**4,502**	**4,042**	**3,179**	**2,279**	**2,989**	**2,629**	**2,860**

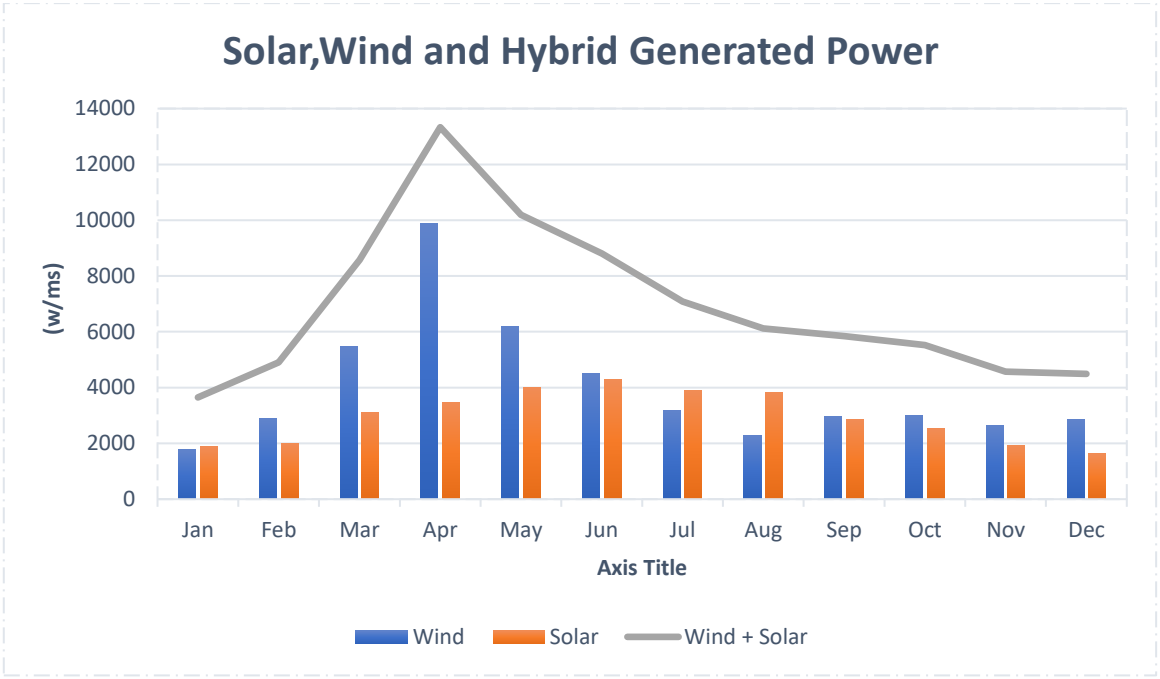


Figure 4.18 Solar, Wind and Hybrid Generated Power.

Figure 4.21 shows trends of solar and wind hybrid average monthly power generation from January to December at Aïn El Ibel. On an annual span, it is observed that there's great increase in Wind power Generation from January up to April and a slight increase of solar generation within the same duration. wind trend is depicting maximum wind power generation at April. The seasonal variations in this region indicates hybrid average power generation. Though wind drastic decreases after April for 4 months to rise a bit in August. The solar trend on the other hand increases during the months of April to Jun and gradually decreases from July until December. Due to which solar and wind trends together shows a simultaneous decrease until the month of last September from November wind and solar trend to increases simultaneously.

After which wind slightly rise and contribute to the Annual trend. The Table 4.9 gives details of generated power. Wind Turbine can generate 47,588 Kw and Solar PV panel can generate 35,480 Kw and cumulatively can generate 83,068 Kw of electricity.

Table 4.9: Annual wind, solar and Hybrid Generated Power.

Type of plant	Annual Wind Energy Production per (kW)	Annual Solar Energy Production per (kW)	Annual Hybrid Energy Production (kW)
The generated power	47,588	35,480	83,068

Note: In This part I was obliged to use information from the PVsyst programme and Cp from (Figure 2.14 chapter02) also I couldn't add the power given from the gearbox linked to the stepper motor X, all of these inconvenient points were because of the covid-19 pandemic.

