College of Science and Technology

DESIGN OF SOLAR POWERED WATER PUMPING SYSTEM FOR A COMMUNITY DRINKING WATER SUPPLY IN DRC

ACEESD/REE/20/06

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A dissertation submitted to the African Center of Excellence in Energy for Sustainable development

College of Science and Technology

University of Rwanda in partial fulfilment of the requirements for the degree of

MASTERS OF SCIENCE IN RENEWABLE ENERGY

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November 2020

DECLARATION

I declare that the present dissertation is the result of my effort except where specifically acknowledged and it has been passed through the anti-plagiarism system and found to be compliant and this is the approved final version of the thesis.

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October 18th 2020

Dr MULOLANI Francis

ACKNOWLEDGEMENT

With this dissertation which concludes two years of study, I want to thank every person who helped directly or indirectly, in whatever way and who mark by their presence an important step in my life.

I am deeply grateful to the All-Mighty God who allows this day to reach by the life's breathe and every new day's blessings he brings up to me, for his love and mercy during this journey.

I address my thanks to my supervisor, Dr Francis Mulolani, for his guidance and advice he was giving me all along this journey. I'm grateful for the experience I have gotten and the achievement under his supervision.

I am indebted to the World Bank, ACE-ESD and the University of Rwanda for this opportunity provided to pursue my Post-graduate studies, for providing the financial support and education during this master's degree.

I would be ingrate not to extend my thanks and love to my both parents Pascal HAMULI and Marie-Jeanne NAMUKE, my friends and classmates through them I could not lack any kind of support, care, encouragement all the way long to achieve my ultimate goal.

ABSTRACT

The DRC is the second-largest African sub-Saharan country has no electricity to pump water in both modern and rural areas. Counting 19% national rate of the electricity access in the whole country, rural communities suffer from the scarcity of the grid electricity only almost 1% of the rural population is connected to the electric grid and Minova is not excluded. Households, health centres and schools that served us as a sizable population of the rural community in Minova are also affected. The use of solar energy using PV modules for providing drinkable water for rural areas of Minova has been presented using the Meteorological condition and coordinate of Minova and it has been shown that the monthly solar radiations were showed up to 4.896 kWh/m^2/day, the designed PV array of 4kWp was capable of pumping water from a deep well of 40 m depth with a flow rate of 15.3m^3/h to supply a community of population more than 500 people, one health centre and one primary school which counted 200 pupils. The detailed sizing system and analysis were provided by using some tools such as PVsyst and MATLAB/Simulink, besides, a storage tank of 76m^3 was taken into consideration to supply water continuously for 4 days' autonomy when the daily water demand is equivalent to 19000litres per day, a solar pump integrated with an MPPT-DC converter was selected in PVsyst based on the total dynamic head of 42.7, the water flow rate of 11.7 m^3/h and the type of the pumping system which was a direct coupling with MPP-DC Converter to control the power from the PV array and much it with one of the motor pumps also the controller could sensor the water level in both the well and the tank.in Matlab/Simulink a brushless motor was analysed by taking into account the PV array of 4kWp and the result showed how performant the system is when the components are very well chosen. Finally, a discussion and result presentation were made based on different software and the comparison has shown that photovoltaic water pumping system is a promising alternative for supplying drinking water for the rural and remote area where the electricity from the grid is difficult to find, also it has been seen that the Solar pumping system is eco-friendly to the environment and cost-effective considering its maintenance cost compared diesel-powered for the water pumping system.

KEY WORDS

Solar-powered, PV array, Water Pumping, Pump-motor, diesel-powered, grid electricity, renewable energy, rural community.

LIST OF SYMBOLS AND ACRONYMS

AC	Alternating Current
BOS	Balance of System
DC	Direct Current
DWP	Diesel Water Pump
DWL	Dynamic Water Level
GHG	Green House Gases
kW	kilowatt
kWh	kilowatt-hour
kWp	kilowatt peak
LCC	Life-Cycle Costs
PV	Photovoltaic
RE	Renewable Energy
SPWPS	Solar Powered Water Pumping System
STC	Standard Test Conditions
TDH	Total Dynamic Head
WEWPS	Wind Energy Water Pumping System

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Chapter 1 : INTRODUCTION

1.1 OVERVIEW OF WATER SITUATION IN DRC

In the worldwide, many people live without access to drinkable water even though in many places, extracting groundwater, the electrical water pumps is most needed by using diesel to supply with power to their system which represents a huge percentage in water extraction but this is mostly done in Urban and Peri-Urban communities [1]. However, those systems require high cost which is characterized by fuel purchasing, high maintenance services and the carbon dioxide emission which is harmful to the environment [2].

In general, the population growth is constantly increasing day today on the planet earth and this is about to continue rising for millions and millions of decades in the anticipated future [3]. As the population is growing and the electricity demand of the human being is increasing as well and thus the energy demand is also projected to grow very fast as the energy provided by the electricity increases at the same time. Being the most used in the worldwide, the more than 30% of the electrical energy use the electric motor in most cases and various pumping system such as fans and compressor applications, centrifugal pumps with fixed speed based on the recent research [4].

By approving the slogan, ‘Water is Life’ it has been seen that since the durability of humanitarian life and the system formed by the ecological community in the watery and dry areas which are associated to areas where the accessibility to water is very comfortable. To access to the natural resources which are not visible by human eyes or are hidden such as water from the underground and those which are visible or exposed such as the atmospheric or surface water can be explored depending on the climate conditions, hydrological and economical settings for a county to another. [5].

In a numerous African countries unlikely where fresh natural water is uniformly dispatched in both space and time as foreseen, the Democratic Republic of the Congo has 35% of the freshwater reservation and is the second with the great size of equatorial forest in the worldwide, the Democratic Republic of the Congo is not excluded among those countries which still struggle with the uneven water distribution to their community in time [6]. Taking into account its meteorological and hydrological data, it has also an abundance of water from the underground which is expected to be very significant for the whole community [7].

Energies like Diesel, petroleum, windmills as well as kerosene have been traditionally used to pump water [8] However, being among the most African richest freshwater countries, the Democratic Republic of the Congo is counted among the countries with low water security because of the poor access to drinkable water and basic need or facilities for sanitation [6].

The drinkable water inefficient access and the inadequate hygienic behaviours belong to the risk factors linked with death and poverty in the country. In the Democratic Republic of the Congo, many people are facing these factors listed and only 52% of the country has access to the basic water facilities along with less than 29 % have access to basic facilities for sanitation [2].

In DRC only 19.1% of the population at the national level has access to electricity and most of the population live in a rural area where the access to electricity is low than 1 % because of the non-extended grid connection [9]. Therefore, due to the shortage of electricity, it is difficult to meet the demand of electricity for pumping water. So, solar photovoltaic water pumping is a good way to go over the electric grid due to its simplicity, its free harm to the environment, reliability and availability thus one of most promising application is water pumping through solar PV.

1.2 BACKGROUND SITUATION OF ENERGY IN DRC

Renewable energy is referred to the energy from natural and clean sources and though they are exhaustible while non-renewable energy come from natural sources which can not be readily replaced thus most of them are fossil fuel. solar, wind, air, waves, water, geothermal, biofuel and biogas constitute the renewable sources whereas non-renewable energy is such that oil, natural gas, mineral coal, uranium, oil shale, tar sands,) are in abundance and diversity in The Democratic Republic of Congo [10].

Despite enormous hydropower potential estimated at 100,000 MW, the access of the population to electricity is rated at 19.1%. According to World Bank data: 49.2 per cent in urban areas and a sobering 0 per cent in rural ones [11].

Wood energy still represents 95% of the domestic consumption of energy, usually in the form of charcoal in the cities and firewood in rural areas. The population uses usually (more than 90% of households) wood fuels for its domestic needs for cooking meals and heating, causing deforestation and degradation of the forest with all the negative impacts on the environment, health, forest, biodiversity and socio-economic conditions [9].

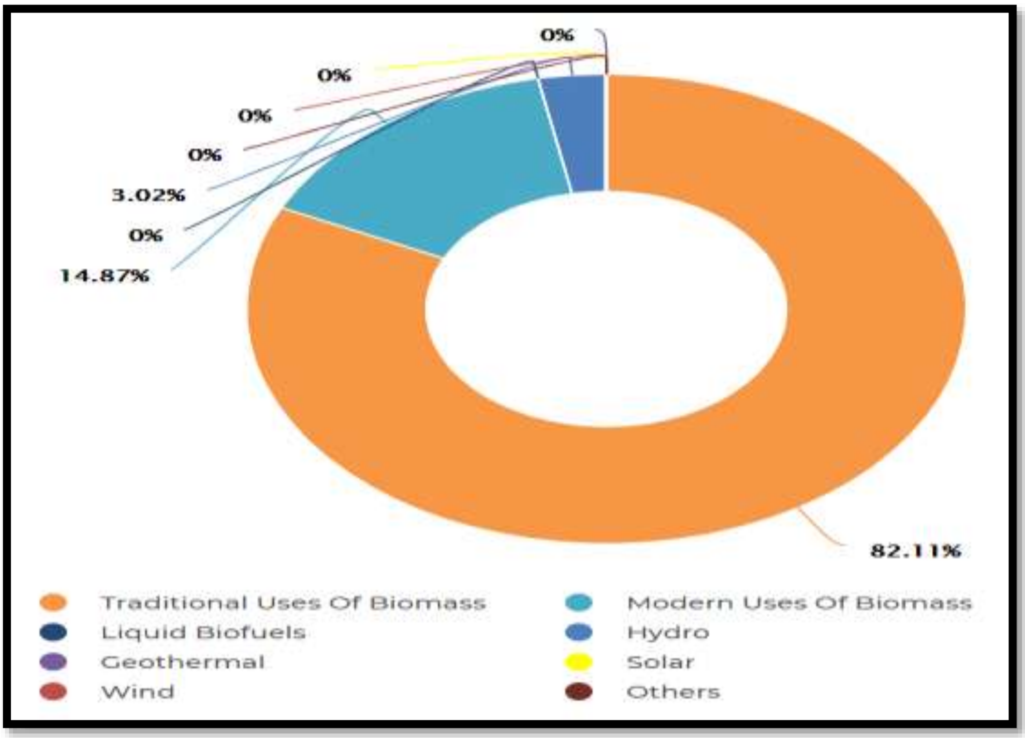

Figure 1-1: DRC's energy consumption during 2015 [12]

Figure 1-1 illustrates that most of the electricity generated today comes from hydro and the Inga project has the potential to provide more to the Democratic Republic of the Congo and some other African countries around. According to the International Agency for Renewable Energy (IRENA), the year 2018 showed that the installed capacity in the Democratic Republic of the Congo was 2750 MW in which hydropower capacity of 2740 MW either 96% which occupied the higher potential over other renewable energy such as wind, solar, biogas and geothermal [11].

Only about half of this total, however, is available for dispatch at any given time due to a maintenance backlog [12]. Meanwhile to access to the electricity in the rural area is limited because generally those who have electricity got it from a solar panel at the rooftop of the house and some have batteries just to fulfil the basic needs for low loads use such as charging phones, lighting and watching television [12].

For some organized communities which have high loads consumption, the power supply is based on the diesel generator where owners make a small business by supplying communities in power provision through an informal community grid. Therefore, several small and medium commercial enterprises pay fees weekly to be connected to that grid [13].

Table 1-1: Energy produced since 2000 -2018 11]

Source of Energy	Unit	2000	2005	2013	2014	2015	2016	2017	2018
Carbone source	Kt	106	132	0	0	0	0	0	0
Energy from Coal	Kt	283	615	3674	3803	3841	4074	4129	4185
From rude oil	Kt	1169	1269	1129	1061	1048	996	946	957
Natural gas source	TJ	0	0	0	0	46	14	0	0

Table 1-1 shows that charcoal is the most produced since the last two decades, followed by crude oil while carbon and natural gas are almost inexistent. As shown Figure 1-2, the most produced Energy in DRC come from coal and the production rate increases proportionally with the year.

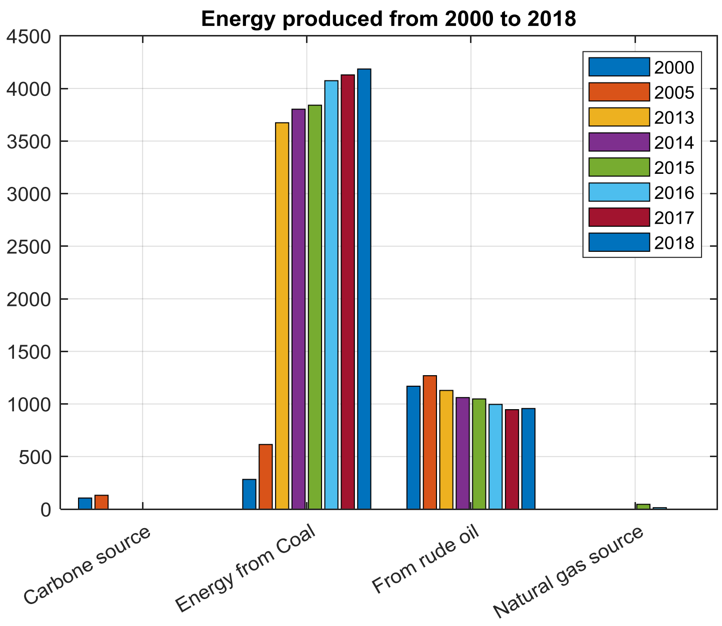

Figure 1-2: Representation of Energy produced from 2000 to 2018 in DRC

Talking about renewable energy, solar has the higher potential with its average of 6kWh/m^2/day as the average solar irradiation in the D RC gives motivation in implementing or promoting solar as energy to supply electricity for different purposes for the entire country [13].

Based on the energy situation in DRC which makes difficult access to water, water supply in DRC is driven by one utility water company 'REGIDESO' in the Urban area working with some branches in peri-urban areas but in rural areas, the water management is done by community organizations constituted by themselves or some NGOs working for the same objectives [14].

Despite the existing water utility company in the Urban the water supply doesn't meet the water demand, meanwhile among more than 80million of people like more than 55% live in the rural area where access to water is a critical crisis [15].