4.7. Conclusion

In this chapter, Hardware, Software systems and methodology as well system design has been shown. Then the stand-alone photovoltaic systems, this part details the method of alignment, mechanical operation and electronic mode of operation, also the algorithm of the operation the configuration of the solar panels and the photovoltaic panel charging circuit, at the least of this part comparison between Stationary Panel and Tracking Solar Panel is shown. Moving on to the second part of the chapter which is The Stand-Alone wind turbine, showing The Wind Turbine Mechanical and Electronic operations also the algorithm of operation and at the end of this part the unordinary charging circuit was presented.

Moving on, The Smart wind solar panel, the hybrid mechanical, electronic operation and hybrid algorithm was explained then the calculation formula of the generated power was presented and explained at the end a calculation of Solar, Wind and Hybrid Generated Power in a chosen site was done.

Finally using this system will enhance the output of the photovoltaic panels because of the tracking system as we have seeing and it will provide us with an additional power generator in the absent of the solar light or at low light conditions which is the wind turbine, lastly, using this machine will prevent us from taking a large space for a hybrid system, as we usually need.

General conclusion

This thesis interested on developing a specific hybrid system with self-diagnosis possibility of the greatest source of energy. A specific structure has been proposed consisting in hybridization of the photovoltaic and wind sources.

First in chapter 01 discussing Renewable energy production and it's benefits on the environment and the economic, moving to the solar potential, also, studied the photovoltaic conversion both the Existing technologies of the PV panels and Third generation technologies, realising in Resulting characteristic that PV panels are modelled as a DC current source with the current output dependant on the terminal voltage, the temperature and the solar irradiation. Taking a brave look at the Blocking Diodes that prevent reverse current flow back, finely studied the Maximum Power Point Tracking technique.

In chapter 02 starting with Hydraulic Power Resources, highlighting Wind Characteristics, Wind Variation with Height and Wind Direction, also, taking a look on the History of Wind Turbines, after that Classifications of wind turbines and wind turbines Parts was presented, moving to the savonius both of The concept of the savonius rotor and operation was explained, in Measurements of The mechanical power and The performance of savonius all of the mathematical equations was bravely explained, moreover, the Pressure distribution on the savonius blades and Flow pattern around a single savonius rotor was presented, in the end of this chapter the Advantages & Disadvantages of Wind turbine was shown.

the third chapter started with components and structure of Hybrid Renewable Energy System, moving on to Drawbacks of Standalone Renewable Energy Sources and Advantages and Disadvantages of Hybrid Energy Systems, in the second part of this chapter Power Management Strategies Based on Energy Storage Technologies was Reviewed, also in this chapter Basic Theory of Energy Storage Systems, Classification of Energy Storage Systems and Application of Energy Storage Systems has been studied in details. Ending this chapter with General Comparisons of Different Energy Storage Systems.

In the last chapter we saw the design of our smart hybrid machine, in the beginning of this chapter the needed hardware and software parts were presented, moving to Methodology and system design in this part in the solution for the flexibility of the solar panels were found, moreover in The Stand-Alone Photovoltaic Systems The Method of Alignment, The Photovoltaic Panel Mechanical and Electronical Operation and the Algorithm of this part of the

system has been demonstrated, The Configuration of the panels and the charging circuit ware presented, finishing this part with Comparison between Stationary Panel and Tracking Solar Panel resulting that there is much improvement in voltage level in the tracking solar panel system compared the static panel.

Moving to second part of this chapter The Stand-Alone wind turbine, flowing the same path The Wind Turbine Mechanical and Electronic Operation, the driver Algorithm and the wind turbine charging circuit has been studied.

Last and not least The Smart Wind Solar Panel, in this part of the chapter The Hybridization of Mechanical and Electronical Operation, also the Photovoltaic Wind Hybrid Algorithm has been demonstrated to be adapted for the considered applications. Moving to The calculation of the generated power in this part all of the mathematical equations where presented, finely the Solar, Wind and Hybrid Generated Power in this part with the use of PVsyst programme we calculated the possible generated power using this machine and resulting a great energy production comparing this to a stand-alone solar panel or wind turbine.

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