Therefore, solar water pumps are powered by solar panels, once you have the panel, the energy needed come from the sun which is completely free of charge and this makes solar pumps more cost-effective once installed than diesel pump which requires fuel or electricity from the grid before working. Such a system is most required in DRC because it is cost-effective once installed the maintenance cost is almost zero, environment friendly and have a good potential in such a place because of its vast water table[16].

By classifying the pumping systems, five groups have been categorized based on different renewable energy sources as follow: Solar Powered Water Pumping System 'SPWPS', Solar Thermal Water Pumping System 'STWPS', Wind Energy Water Pumping System 'WEWPS', Biomass Water Pumping System 'BWPS', Hybrid Renewable Energy Water Pumping System 'HREWPS' [16].

1.3 PROBLEM STATEMENT

DRC is the richest freshwater resources' country while it is suffering from acute drinking water supply crisis and it has the lowest rate of access to drinking water in sub-Sahara Africa. As a result of inadequate water supply and sanitation service is waterborne disease include diarrhoea, typhoid and cholera.

Because of the scarcity of water, it has been seen that children and women face a lot of trouble to get water due to the distance of the sources and the result is the failure to go school for children due to tiredness because by the time they could have been preparing to go to school or to study for exams, notes and review that is the time to go and look for water, the same case is seen to women, they spend more time looking for water while they could have been doing some different works which can increase their income.

On the other hand, where water is available but in low supply quantity than the demand, people are forced to go to the public tap early in the morning so that they can get water and this has many consequences such that you may meet bad intentioned people even some other drama which can misuse someone's personality.

After living the above scenario, solar has been the most promising renewable source which could help to pump water through PV module which catches the sunshine and convert it into electricity for water pumping purpose to a rural or remote area with drinkable water by making them a better and sustainable place for human beings.

1.4 AIM AND OBJECTIVES OF THE RESEARCH

1.4.1 AIM OF THE RESEARCH

The core objective of this present dissertation is to make a simple and comprehensive PV design which could meet the requirement for pumping water to supply a DRC's rural community where the access to the grid electricity is limited with drinkable water at an effective cost, reliable and eco-friendly to the environment and at the end translating the results into recommendations for decision-makers for its implementation.

1.4.2 RESEARCH OBJECTIVES

- To determine present water sources and the possibility of pumping in the selected area,
- Design a PV water pumping system which capable of meeting the demand in the water of a selected rural community.
- To analyse the performance of the designed system by simulation using PVsyst and Matlab/Simulink software,
- To evaluate the system performance using tools such as PVsyst and Matlab/ Simulink

1.5 SCOPE OF THE STUDY

The inefficiency of electricity from the grid and the high fuel costs harm the water supply and therefore the requirement of the pumping system in some communities, so, one of the promising ways to overcome this impact is the use of natural resources such as solar photovoltaic. In the present research work, we will develop a model theoretically but which can be implemented practically. Moreover, the system will consist of a PV array that converts the sun into electricity by the photosynthesis process for the pumping purpose.

The system is such that The PV panels connected into series and parallels convert the sun into electricity which runs the motor. From the motor, the mechanical energy is converted into hydraulic or potential energy through the pump and the system are done. To match the voltage from the PV array with the one of the motor, a boost converter is placed in between. Because of the intermittency of the sun, a water tank is envisaged for some day's autonomy to ensure the continuous supply. Moreover, the sizing and calculation using hand and software tools such as PV Syst and Matlab/Simulink were to see the system performance.

1.6 SIGNIFICANCE OF THE STUDY

The tangible influence derived by this research is the access to water at a low cost for a community far away from the water sources, once implemented, this project has an economical and environmental impact in the society referring the agenda 2030 based on sustainable development goals, the followings benefits from this study are:

- Providing informations on sustainability, affordability and reliability of water supply which can be implemented to solve water scarcity problem, and therefore reducing waterborn disease, failure at school for children and the possibility for women to increase their incomes.
- Providing a means of economical, environment and social improvement of the live hood for the community.
- Providing a way to create jobs opportunity for the community members.
- A means to enable successful results at the education level.

1.7 PROPOSED OUTLINE

Chapter 1: This chapter will describe briefly the background situation of this dissertation, the problem statement, it will highlight the objectives, scope and expected output result. This section is to give the content body to the ready, it will help him/her to understand what the work is about.

Chapter 2: This part relates the Overview of Solar PV Pumping System here, the theoretical background on the context of solar PV pumping will be conducted based on the environment, technical, economic and social aspects and also the main contribution of the researcher also the previous related work will be discussing to understand the following sections.

Chapter 3: Being the core of the work, Methodology and case study will consist of an overview of the system for a better understanding and the description of the entire system based on the data collected.

Chapter 4: this section consists of choosing the proper design components and analyse properly the site selected and here a design hand calculation will be conducted to make sure that the output is as we were expected, a simple comparison between solar-powered and diesel-powered will be presented based on their investment cost and their life span.

Chapter 5: This part will be made by a simulation with tools such as PV Syst and Matlab/Simulink comparing the result got by hand calculation with the one in software, thus the result will be presented with some discussion according to the online and field data collection.

Chapter 6: The present section will summarize the above three-section by coming up with a simple and understanding Conclusion. The recommendations will be addressed to the DRC’s government and the future researcher also in this section the final results will be highlighted and carried out barriers and obstacles which can be settled out by the future researchers.

Chapter 2: REVIEW OF SOLAR PV WATER PUMPING

2.1 INTRODUCTION

In this chapter, we will be reviewing the solar PV water pumping system, its types, advantages and disadvantages, factors affecting the system efficient and different parameter taken into account while designing the solar PV water pumping system also some previous works done on solar-powered water pumping have been highlighted to find to pursue our present work.

2.2 OVERVIEW OF RENEWABLE AND NON-RENEWABLE ENERGY

In the modern era, energy is considered as the lifeblood of the society but still fossil fuels such like coal and oil are the most used due to their consideration as spices while producing energy in our daily lives [17]. But unfortunately, the world is facing global warming because of the energy crisis with natural reserves of fossil fuels being expended fast and fast due to overconsumption. One of the possible solutions to overcome the global energy crisis is to start exploiting energy from renewable sources instead of non-renewable [18].

The abundance and inexhaustibility of the sun in the worldwide with the average solar energy per year of 1.56 × 1018 kWh which is almost 10 000 times larger the present worldwide energy consumption on earth makes the solar energy the ideal renewable energy resources [2]. This is explained that the earth receives more energy per hour than the one it consumes in the entire year this verify the ratio of the production and the consumption [19]. Grid electricity and diesel power for pumping systems are most used all over the world and thus in the DRC as well for supplying water [20]. With the way to go to the development, water and energy presented a high rate in need for the last decade and due to the increasing rate of industries, human being and new technologies, the need will be shown more essential soon [19].

By promoting renewable sources, usage of solar PV has been increased more and more that is why in our research we are focused on the PV system as a means of energy production to supply water and trying to develop a design that can be economically feasible and eco-friendly to the environment.

2.3 TYPES OF SOLAR PUMPING SYSTEM

The pumping system is a broad topic that plays an integral role in many industries such as water and wastewater, agriculture, mining, oil and gas. To categorize the pumping systems, three basic solar pumpings are classified based on the system coupling such as direct, with battery and hybrid systems [21].

2.3.1 DIRECT COUPLED SOLAR POWERED FOR PUMPING SYSTEM

In the presence of the sun, the sunlight hits the PV array and converts it into electricity, however, the same electricity directly sent to the pump and in its turn pumps the water passing by a pipe. The total quantity of water pumped per day depends first on the sunshine which hits the PV array, how the PV or at which angle the PV are tilted and this depends on the location of the region but also another important parameter is the type of pump used [22].

When the sunlight is in the optimal time, the operating pump efficiency goes up to 100% or near within its maximum flow rate but during the morning time and in the late afternoon, the operating efficiency can drop up to 25% and this occasioned the drop in flow rate [23].

The system is simple to design and here three main components such as PV modules, pump controller and pumps as illustrated Figure 2-1. Many people use an extra tank to store water for three to five days which can be costly expensive a little bit [24].

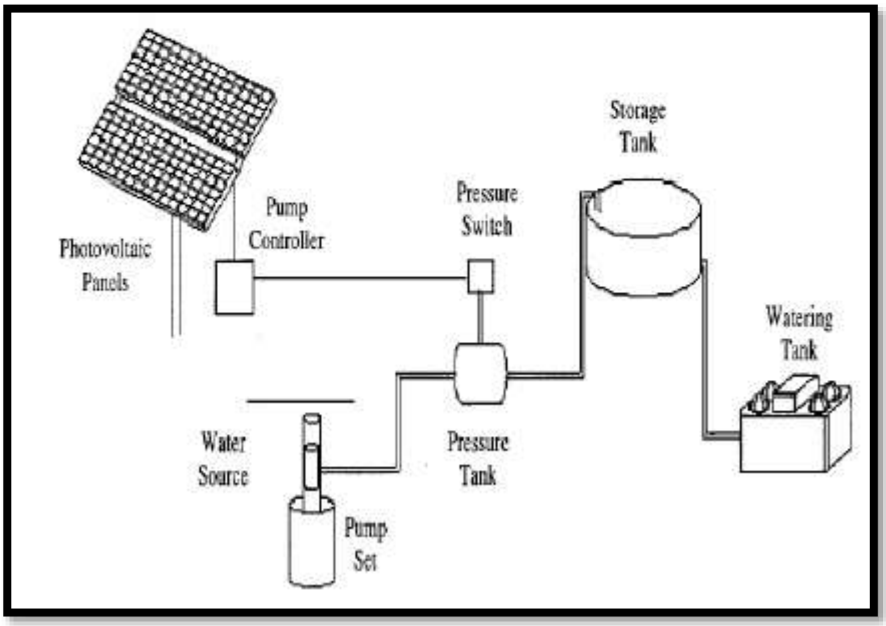

Figure 0-1: Direct-coupled solar PV pumping system [25]

The main advantage here is its economical side of it which is justified by the absence of batteries and storage tanks. It has a simple design and does not require maintenance. However, the system has no backup; in case of shortage of power required from the pump, the system lacks a battery. Again, it has no storage tanks, so in the cloudy days, there will be less pumping from the system and can be a shortage of water this constitutes the drawback of the system [26].

2.3.2 SOLAR WATER PUMPING SYSTEM WITH BATTERY

Contrary to the direct-coupled, the system with battery consists of two storage technologies, one is battery and another is water tank as shown in Figure 2-2 [27]. With these two storage technologies, the most used and preferable by people is tank storage because of its less initial cost and its less complexity than the use of batteries storage which requires the conversion of electrical power into potential power [28]. Though it happens in most cases, using batteries has also some importance.

Mainly, we can talk about the night and rainy days when the PV panels cannot work. Solar panels are inactive without sun rays. As we know that Photovoltaic is intermittent some backup systems are needed in night time such as batteries to supply the loads during cloudy days in stand-alone. When we need extra pressure on water, we can use the energy which is stored in the batteries. Therefore, there are many types of batteries but we will only enumerate two most used such as:

Lead-acid batteries: Being widely available and affordable in price, these batteries are the most used in a PV system in addition to this they can provide a huge current much higher than the available instantaneous current from PV, the output voltage is controlled too much with the load demand [29].

Deep cycle batteries: As batteries are one kind of balancing system component, those are very important. Deep-cycle batteries are the most appropriate for PV applications due to their ability to withstand the cycles of up to 80% discharge [29].

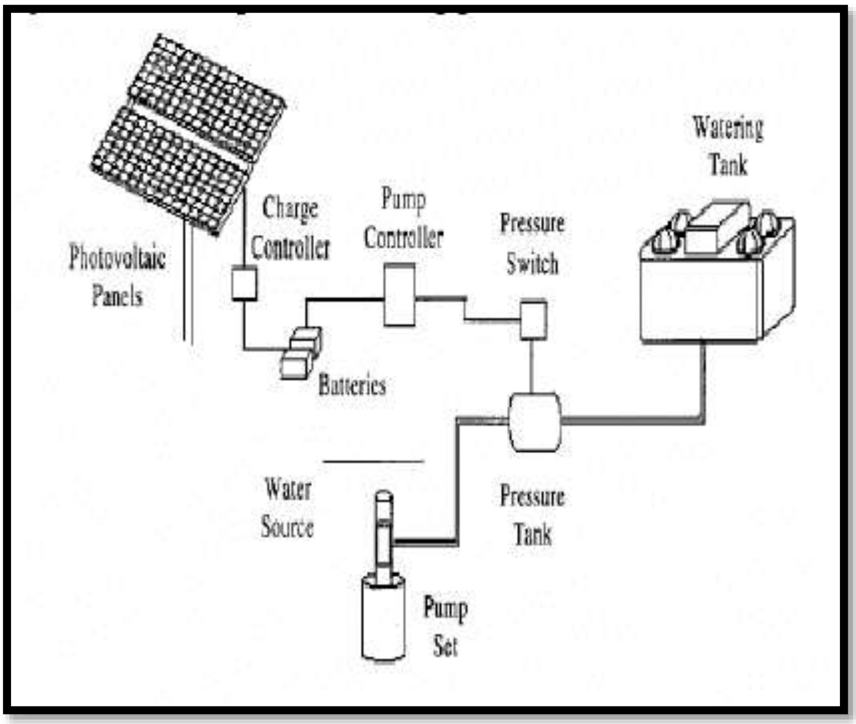

Figure 0-2: solar power pumping system with battery [30]

The system has the advantage such as Creating another method of managing the solar power, maximize self-consumption of solar power, reduces network costs which control us when we use power and how much we pay and keep the motor on if the power is gone. It's the backup plan for when the power goes out [23].

Most of the batteries are expensive and less effective than the water tank, they reduce the system's efficiency and require regular maintenance therefore the system becomes more complex. This consists of the main disadvantage of a system with batteries [31].

2.3.3 SOLAR WATER PUMPING HYBRID SYSTEM

A hybrid system is the one which uses two or more different power sources for some application as seen on Figure 2-3, it is both economical and desirable by using it whereas that PV powered supplies some loads but others might require the diesel or petrol generator [32]. The backup allows the cost-effective design of PV and also the energy-saving using batteries capacity but naturally for a lot of applications in particular in rural and remote regions the hybrid such as generator and PV applications are not compatible.

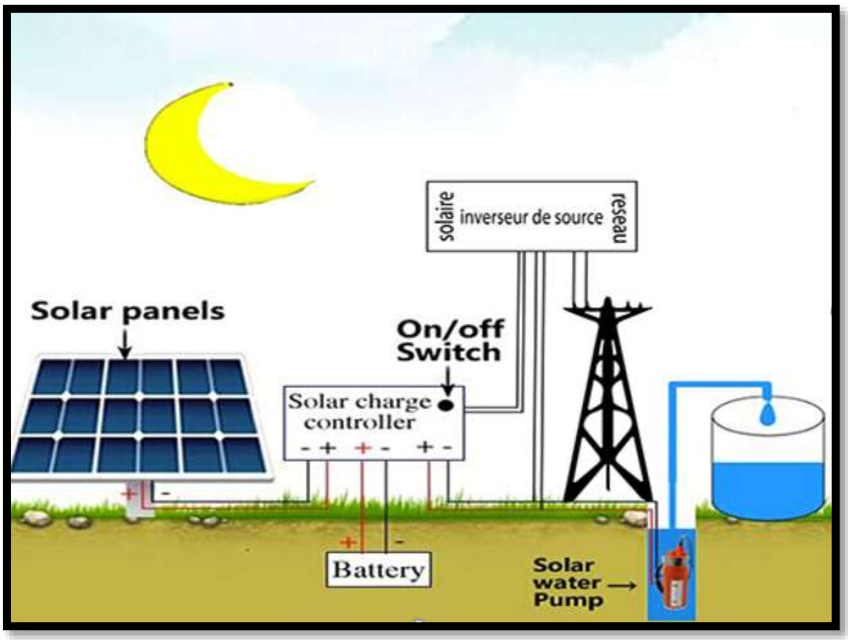

Figure 0-3: Hybrid Solar Pumping System [33]

The less initial cost and simple design installation are the main advantages of the hybrid system. its disadvantage is the very high maintenance cost, it also increases carbon footprint which leads to global warming, since it is not renewable energy we should maintain it efficiently [34].

2.4 PERFORMANCE PARAMETERS OF PV PUMPING SYSTEM

The PV pumping system performance depends on many parameters such as the water pressure while pumping, the solar irradiation and air variation which depend on a region and another and influence the water flow rate because of the weather condition [35]. Also, the meteorological data, the water demand per day, the height or level at which water has to be lifted, the tank volume storage, the PV capacity, the energy required per day, the characteristics of the pump while choosing must be taking into account to evaluate the system performance. [36].

Besides the PV modules degradation is one important parameter which can affect solar pumping system performance due to the regional temperature and others external intemperate after a long time of operation PV module start to get damaged and are not able to deliver the same output like the time they were new. [37].

The required hydraulic energy potential for lifting the water from the source to the discharge is calculated in Equation 2-1 as follows,

$$E_h = \frac{\rho * g * v * TDH}{3600} \qquad (2-1)$$

Where, ρ the density of water, g the acceleration of the gravity which is 9.81m/s^2, TDH the total height in (m) is the summation of the static and dynamic head including friction losses, E_h the hydraulic energy in Wh/day, v the quantity of water needed per day in term of volume in m^3.

Hence, to calculate the power required to pump water, Equation 2-2 was used as it is shown below,

$$P_{PV} = \frac{E_W}{I_T * \eta_{Sub} * F} \qquad (2-2)$$

Where P_{PV}, the solar photovoltaic power array in Watt, E_W the energy required in Watt h/day

I_T, the average daily solar radiation in an hour at 1000W/m^2/day (STC), F the array mismatch factor, η_{sub} The efficiency of the subsystem.

Also, the volume of water is calculated as follows in Equation 2-3

$$V = \frac{P_{PV} * I_T * \eta_{mp} * F}{\rho * g * TDH} \qquad (2-3)$$

And the PV system efficiency as shown in the Equation 2-4 is calculated as follow,

$$\eta_{PV} = \frac{P_{PV}}{I_T * Area} * 100 \qquad (2-4)$$

Hence the overall PV pumping system efficiency is obtained in the Equation 2-5

$$\eta_{tot} = \eta_{PV} * \eta_{mp} \qquad (2-5)$$

This is the total system effiiciecny after taking into account all parameters and losses besides, this shows the system performance.

2.4.1 OVERVIEW OF SOLAR PV TYPES AND TECHNOLOGIES

As the demand in PV modules increases, the PV technologies are being developed as well and implemented. Typically, four types of PV cells exist for now such as Monocrystalline, Poly-crystalline, Thin film and Amorphous silicon. It should be noted that mono-crystalline and multi-crystalline silicon are also referred to as single-crystalline and poly-crystalline silicon. The crystal growth process during manufacture is behind the formation of the two different types of crystalline-based solar cells [38].

Single-crystalline or monocrystalline: The most advantage of this type of solar cell is its wide availability and efficient cell material. The power is produced the most per meter square per module by dividing each cell of a single crystal into a rectangular shape to maximize the number of cells on the solar module.

Polycrystalline or multi-crystalline cells: Most similarly to the silicon material with the only difference based on the number of crystals in which can grow or be developed. After being melted, instead of forming a rectangular shape, a square block is formed that can be cut into square wafers with little waste of space.

Thin-film cells: Being a new technology, a thin film is not yet very available widely. Based on their constitutions, they are directly set on stainless steel or other compatible substance. Under low sunlight weather, thin fill performs far better than crystalline.

Amorphous Silicon: It is a sub technology in the new thin-film cell which is placed on two amorphous micrometre stick, on a stainless steel roll.it is very economic spatially compare to crystalline because it uses only 1% of the material.

The counterparts of crystalline silicon cells are thin-film cells. The common ones are summarized in Table 3-3. [39] [40] [41].

Table 0-1: Solar PV type with efficiency

Cell type	Efficiency [%]	Acronym
Mono-crystalline or single-crystalline silicon	12-18	Mono-c-Si
Multi-crystalline or poly-crystalline silicon	12-18	Poly-c-Si
Thin-film cell	08-10	TF-Si
Amorphous Silicon	06-8	a-Si

2.4.2 OVERVIEW OF WATER PUMPS-MOTOR

As the name suggests, the pump motor is a DC or AC motor device that moves fluids depending on the power source. The conversion of converts the direct electrical current into mechanical power is done by a direct current motor and it works on the principle that when a conductor which carry the current is in between a magnetic field, therefore electrical torque is experienced and tends to move toward. This principle is known as motoring action in the other hands, Pumps operate by some rotary mechanism with the help of motor but they consume a lot of energy while operating due to the work done mechanically by moving the fluid. Moreover, pumps can operate with many sources of energy including manual from the human operation, grid electricity, diesel and other renewable energies such as wind, solar; they are designed according to the applications that are why they come in many different sizes from microscopic size for medical use to huge industrial pumps size [42].

Based on availability, motors such as synchronous and asynchronous, brushed and brushless, permanent magnet and variant reluctance and many others are found in the market depending on the application. The use of a dc or ac motor for solar PV application depends on the type of system. It can be directly connected here a direct current motor is needed or connected via an inverter then an alternating current motor is needed in this case.

For some pumps, motor and pump are designed together, so, the user does not have the choice of choosing the pump and motor separate because both are integrated and also the performance examination is done by the controller inside the pumping system contrary to the surface system, the possibility to choose the ump and the motor separately is available [43].

Whether the availability of electricity from the grid is rare, the electrical grid remains the main primary source of power and it is mainly used in the whole world to drive the pumps. In remote and rural areas where there is a limitation of electricity from the grid and the use of diesel generators have taken a big percentage since a long period to power irrigation and water distribution pumps in regions without disconnected to the grid [27].

Table 2-2 descibes the pumping systems types since the human being started to think about that is from the hand pump with the advantages and disadvantages of all the methods.

Table 0-2: Water pump method: Advantages and Disadvantages[44]

Types	Advantages	Disadvantages
Hand pumps	Easy to maintain with no fuel and can be manufactured locally with a low capital cost.	The inefficiency of boreholes with loss of human productivity and very low flow rate.
Animal drove	It is efficient and less costly than human power and their dung might be used as manure and biogas once fermented.	The main drawback of this system is that animals must be fed every day properly to improve their work efficiency.
Hydraulic pumps	No fuel cost is required, reliable and easy maintenance at cost-effective with a long lifespan.	Not efficient everywhere so the site condition must be taken into account
Wind pumps	Reliable and renewable, suite to manufacturing locally and no need for fuel to run the pump.	Its main disadvantage is its intermittency and the wind speed also the design is somehow complicated.
Pumps solar	Same as the wind with an estimation 20 years lifespan with no fuel costs and very easy to install.	High initial capital costs and Water storage is required for cloudy periods and repairing require skilled technicians.
Diesel and Gasoline pumps	Quick and easy to install with low capital cost and they are Widely used with the portable possibility	Expensive cost of fuel with high maintenance cost and short life expectation also harmful they are due to noise and smoke.

2.4.3 OVERVIEW OF SOLAR PUMP

Solar pumps are the one which operate with power from the sun and as rated per voltage supply but they need and require accessories to operate properly. The design of the solar pumps is high quality, low lead marine grade bronze and stainless with corrosion-free and maintenance-free service even in a severe environment with long term performance and reliability [45].

Based on the classification, pumps are typically categorized into three models from their applications and the water source. Therefore some pumps are called surface pumps when the water is lifted from the surface shallow well while submersible lifts water from a deep well to the discharge and the last one which is floating pump lifts water from a reservoir or a tank with the ability to adjust height [45].

For submersible pumps, the motor and pumps are designed together to facilitate the maintenance once needed this is applied also to the floating pumps whereas for the surface pump, the motor is separated to the pump and thus the user has a possibility of choosing the favourable component for his/her application [45].

The unique combination for a pump is its flow rate and the height and though for a high flow rate the low head is configurated and vice versa for given input power. Liberally, the classification of the pump based on the operating principle is currently two along with a positive displacement pump and the dynamic pumps.

Dynamic pumps work for high velocity and pressure through a diffusing flow passage this operation make the pump to have a low efficiency compared to the positive displacement pumps but by comparing the maintenance cost, dynamic pumps are cost-effective.

However, the working principle of the positive displacement is that an amount of the fluid is trapped the volume into the discharge pipe [45].

Dynamic and positive displacement pumps are grouped into categories as well that is why the most used will be listed below:

i. **centrifugal pump for surface application:** Used for the total height less than six meters, surface centrifugal pumps are more efficient for less lifting and high discharge rate of water because they are outside or on the earth surface, surface centrifugal pump need careful maintenance and protection against the dirt dust and external water to enter the pump, Figure 2-4 describes the main parts of the centrifugal pumps. These pumps are relatively less expensive which is one of the advantages of them also they are available in the market but the main drawback of these pumps is that once the air enters, the pumps have difficulty to push water because air is heavier than water in pumping this is a factor is due to the non-self-priming standard and it is called air bound [46].

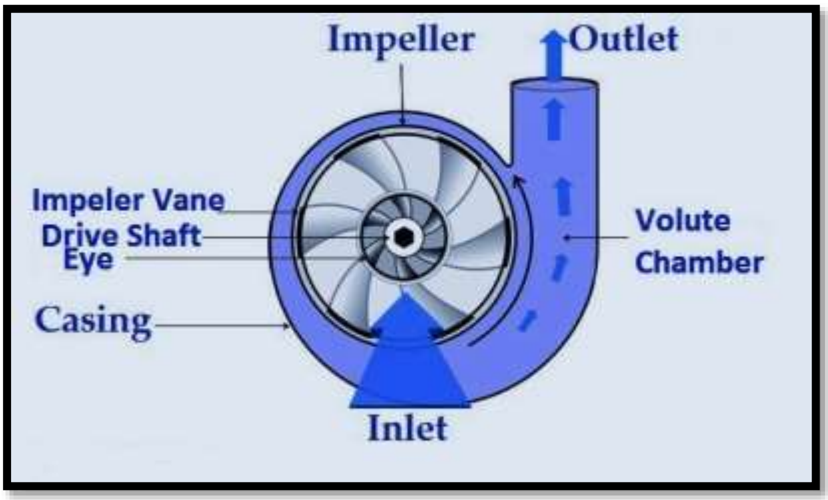

Figure 0-4:Centrifugal pump described by parts [47]

By creatinlow pressure at the inlet which causes a high pressure of water to flow due to the atmospheric pressure met in the area, surface pumps even though it has a perfect vacuum at the inlet, the atmospheric pressure creates a limitation in lifting liquid. Equation 2-6 shows why there is a limitation of the suction head for surface pump:

$$h = \frac{P*10.197}{SG} \qquad (2-6)$$

where is the lifting height in (m), p is the standard atmospheric pressure at sea level which equivalent to 1.01 bar, 10.197 is the conversion factor of 1.01 bar to the water column in (m) and SG, the specificl gravity of water at 25°C which is equivalent to 0.999.

Now, by solving Equation 2-6, we substitute the value and obtain 10.34 m as the lifting head. This means, for a temperature of 25°C, the suction head of the pump is limited to 10.3 m in ideal condition and with such ahead, the water weight in the pipe suction is equalled to the force used by atmospheric pressure.

ii. **Submerged pumps:** As suggests the name, the submersible shown on Figure 2-5 is the ability to be submerged, with pump and motor attached and the operation is done while submerged in water. Because of the combination of the pump and motor, submersible pumps do not require priming to operate and they have better reliability than surface pumps since they are submerged and outside of other environmental harms. And though the capacity of the pump is determined by the width and the number of impellers [48].

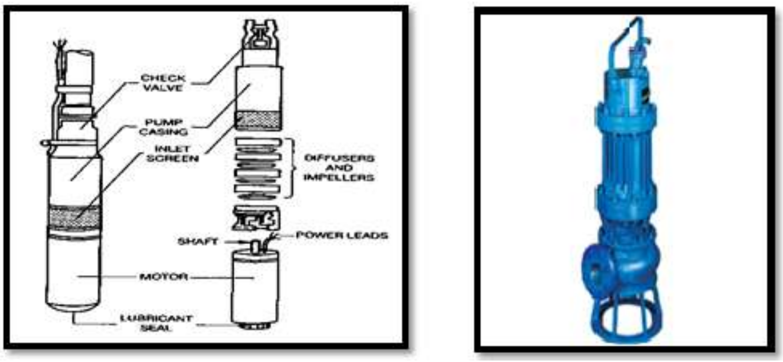

Figure 0-5: Submersible pump with different parts [98]

2.4.4 OVERVIEW OF DC/AC MOTORS

A DC or AC motor is an electrical machine which converts electrical into mechanical energy by rotary motion, it has been demonstrated that when the motor receives power passing through a magnetic field then the operation of the motor is done.

They are classified into two types as shown the Figure 2-6 and the one used for the pumps are brushless which is a DC machine that consists of three winding and which works two by two and the rotary movement is controlled by the sensors.

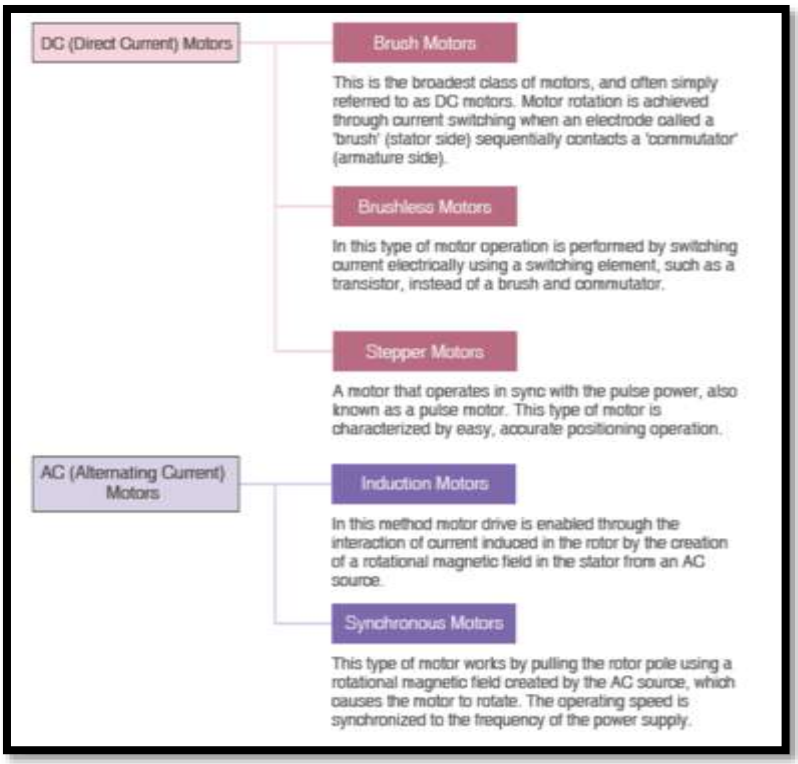

Figure 0-6: Types of DC/AC motors[49]

2.5 RELATED WORKS ON SOLAR PUMPING SYSTEMS

Photovoltaic power for pumping purpose is the most promising system in cost-competitive comparing with the other conventional energy resources for the small-scale water pumping system. The solar technology being developed in decreasing the cost of watt peak for solar cell due to their production in mass, meanwhile the exorbitant increase in fossil fuel cost, allow photovoltaic to become in the future more economic and most used [50].

PV water pumping systems have become more and more promising in agriculture, livestock and water supply in remote locations where the access to the grid electricity is limited [50].

Recently numerous studies have been brought out on PV pumping system and most of them were focused on the performance evaluation, the system optimization, the technical sizing, the improvement of the efficiency, and factors affecting system performance, economic analysis and environmental impacts in many rural and remote area with different applications.

In Egypt, Mahmoud and Nather investigated one of solar-powered pumping system coupled with batteries system performance to sprinkle and drip irrigation systems. As shown the result, the system is more efficient in agriculture sector based on the system efficiency and the economical side where farmers spend less when starting a project but harvest a lot due to the abundance of water for irrigation, however, the one drawback of this system is the cost of the batteries [51].

The cost analysis of photovoltaic pumping systems is lower than the one of the classical energies and diesel-power for pumping application. It has been illustrated that PV system could effectively operate in a region where the sun is in abundance for irrigation application compare with the classical energy system which requires fuel for some and other are very expensive based on the maintenance and lifespan periods. This system improves the quality of life and promotes socio-economic development in a rural area [51].

Still in Egypt, Mankbadi and Ayad discussed the performance of small capacity direct PV water pumping system under the meteorological conditions of Egypt and reported that small capacity direct PV water pumping systems are most suitable for domestic water pumping applications also because of the domestic use of solar this could play both roles in supplying water and electricity [37].

Meah et al. presented the economic analysis in Bangladesh rural location facing a shortage of electricity from the grid. The work aim was to compare two systems from different energy sources and the result was carried out that solar PV was more effective than diesel generator by taking into account their lifespan parameter and the cost of fuel for the generator [52].

Besides, in the same economical point of view, it has been seen that for the same season irrigation period, the PV system is very costly than the diesel due to the higher cost of the solar panels [53].

The design of the PV Coupled with battery system was made to supply power to brackish water pumping and reverse osmosis desalination unit. The process was based on the use of 2 different metrics; the net present cost (NPC) and energy cost (EC) were used to optimize the size of the system. The system performance was done using HOMER package and the Results confirmed that PV array of 75kW, Batteries system of 32 units, and converter of 28 KW was the optimum size to supply power and water for the community. The NPC and EC costs are $109,856 and $0.059 respectively and it has been concluded that this system could be a life quality improvement and could bring socio-economic development in a remote area. The comparison of a coupled and standalone system based on the cost and system reliability was highlighted in here [34].

R. Sharma, S. Sharma and S. Tiwari in [54] used a theoretical analysis on solar PV power system including hydraulic calculation, to size the PV array, motor and calculate the efficiency. The second method was the simulation using PVsyst software. Finally, different parameters affecting the system performance were discussed [54].

Environmentally speaking, an original hybrid PV-T-air dual sources heat pump based on a three-fluid heat exchanger was proposed by Penglei Zhang, Xingyue Rong, Xiaorui Yang and Dalin Zhang in Beijing. In the dry or sunny period, solar and air are absorbed simultaneously by the system; in the rainy period, it is the time for the PV modules to be cooled actively or passively by a heat pipe. The system was designed to supply heat and electricity for a rural single-family house in Beijing, and a mathematical model was developed. The proposed integrated system had the advantages of a compact structure, standardized production, easy maintenance, and no risk of freezing [55].

Anjani Kumar Mishra and Bhim Singh proposed a model of a single-stage interactive solar-powered switched reluctance motor-driven water pumping system with a control technique efficiency. The control of the proposed system provided the maximum power point technique (MPPT) tracking and motor drive control with bidirectional power flow between the photovoltaic array and single-phase grid. The control block can eliminate the harmonics in the component, to improve the performance dynamically and the capability of reject dc offset compare to the other control. Also, the developed control model includes Panels feeds forward term to improve the performance dynamically by minimizing the dc-link capacitor and an improved MPPT technology based on the perturb and observe algorithm. This is used to reduce PV losses, especially under varying irradiation levels. The model of the developed control was tested on an improved prototype and its suitability is authenticated through simulation and test results were presented under various conditions [32].

PV modules generate electricity as long as sunlight falls on them. Attempting to cover them, using a blanket or cardboard, for example, is not a safe practice because they create a shade which can impact the performance output of the PV panels even though the light could still reach the PV module, or the cover may come off still the shading impact there [37].

According to Anuja Inglea, D.I.Sangotra, R.B. Chadgeand and Pratik Thorat, The configuration of the PV modules have a great impact on the system performance improvement. The present paper discussed the impact of different configurations such as series, parallel, series-parallel, the total cross-tied, bridge link, honeycomb and the highlighting on the current issues and challenges involved in solar-powered systems [22].

Sundaram Senthilarasu developed a dynamic model for both PV with batteries and without batteries system for running a motor-pump set to lift groundwater for irrigation purpose. Sizing was done for the battery-based system in HOMER which was also validated using hand calculation. Water tank equivalent to the battery storage was also calculated for PV system without battery system. Two different dynamic models were built in MATLAB Simulink to demonstrate the system with battery and without battery system performance. Comparing both systems in the economical side of thing, the diesel generator is cost less compare to the battery-based system but by combining both, the system becomes more and more efficient [4].

2.6 RESEARCH GAP

Most of the work done on PV water pumping system as discussed in the above section were focused on the system performance and evaluation, the sizing technics, economic and environmental aspect of the system but few of them worked on the design and analysis of the system and none even on the sociological aspect of it, therefore, we have found important to present a design based on the sociological aspect of the system in the remote area also using tools PVsyst and Matlab/Simulink to evaluate and interpret the results obtained.

2.7 CHAPTER CONCLUSION

The previous section was reviewing the solar-powered water pumping system by taking into account the different parameters, components for the system performance and relating some previous works done already on the same topic by presenting their methodologies and results and finally we came up with the gap found after going through some related works.

Chapter 3 : METHODOLOGY AND SITE PRESENTATION

3.1 INTRODUCTION

This chapter consists of different methods and techniques we used for reaching our goal as shown in section one, the field visit included household survey, data collection from the site, some physical measurements and consultation of some reports.in the other hand, the Internet with its research motor Google was the other method to collect data by reading some books, reports, articles, journals, etc.

3.2 SITE AND METEOROLOGICAL DATA IN MINOVA

3.2.1 SITE SELECTED

We selected Minova as the field of study which is located at 1472 meters above the sea in DRC, South Kivu province and Kalehe district. its UTM position is QU21 and its joint operation, the Graphics reference is SA35-08. Its Geographical coordinates in decimal degrees (WGS84) are such that the Latitude south and Longitude East of -1.708 and 29.018 respectively and in degrees- minute-seconds of -01°42'28" and 29°01'27” respectively. The sunrise at 06:08:52 AM and set around 18:10:44 PM [56].

The Minova ‘Air de santé’ is populated with 40279 inhabitants with a population growth rate of 2.33% [6]

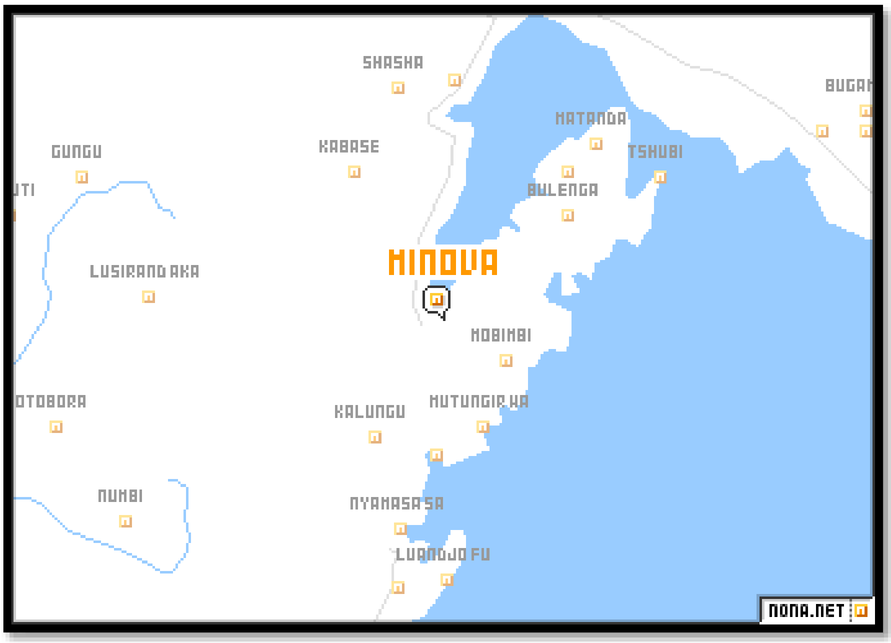

Figure 3-1 Minova map and its surroundings [57]

The map on the Figure 3-1 represents Minova Health Zone in general which is surrounded by other health zones commonly called 'Zone de santé' such as Bulenga, Buumba, Muchibwe, Bobandana, Kalungu, Bwisha etc. and the other hand, the important information about the site are shown such as the terrain elevation, the temperature the irradiance at the optimum angle, etc.

3.2.2 SOLAR IRRADIATION AND TEMPERATURE IN MINOVA

The irradiation is the quantity of energy from the sun that hits a certain area on earth in a specific time and fluctuates according to seasons. Besides the electromagnetic incident on the earth surface per unit time and the unit area is called the irradiation. The total amount of irradiance is determined as the quantity of radiant reflected by the sun over all wavelengths that fall each second on the one-meter square outside the earth's atmosphere [58].

Equation 3-1 shows how to calculate the irradiation at a given site

$$\text{Irrad} = \frac{\text{Av. insolation}}{\text{Av. daily bright sunshine hours}} \quad \text{in} \quad \text{kWh/m}^2 \qquad (3-1)$$

Minova irradiance can be calculated knowing its average solar insolation and its average daily bright sunshine hours. Table 3-1 and Figure 3-2 helped us calculating the irradiation in Monova.

Table 3-1: Monthly Global insolation and temperature in Minova

Months	Insulations [kwh/m^2]	Temperatures in Celsius degrees
January	4.9	21
February	4.9	22
March	4.9	21
April	4.8	19
May	5.0	19
June	5.1	19
Jully	5.1	20
August	5.1	21
September	5.1	21
October	5.0	21
November	4.9	20
December	4.9	20

Therefore, the annual average insolation is $4.975\ \text{kWh/m}^2$

According to the Global Solar Atlas by world Bank, Minova has a yearly direct normal irradiation of 1177kWh/m^2 as shown the Figure 3-2 [59]. The yearly average temperature in Minova is from 21 Celsius degree. Table 3-1 shows the temperature data for the year 2019 and the variation is seen based on the changing in weather, that is why the climate data is not the same yearly thus they might change accordingly.

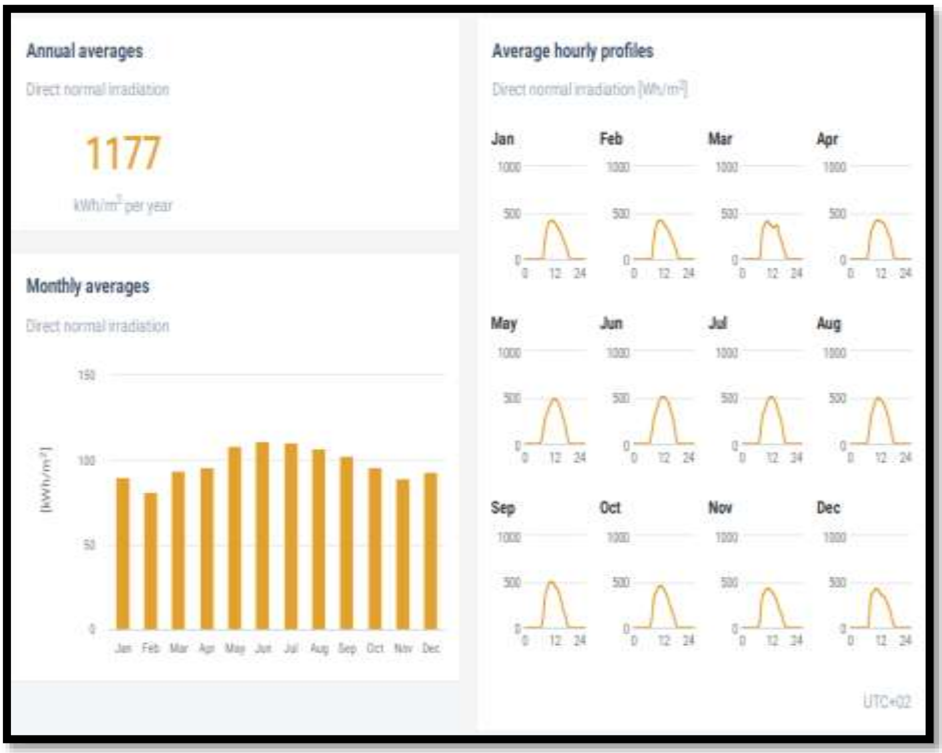

Figure 3-2: The average hourly, monthly and yearly direct normal irradiation of Minova

The average daily average bright sunshine in Minova is 5 hours, hence, by substituting in Equation 3-2 ,the irradiance become

$$I_{RR} = \frac{4.975kWh/m^2}{5.2h} = 956.7W/m^2$$

3.3 SECONDARY DATA COLLECTION

To conduct this research, we were focused on the literature review of articles, thesis and many other documents related to this topic without forgetting the evaluation of the report on public health.in brief, all document which we used to get information about the site, the orientation of the proper person, NGOs or some other moral person to collect important data for our work. although it was about the project proposal, final activity report and budget report. the secondary data we collected helped us to get an idea on the impact of the project mostly on the socio-economic and gender aspects of it.

3.4 PRIMARY DATA COLLECTION

On the field, we have used active and participative methodologies to make intervene the targeted population using interviews with Minova inhabitants, some school and health centre staff, we were guided to some water sources by the TDR[1] of Minova health zone and some conversation were made with the water management staff at ASUREP[2].

However, the field visit helped us to have an idea on the feelings of the Minova 'Air de Santé' inhabitants. Altogether, we interviewed 100 households' owners, one primary school and one health centre in the region selected.

3.4.1 INTERVIEWS

The main approach in gathering information and data was to use a survey questionnaire. 100 households' inhabitants were interviewed on the water condition. As a result of this, an observation was brought to their situation and the additional note was taken where needed. From their replies, the scarcity condition of potable water especially during the dry season. The analysis shows that the MINONA inhabitants, such as households, health centre, schools suffer a lot because of water scarcity and this causes socio-economic problems. It has been proved also that most of the inhabitants are women and girls and they are the one who collects water for their households. This has a very good impact on their living conditions especially in their activities and schools for children.

In most of the cases, in Minova the water flows gravitationally and the electric pumping system and the last one presents a big problem of load shedding. Moreover, the fuel and the maintenance cost of the pumping system is very costly to people. Yet they manage it somehow to survive while others use water from the river for everything. Therefore, the waterborne disease rate in Minova is high because the water is not treated and some can go wash from there while others are fetching. When we asked about the solar-powered pumping system, we found out that it is a new topic and they don't have any knowledge about the system they use manual pumps which is very tiresome and unhealthy in many places of the region.

[1] TDR : 'Technicien du Developpement Rural'

[2] ASUREP : 'Association des Usagers de Resau d'eau Potable'

3.4.2 WATER SUPPLY AND SOURCES IN MINOVA

The main water sources in Minova are surface water such as lake,rivers and groundwater despite the enormous water sources, water from the rivers and from the mountain remain the most used and in unproper ways because most of the sources are not accommodate. The pumping system is done most by gravity and where there is a pump, the generator is used to supply the pump motor. For the community which is supplied by the water pumped,they complains about, the average investment cost of a pump which is higher than the average monthly salary they get and some of them did not contribute to buy the pump.

For considering the pump life span and its maintenance, the pumps can break monthly and therefore they find themselves spending more than seven times maintenance cost in a year than buying a new pump.

Because most of the pumps were implemented by the NGOs therefore when they get damaged it is very hard for the community to organize themselves to get them back to normal.

Minova “Air de Santé” has five water sources installed in Kinyamuheke, in Kishinji, two sources in Kashenda which are located already in the Northern Kivu province in the Masisi and finally another in Kabalekasha in the Masisi as well. all the five sources supply water in the Minova “Air de Sante” but they are not enough due to the population growth and also the unappropriated construction for distribution based on the distance. In addition to this, there is another source in Kirwa which is abandoned because of the lack of maintenance. However, groundwater and springs are the major water sources in Minova to hand and mechanical pump well [20]. Drinking water in rural areas falls under the National Rural Water Service (SNHR) [60]. especially in Minova, drinking water is managed by a sub-branch ASUREP “Association des Usagers de Reseau d’Eau Potable” which is the community water management.

3.4.3 WATER DEMAND AND INHABITATION

Most of the inhabitants are females and they are the most who go and fetch water.it has shown that the main common distribution water point is the public tap which is mostly used by the whole ever, it has been seen also that people try to manage and get satisfaction with the resources they have, using six jerry cans of 20L per day for the whole family seems effective for them but also the cost of 100 CFR per jerry can with the monthly salary less than a hundred USD could have caused a shortage in income. The complaining about the scarcity of water was manifested in January, June, July and August when the sun is too much. not having enough information on solar pumping, the community is excited to know what is it and how better it is compared to the diesel, hand pumps because none has ever been implemented there before.

3.4.4 SOCIO-ECONOMIC SITUATION AND PROBLEMS

On 100 households taken as a sample, most of the people explained that their main economic issue was the cost of water even though it has to be paid once a week also the distance from their houses to the tap causes the social problem this makes most of them go to fetch water from the lake, rivers where water is free of charge. We also went to a primary school where pupils don't have drinking water or water which can help them in their basic needs such as washing hands, using washroom services. Therefore, we found out that the normal condition for one pupil per day is 20L. Besides, one health centre was visited and the issue is very serious there while it is the most critical place where water is needed in the first emergency.

3.4.5 KNOWLEDGE AND OPINION

When we reached the field, a solar-powered water pumping system was quite unknown to the interviewees. Hardly, one or two of them had heard about solar-powered water pumping system. Though everyone was very interested, most of them lacked knowledge about the technique and therefore were a bit confused. Besides they were anxious about maintenance cost, distance and the availability of water during cloudy days. After assuring them about its performance, they were keen to use the solar-powered water pumping system.

3.5 PROPOSED SYSTEM MODEL

As suggests the slogan "water is life", to satisfy basic human needs, to ensure food security and production to protect ecosystem and health, to ensure sustainable and socio-economic development, water sources are needed the most. PV module is the basic power generation unit and its output depends on the solar irradiation and the temperature [61]

In this work, the power is generated by the solar Photovoltaic modules which are connected in series and parallel to form a PV array which its turn is connected to a DC-DC converter to match the voltage from the PV array with the one at the pumping side. The pumping bloc contains a controller to sensor the water level from the source and one of the discharge levels. Figure 3- 3 represents a schematic block of what we will be discussing about later on.

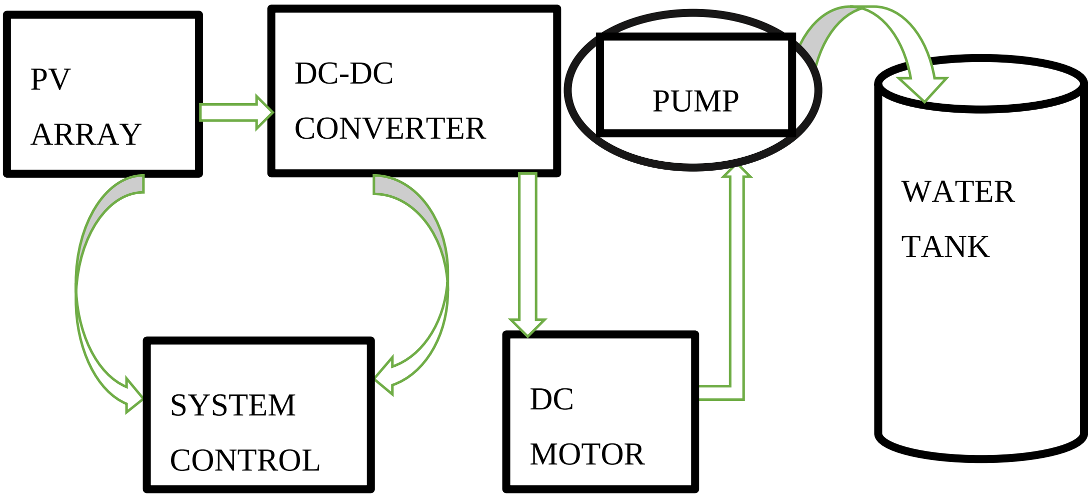

Figure 3-3: Proposed system bloc diagram

3.5.1 SOLAR PV MODEL

The Solar PV module fundamental building block is formed by a cell photodiode which can convert sunlight into DC using the photovoltaic effect. The schematic diagram on Figure 3-4 shows a simple equivalent PV solar circuit [62][63].

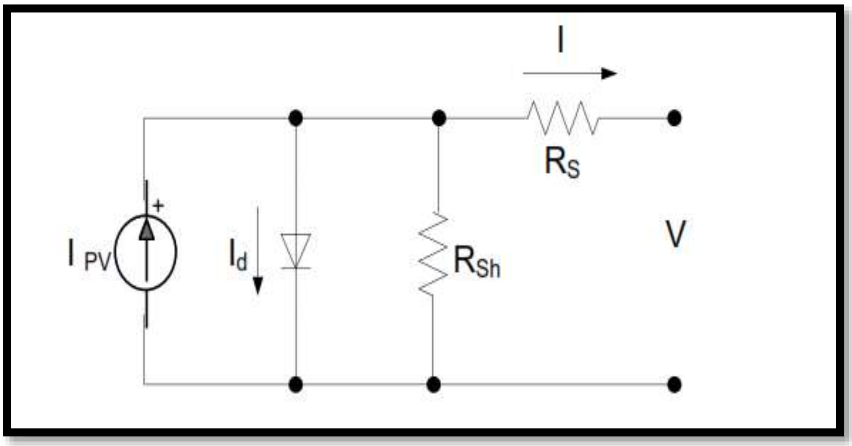

Figure 3-4: PV solar circuit equivalent

The practical PV module is configurated by a fixed number of solar cells in series and parallel based on the voltage need. The I-V characteristics of a PV module are represented mathematically by Equation 3-2 and 3-4:

$$I = I_{PV} - I_O \left[Exp\left(\frac{V + R_S I}{V_{Therm^a}} \right) - 1 \right] - \frac{V + R_S I}{R_{Sh}} \qquad (3-2)$$

Where I_{PV} and I_O are the photocurrent and the diode saturation current, respectively.

$$V_{Therm} = N_S \left(\frac{K_T}{q} \right) \qquad (3-3)$$

V_{therm} is the thermal voltage, N_S the number of modules in series and constitute a string to increase the output voltage of the system, k is the Boltzmann constant ($1.3806503 * 10^{-23}$ J/K), T (in Kelvin) is the temperature of the p-n junction of the diode, and q ($1.60217646 * 10^{-19}$ J/K) is the electron charge. Also, R_S and R_{sh} are the series and shunt resistances respectively of the array and *a* is the ideality factor usually chosen in the range 1 ≤ *a* ≤1.5. Here *a* is set at 1. The PV solar characteristics are shown in the following graph in Figure 3-5

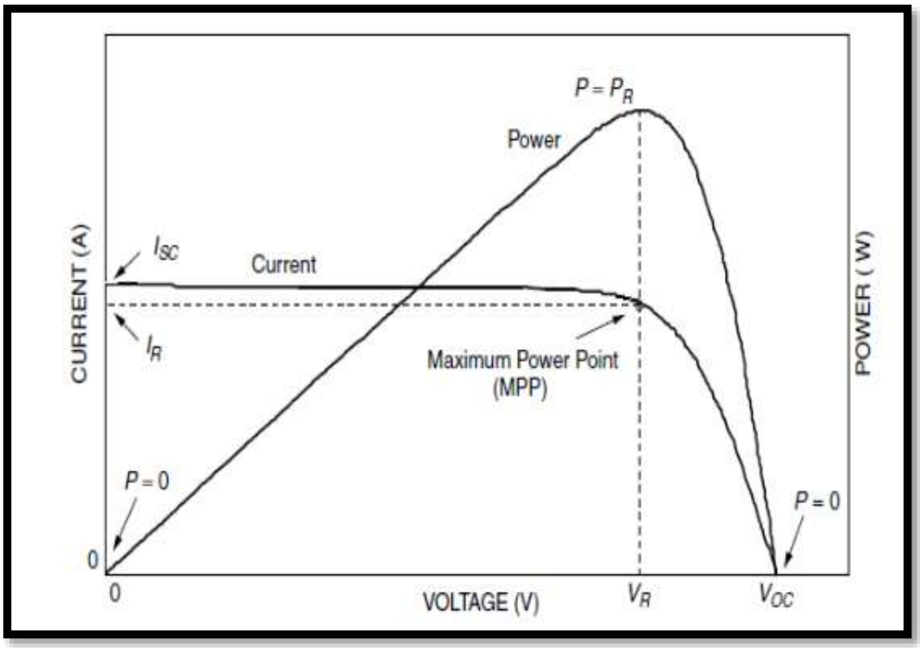

Figure 3-5: Solar PV characteristics

3.5.2 PV ARRAY

A PV array is the constitution of PV modules configurated in series and parallel. However, there are mainly two main families of PV modules: Monocrystalline PV modules and polycrystalline PV modules. [64].

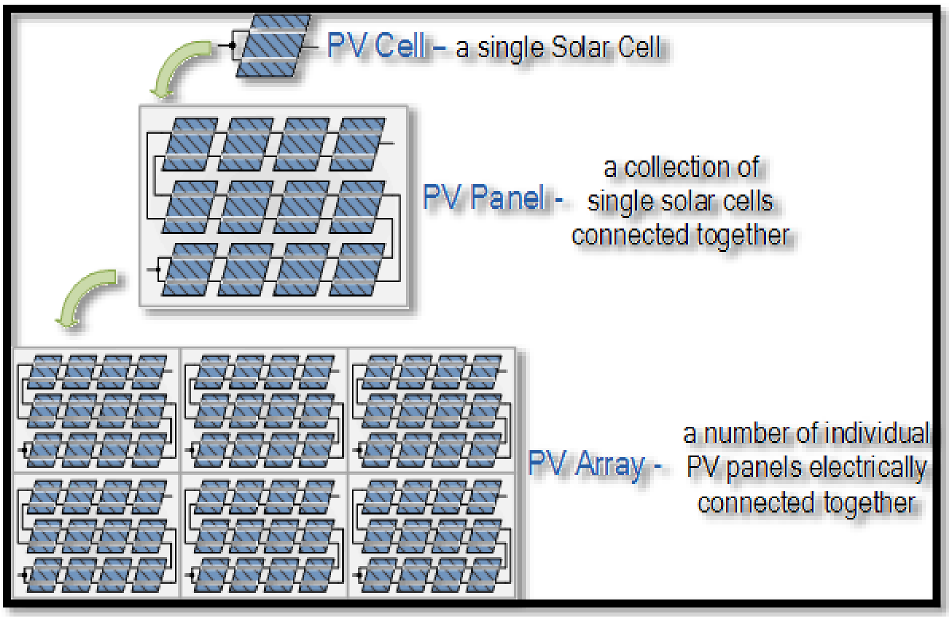

Figure 3-6: Photovoltaic Array constitution[65]

It is important to note that photovoltaic panels or modules from different manufacturers should not be configurated together in a single PV array, even if their electrical characteristics are the same. This is because differences in the solar panels I-V and P-V characteristic curves as shown in Figure 3-7, as well as their spectral response, is likely to cause additional mismatch losses in the array, therefore reducing its overall efficiency [66]

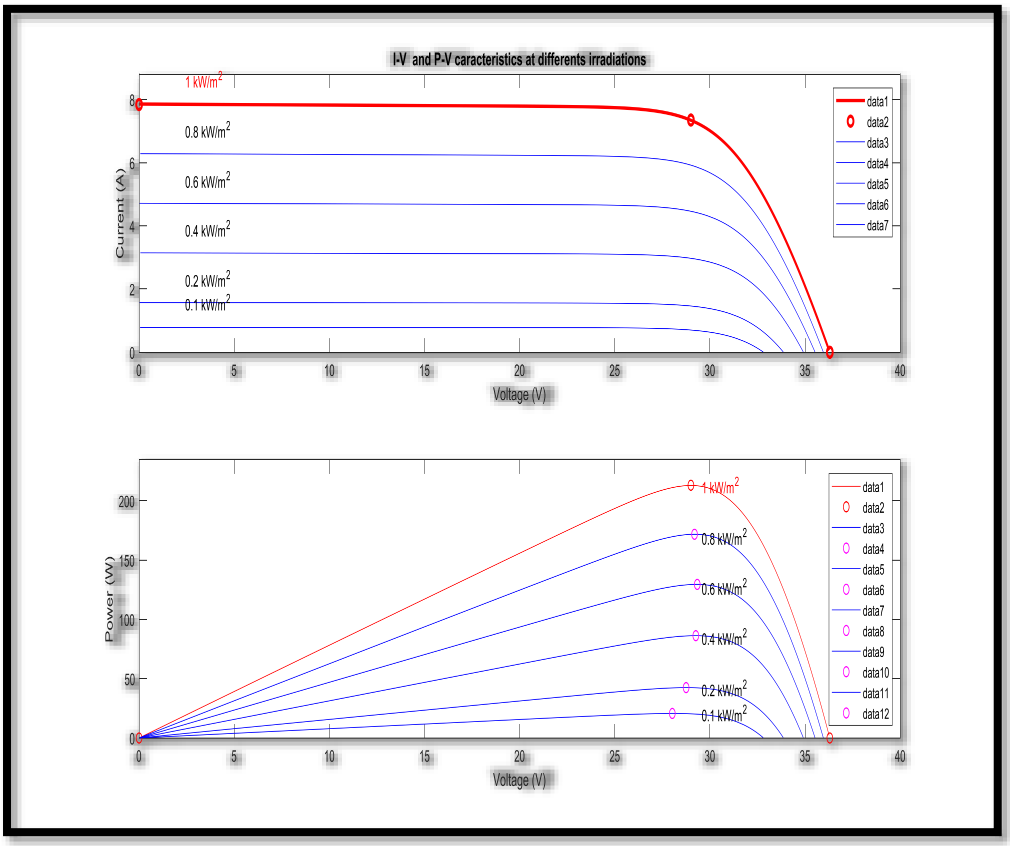

Figure 3-7: I-V and P-V PV Array characteristics with

The graph on the above on Figure 3-7 shows the power which varies directly proportional with the irradiation. And it is indirectly proportional to the temperature.

3.6 OVERVIEW OF DC to DC CONVERTERS

DC-DC converters are power electronic device or circuit that convert a dc voltage into a different dc voltage level by providing a regulated output [16]. Power electronic device in this case of a solar pumping system is the starting controller, a pump accelerator between the pump and the PV array (in 12V, in 24V, in 36V, in 96V until 200V). Its main function is to optimize the daily efficiency of the pump.it can be connected to a commanded switch though a floater in the reservoir [32].

The following bloc diagram on Figure3-8 represents the classification of DC-DC converters.

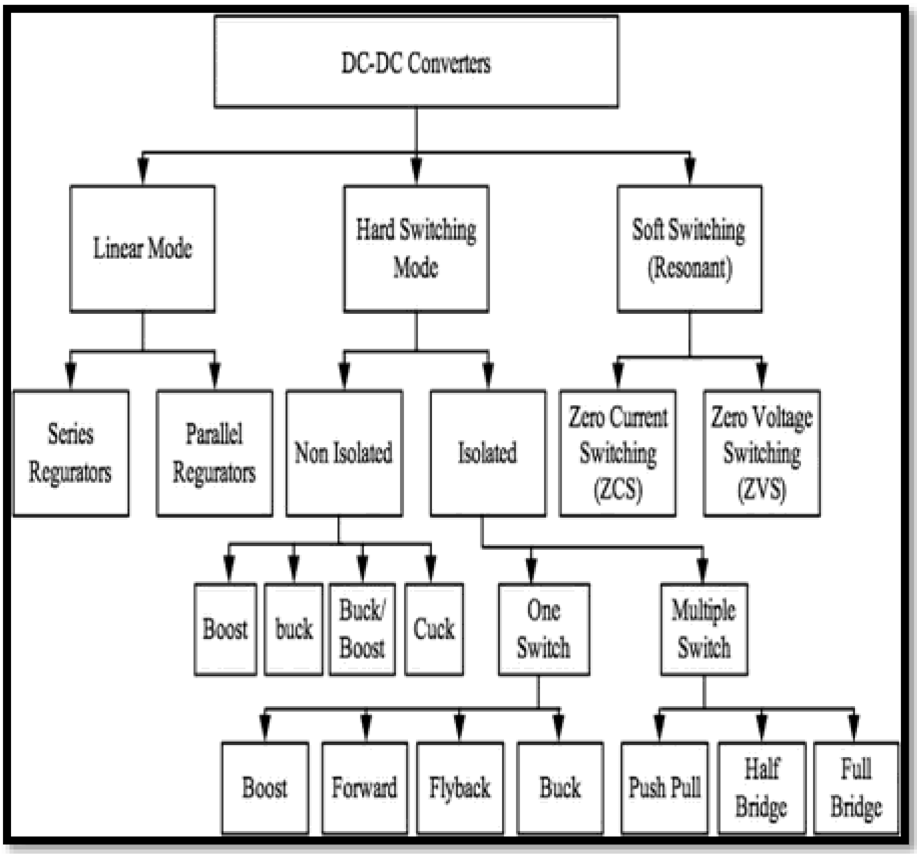

Figure 3-8: DC-DC Converter classification [67]

As shown on the Figure (3-8) there is a numerous type of DC-DC converters but we can discuss a bit on the most used non isolated converters [68].

3.6.1 DC-DC BOOST CONVERTER

Called step-up converter, the Boost converter is an electronic device which consists of stepping up the voltage.it operates under ON-OFF modes. When the switch is OFF, the diode is reverse biased. Kirchhoff's voltage law around the path containing the source, inductor, and closed switch is [69].

$$V_L = V_S = L\frac{di_L}{dt} \qquad (3-4)$$

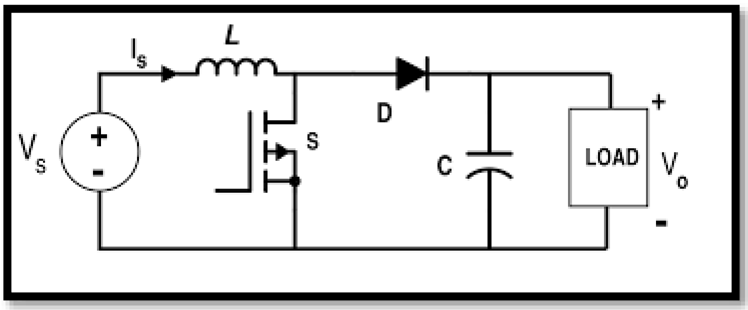

Figure 3-9: Schematic diagram of a boost converter [70]

3.6.2 DC to DC BUCK CONVERTER

A Buck converter is shown in Figure 3.10a, with a bipolar switch of the power pole made by the transistor and the diode .in the capacitor, the equivalent series resistance (ESR) will be neglected. By turning ON the transistor, the inductor current in the sub-circuit of Figure 3.10b increases while turning OFF, the inductor current "freewheels" through the diode, as shown in Figure 3.10c decreases.

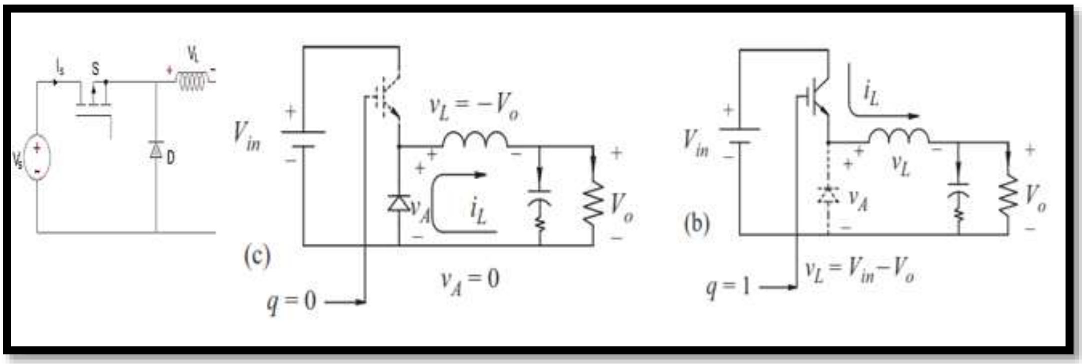

Figure 3-10: Buck converter schematic diagram [71]

3.6.3 DC-DC BUCK BOOST CONVERTER

This type of DC to DC converter has a magnitude of output voltage which can be low or higher than the input voltage depending on the wanted application. The buck-boost converter is equivalent to the flyback circuit and the single inductor is used in the place of the transformer. These converters can produce the range of output voltage than the input voltage. The following diagram shows the basic buck-boost converter [31].

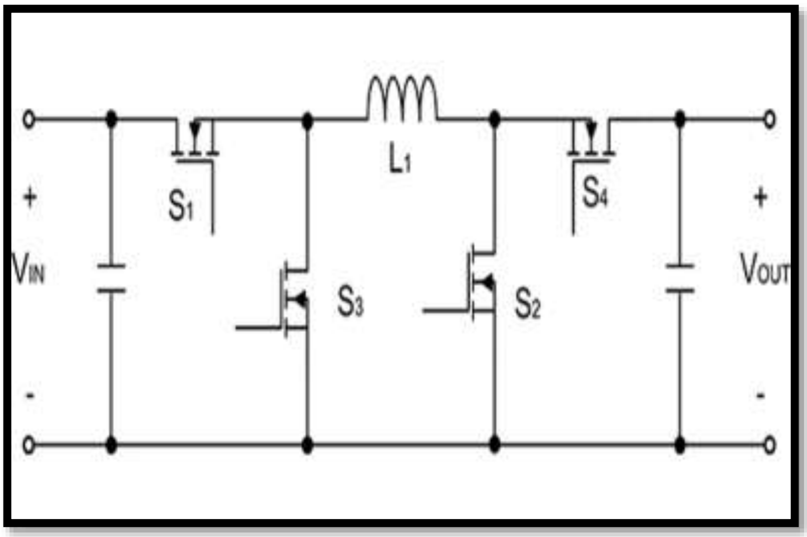

Figure 3-11: Buck-Boost converter[72]

3.6.4 DC-DC CUK CONVERTER

Cuk converter is derived from the boost converter. Its circuit diagram is shown in Figure (3-10) however the inductor current $I_L$increase with slope V_g/L and decrease with a slop $-(V_1 - V_g)/L$ Since L during switching off. Thus, since $L_2 - V_2$ is a low-pass filter, the output voltage is calculated by the formula[73]

$$V_O = V_1 - V_g = \frac{K}{1-K} V_g \qquad (3-5)$$

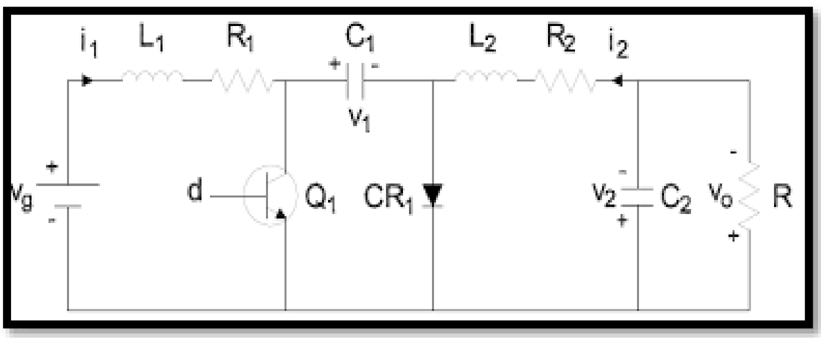

Figure 3-12: Electrical simplifies cuck converter[74]

However, due to the radiation and temperature variations which impact the maximum power point, it is not easy to set an optimum power matching with all radiation variation levels unless the special design is done for DC motor.

3.7 MPPT TECHNICS

To improve the PV pumping system performance, an MPPT Controller is needed to continuously match the output characteristics of the PV array to the input characteristics of a DC motor. The MPPT usually consists of a controlled power electronic circuit which tracks the maximum power from the PV array and therefore improves PV system efficiency [75]. Two main MPPT technics are classified such as P&O and IC method

3.7.1 PERTURBATION AND OBSERVATION ALGORITHM

The P&O algorithm has based the increasing or decreasing of the PV array voltage or current at regular period and then comparing the output power of the PV with those of the previous samples point as illustrated on the Figure 3-13.

Mathematically speaking $(\frac{d_P}{d_V} = 0)$, Figure 3-14 showed the process of MPPT system. when the PV array operates to the left area of the MPP curve, the output power increases based on the increase in voltage and output power decreases on decreasing voltage when the same operate to the right area of the MPP Curve. Hence if $(\frac{d_P}{d_V} > 0)$, the system keeps disturbing, and if $(\frac{d_P}{d_V} < 0)$, the disturbance should be reversed. The process repeats until the operating point is across to the maximum PowerPoint. Where P and V are power and voltage at the output of the PV module respectively. The main advantage of the P&O algorithm is its simplicity. Generally, the system presents a good operation because the solar radiation does not deviate very quickly but the poor efficiency is remarkable at the steady-state when the irradiation is very low. the operating point oscillates around the MPP voltage usually in terms of light fluctuations but never reaches exactly the MPP. For this reason, alternative solutions have been proposed such as a modified or improved P&O method.

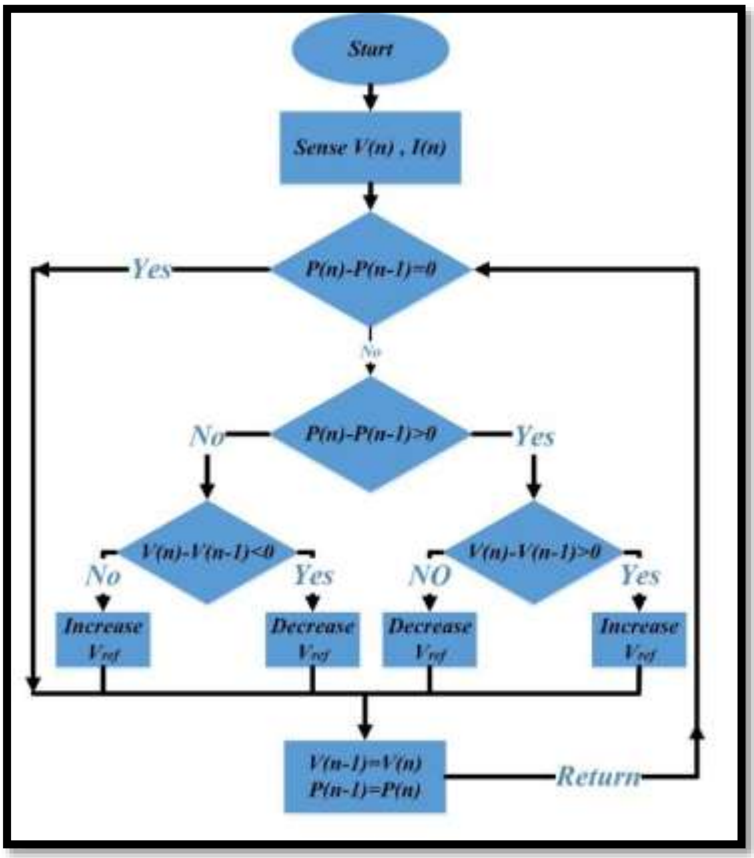

Figure 3-13: P&O method flowchart

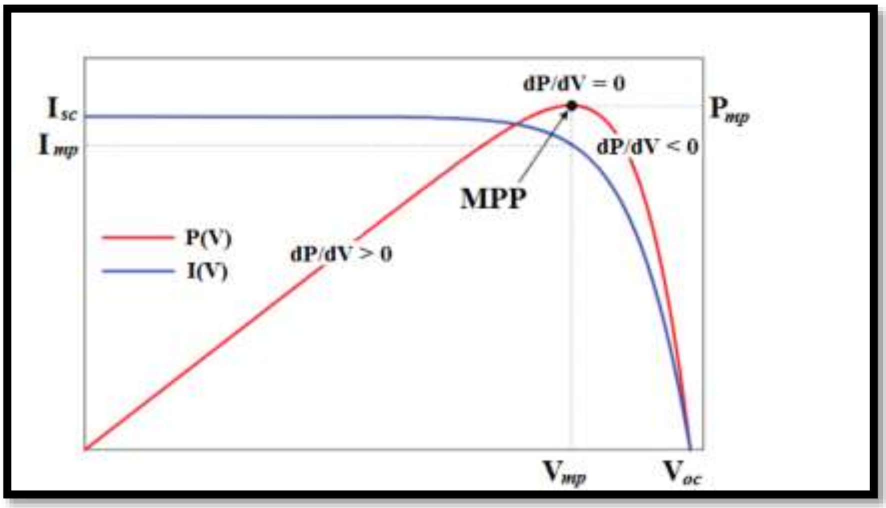

Figure 3-14: Example of a Perturbation and Observation

3.7.2 INCREMENTAL CONDUCTION ALGORITHM

The Incremental Conductance algorithm is based on the observation that the Equation 3-6 holds at the MPP:

$$\frac{dI_{PV}}{dV_{PV}} = \frac{I_{PV}}{V_{PV}} \tag{3-6}$$

With I_{PV} and V_{PV} , the PV array current and voltage respectively.

When the optimum operating point in the P-V plane is to the right of the MPP, $\left(\frac{dI_{PV}}{dV_{PV}} + \frac{I_{PV}}{V_{PV}} \prec 0\right)$

also, when the optimum operating point is to the left of the MPP, $\left(\frac{dI_{PV}}{dV_{PV}} + \frac{I_{PV}}{V_{PV}} \succ 0\right)$

Therefore the sign of the quantity $\frac{dI_{PV}}{dV_{PV}} + \frac{I_{PV}}{V_{PV}}$ indicates the correct direction of perturbation leading to the MPP here is when calculating by substituting real values. Via the IC method, it is therefore theoretically possible to know when the MPP has been reached, and also when the perturbation can be stopped. This system offers a good performance under rapid changes in the atmospheric conditions [63].

3.8 OVERVIEW OF MOTOR-PUMPS

In general, pumps are classified based on different criteria such as conception of the pumps, their position in the system and the type of motor used. [76]

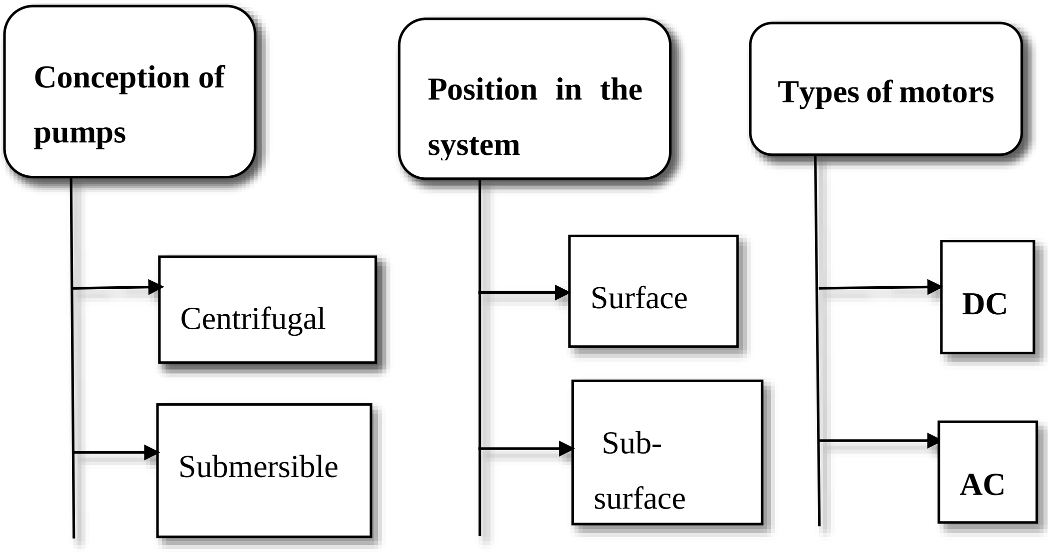

Figure 3-15: Types of Pumps based on conception

As seen in the above image, the pumps are classified according to the water sources, However, the table below represents the choice of the pump based on the type of current and their conception.

Table 3-2: Category and choice of pumps accordingly

Type of motors	Direct Current	Solar pump 12V, 24V, 36V, 96V etc
	Alternative Current	Classic pump 220V; 380V
Conception	Centrifugal	Adopted to the high flow rate and big heights with good efficiency and Economically viable for solar pumps.
	Submersible	-Adopted to low flow less than 5 m^3/h and big heights with good efficiency; low maintenance but not economically viable for solar pumps
Position in the system	Surface	When the pump is positioned at the earth's surface at the depth less than 1.5 m
	Subsurface	When the pump is positioned at the earth's surface at the depth great than 1.5 m

3.8.1 HYDROLOGICAL DATA OF MINOVA

Based on the data and the area we selected, the main source of water is the surface water such as lake, river and the underground (well) and water from the mountain which commonly supply all Minova and very preferable because the water is clean and pure also its availability it does not need any purification, therefore the information which needs to be determined by the driller is such that static height, drawdown depth, recovery rate and water quality [68]. Sub-surface water or groundwater is fresh and located in the pore space of soil and rocks. It is also flowing within aquifers below the water table. Subsurface water can be exploited the same terms process as surface water: having inputs, outputs and storage[77].

However, the pumping system using electrical pumps system exist in miniature in Minova for some places due to mountain and rocks, in the site we selected the water flows gravitationally without any pumping help system. In our system, we considered the water from the underground as the source which makes the system a deep well pumping.

3.8.2 TOTAL DYNAMIC HEAD DEFINITION

The TDH for a pump is the summation of the static and dynamic heads counting the friction loss as seen in section 2. Friction losses are found in the pipes and appear at the intake point and the outlet point such as inlet and pressure tank respectively. From the storage to the point of use, the flow is gravitationally fed that is why between the storage and the use point, friction losses are independent of the pump and when sizing it, they can be ignored. [78]. the following bloc 3-16 shows the TDH of the system.

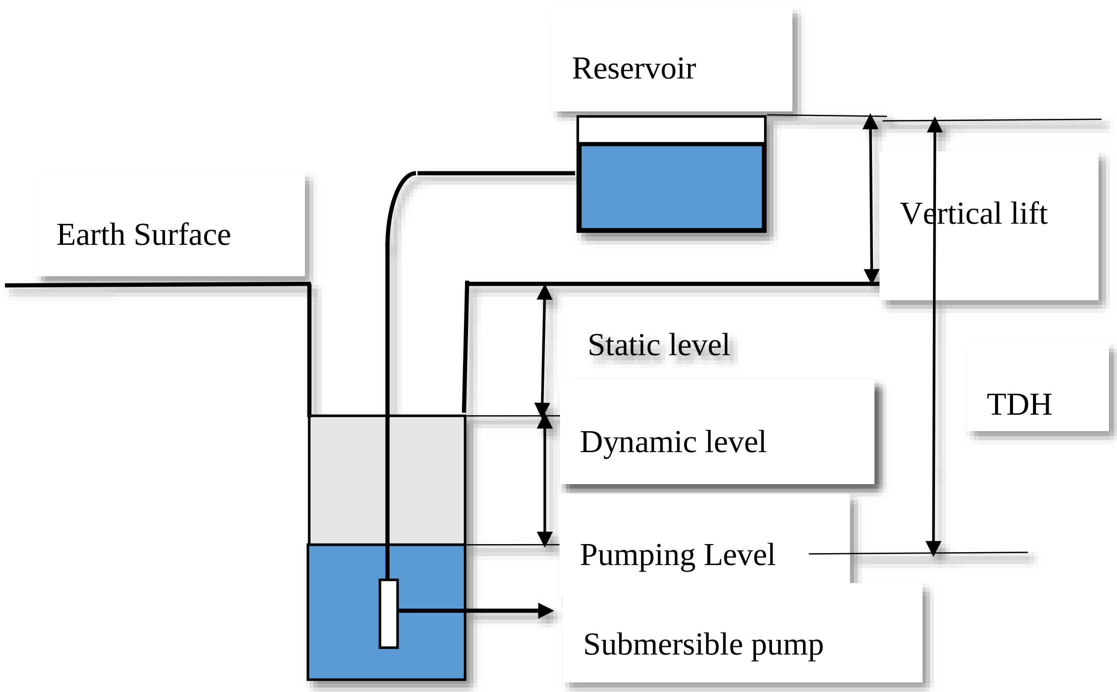

Figure 3-16:Vertical measurements of submersible pump systems

The development of the aquifer zone conditioned by fractures is the main geological formation found in DRC. It extends from Northeast in Orientale province to South-East in Katanga including the Kivu [79]. The monitoring of the data in the Democratic Republic of the Congo is somehow nonexistent because still data are kept in archive hard copies format. Therefore, finding the data is not easy work because their availability to the public is limited. Groundwater resources database in DRC is almost nonexistent; the few existing information on hydrogeology, Geography and climate, reports and publications are stored in hard and this renders the access to data difficult. Moreover, based on the site selected, we found some information in the archives on the static level which is estimated to 2 m and the artesian level is about 50 m with a drawdown of 43 m and a normal yield range from 10 to 45 m^3 /h [80].

Vertical lift: This is the distance from the water surface at the source and the water surface in the tank. As previously stated, the water level in the source can change depending on the seasons and usually change when the pump is running. Therefore, the vertical lift should be designed when the water level is at its minimum.

Pressure head: This is the pressure at the delivery point in the tank. However, if the delivery point is on the top of the tank, then the pressure parameter can be set to zero at that point of delivery.

Friction loss: the friction loss is those losses found in the pipe due to pressure and they are determined by four parameters such as inner diameter, length, roughness of the pipe as well as the water flow rate. The friction losses can be obtained from the friction loss chart or table.

During the pumping process, the water level inside the well seems to drop down to the velocity of which the regeneration of the well come about to stabilize the quantity so that the pumping process restart. The water level dropping depends on a certain number of factors such as the type and permeability of ground and weight of aquifer.

The total height is the sum of the static and dynamic height as shown Equation 3-7

$$H_T = H_S + H_D \qquad (3-7)$$

For some wells which present an important level of the water drop, a corrective term can be added on the equation in the function of the flow rate as followed

$$H_T = H_S + H_D\left(\frac{H_D + H_S}{Q_P}\right)Q_A \qquad (3-8)$$

Where,

H_S is the static level in meter (m) which is the difference between the static level of water inside the well up to the maximum elevation level where water has to be pumped,H_D is the dynamic level in meter (m) which represents the losses in the pipes while pumping water

The Darcy Welsbach formula enables us to calculate the H_D as follow,

$$H_D = f\,\frac{Lv^2}{D2g} \qquad (3-9)$$

Where, f the friction losses coefficient, L the pipe length in meter (m), v the fluid velocity in (m/s), D is the pipe diameter in (m) and g the acceleration in m/s^2. To calculate the available solar energy, the average daily or monthly solar irradiation of the site and the hydraulic energy are taken into account. However, the PV module inclination at the horizontal plane must be done concerning the ration of solar irradiation and the hydraulic energy [81].

3.9 CHAPTER CONCLUSION

In this chapter we were presenting the data got from the site we selected by associating them with different data from internet which were developped to get as a means to introduce the following chapter.

Chapter 4 : DESIGN AND CHOICE OF COMPONENTS

4.1 INTRODUCTION

This chapter consists of the design and choice of components for the proposed system in the previous section,here the a cost analysis is done by Life Cost Cycle for the designed system.

4.2 WATER DEMAND IN MINOVA

Based on the survey from 100 houses, one primary school and one health centre, the admissible water requirement to fulfil the basic needs in a household, at school and the health centre based on different activities by sectors are equivalent to 30 litres/person/day, 20litter/pupils/day and 3000litres/health centre/day in normal condition.

From the survey we did, the data we collected was centred on school, household and public health centre. therefore, the table below summarizes the water demand of the selected area.

Table 4-1: Water need per sector in Minova

	Quantity of water required per day	Conditions	Percentages
Households	40L	Surviving	15%
	80L	Fair	36%
	120L	Recommended	49%
Primary School Pupils	5L	Not enough	15%
	10L	Fair	35%
	20L	Recommended	50%
Health center	1000L	Less hygienic	9%
	2000L	Fair	34%
	3000L	Recommended	57%

Based on the analysis from the data on Table 3-5, we took into consideration an average of 4people per house, the water need for 100 houses comes to 12000Litres per day as recommends the WHO, For a primary school of 200 pupils, taking the recommended conditions, 4000litres are required to fulfil students' needs and finally, for one health centre it has been seen that 3000litres per day could be very useful and recommended, altogether a total of 19000litres per day would be enough to supply water for the small community listed above.

$\text{Total water Demand} = 4000\text{liters} + 12000\text{liters} + 3000\text{ liter} = 19000\text{ liters per day}$

In a solar pumping system application, the storage can be done in two different ways: hydraulically using a tank or electrically using batteries. The hydraulic storage is more used than batteries because of its cost-effective and its availability, However, based on the cost of the batteries and their performance at a certain environment, hydraulic storage is chosen over electrical one most in the rural area. In our case, we have considered a tank of $76m^3$ volume.

4.3 CALCULATION OF THE FLOW RATE

The flow rate is the quantity of water pumped per unit time, however, because we are using solar, let us take into consideration the peak hour of the cloudy month which is estimated at 5 hours per day when the sun rises at 8 am and set at 3 pm. The Equation 4-1 determines the maximum flow rate by taking into account the total water need and the total volume to fill the tank, let us take into consideration the tank volume.

$$Q = \frac{V}{t} \qquad (4-1)$$

Where, V is the volume of the tank equivalent to $76m^3$ per day in m^3 and t the sun peak hours for a cloudy month which is 5h, therefore, by substituting in Equation 4-1 the pump flow rate become 15.2 m^3 per hour or 67.03GPM.

To calculate the flow rate we have taken the tank volume to desgn the pump which could be able to supply water for the community and get extra water for the tank itself.

4.4 PIPE SIZING

Two methods are used to determine the pipe size such as the velocity limit method and the friction factor method. However, the first method based on the velocity limit is the most recommended and the one we used in this work. The Equation 4-2 helps to calculate the inside diameter of the pipe but here the Hunter friction losses table characteristic is used as referred in [82].

$$d = \left(\sqrt{\frac{0.408 * Q}{v}}\right) \qquad (4-2)$$

With d the pipe inner diameter, Q is the flow rate in GPM and v the velocity in feet/second. Therefore, the inner diameter of the pipe is 3 inches or 7.62 cm for a polyethene (PE) pipe,this was chosen based on the flow-head chart.

4.5 CALCULATION OF THE PUMP POWER

The high recommendation from the technical guide stipulates that always better to calculate the theoretical pump power to choose an optimum pump before jumping to the manufacturing catalogue the Equation 4-3 determines the hydraulic power in kW

$$P_H = \frac{\rho * g * Q * H}{3.6 * 10^6} \quad (4-3)$$

H the $Total$ $Head$ which is 40 m,

g the Acceleration of gravity which is 9,81m$/s^2$,Q is water flow rate is 15.2 $\frac{m^3}{hour}$

ρ the density of water which is 1000kg$/m^3$

$3.6 * 10^6$ **i**s the conversion of an hour to second then multiply by 1000 to convert to kW.

Therefore, by substituting the above values in Equation 4-3 the hydraulic power is equivalent to 1.6568 kW.

The Equation 4-3 gives the hydraulic power without taking into account the pump efficiency, however, the theoretical pump power is given by the pump shaft as shown the following Equation 4-4

$$P_{Sh} = \frac{P_H}{\eta_P} \quad (4-4)$$

P_{Shaft} is the shaft power in kW

η_P is the pump efficiency which is obtained from the catalogue let us take it as 48%

Therefore, the $P_{Shaft} = \frac{1.6567}{0.48} = 3.45kW$

4.6 CHOICE OF THE MPPT- DC CONVERTER

The output current of the converter is determined by taking into account the electrical power and the voltage from the motor, we have chosen a generic device MPPT converter of 96% efficiency [83].

$$I_{Out} = \frac{P_{Elec}}{U_{mot}} \qquad (4-5)$$

Taking into consideration a normalized voltage constant of 120V, the output current at the MPPT DC converter is calculated as follows [83].

Equation 4-5 becomes $I_{Out} = \frac{3450W}{120V} = 28.75\,\text{A}$ So, the MPPT-converter was chosen based on the output current and efficiency.

4.7 CALCULATION OF POWER FROM THE PV ARRAY

The solar photovoltaic array consists of the PV panels in parallel, series and series-parallel and is calculated based on Equation 2-2 in chapter 2

With I_T, 5 hours is taken here which is the average sun peak hours in Minova

F is the array mismatch factor which is 0.70 [44]

E is a daily subsystem efficiency which varies from 0.20 to 0.40 typical, [84] However, in our system we were considered the pump, motor and converter efficiencies as our subsystem efficiency and estimated it to 0.3. Hence, the PV power is rated at 4 kW as substituted in Equation 2-2 Hence,

$$P_{PV} = \frac{4.142kWh/day}{5.2h/day * 0.7 * 0.3} = 3.79kW \cong 3.8$$

4.7.1 CALCULATION OF THE TOTAL NUMBER OF MODULES

The number of solar PV is determined by taking into account a chosen module or PV electrical characteristics in this stage we need the watt peak power.

Table 4-2: PV module electrical characteristics

Type	JAM5L(BK)-72-200/SI
Rated maximum power at STC (W)	200
Open Circuit Voltage (Voc/V)	45.62
Maximum Power Voltage (Vmp/V)	37.26
Short Circuit Current (Isc/A)	5.66
Maximum Power Current (Imp/A)	5.35
Module Efficiency (%)	15.67

Based on Table 3-6 the total number of modules is calculated as follows:

$$N_{PV\,\mathrm{mod}} = \frac{P_{PV}\,Array}{P_{N,}STC} \qquad (4-6)$$

With $P_{PVarray}$ the power calculated in the previous paragraph which is 3.8 kW and P_N, STC the nominal power for one module at the STC, we have chosen 200Wp

$$N_{PV\,\mathrm{mod}} = \frac{3800}{200} = 19 Modules$$

4.7.2 PV ARRAY SURFACE AREA CALCULATION

The surface area of the PV array is determined by the equation 3-16

$$Area(m^2) = \frac{P_{PV}}{PSI * \eta_{PV}} \qquad (4-7)$$

Where PSI (Peak Sun Insolation) is $1000\ W/m^2$ at STC (Standard Test Condition) and η_{PV} the PV efficiency. Therefore, we get,

$$Area(m^2) = \frac{3800W}{1000W/m^2 * 0.1567} = 24m^2$$

4.7.3 CALCULATION OF THE NUMBER OF STRINGS

When sizing a PV, it is critical to know the minimum and the maximum number of PV modules that can be connected in series. By Connecting many PV modules in series, the output voltage is increasing the voltage and constitute the output voltage of the string. the minimum and the maximum number of strings, N_{smin} and N_{smax} , respectively, which are calculated based on dc input maximum power point (MPP) voltage level $V_{i,max}$ and the maximum permissible dc input voltage level, $V_{DC,max}$ both specified by the PV converter manufacturer, as follows [85]:

$$N_{s\min} = N_s \le N_{s\max} = \min\left[floor\left(\frac{V_{c,\max}}{V_{M,\max}}\right), floor\left(\frac{V_{DC,\max}}{V_{OC,\max}}\right)\right] \quad (4-8)$$

Where $V_{oc,max}$ and $V_{M,max}$ are the maximum open-circuit voltage (V) and MPP voltage (V), respectively, which can be developed at the PV module output terminals based on the incident solar irradiation and ambient temperature conditions that are used at the PV array installation site during the year.

From the equation (3-17), the number of solar panels in series can be obtained;

$$N_{s\min} = \min\left[floor\left(\frac{120}{37.26}\right), floor\left(\frac{200}{45.62}\right)\right] = \min[3,4]$$

$V_{i,max} = 120V,\ V_{M,max} = 37.26V,\ V_{DC,max} = 200V$ and

$V_{oc,max} = 45.62V$ from the technical datasheet [58][85].

4.7.4 NUMBER OF SOLAR IN PARALLEL CALCULATION.

Connecting modules in series means increasing their output current, hence the number of PV modules connected in parallel is calculated using the values of the current of the module and the current of the converter:

$$N_{P\max} = floor\left(\frac{I_{DC,\max}}{I_{M,\max}}\right) \quad (4-9)$$

Where the specification used of the inverter are $I_{DC,max}[A]$ is the maximum continuous current; and the specification of the PV module used in this calculation $I_{M,max}[A]$ is the maximum MPP current. From the selected Solar PV panel and inverter specifications, we get: $N_{P\max} = floor\left(\frac{28.75A}{5.35}\right) = 5.3 \cong 5$

4.8 CABLES SIZING

Wiring is very important in PV system both for the safety of man, effective performance of the PV system conductors and insulation must be rightly sized. If cables are undersized it could resist in a fire hazard and high losses across the cables.

Based on the standard normalization, the voltage drop between the installing origin and the end-user must respect the admissible values instituted by the French norm NF 50-100 [86]. However, the admissible voltage drop in DC installation is set at 3% [87]

The cable section is calculated in Equation 4-10

$$\Delta_U = b\frac{\rho}{s} * \cos\varphi * (I_B * L) \qquad (4-10)$$

Where b is the constant whether in one phase or three phases and we will be considered 2 as we are working in one phase (monophasic)

ρ is the conductor resistivity which varies depending on the type of material here copper is considered at 0.0225Ω mm^2/m

s the conductor section in mm^2

I_B is the current of utilization which is 39.71A

$$\Delta_U(\%) = \frac{\Delta_U}{U_N} \qquad (4-11)$$

U_N The nominal voltage 114V, Hence, $0.03 = \frac{\Delta_U}{114}$ and $\Delta_U = 3.4V$

L is the conductor length in m which is estimated at 50m based on the head.

Hence, the suction cable is equal to 25.8mm^2 then 25mm^2 is taken into account because it is normalized.

4.9 SYSTEM COST ANALYSIS

The cost analysis is a critical point in designing a project.in this paragraph, the total capital cost of the solar powered water pumping system will be taken into account. The consideration is made on the PV solar modules, the pump motor, the driller and the system balance component. Table 3-7 shows the assumed value of the cost of each component as referred in [88],[89],[90],[91],[92] [93].

Table 4-3: Cost assumed per component and the inverstment cost of the SPWP.

Components	Unit cost	Total Cost
PV module	0.869	$ 3584
Supporting	0.5936	$ 52.5
Pump including controller	5.0796	$ 17,752
Total of subsystem	6.5422	$ 21,388
BOS	20%	$ 4,277.6
Running Cost	5%	$ 1,069.4
Taxes	15%	$ 3,208.2
Net investmet	20.99101	$ 29,943

Considering 21 PV modules of 4000W, 1 motor pump 3450W including the MPPT controller ,20% of the subsystem listed above then finally 5% for running cost of the system the Table 4-3 describes the Net investment cost of the system. Figure 4-1 illustrates the repartition of cost in term of percentages and we realized that motot pump takes more than half the cost of the entire system.

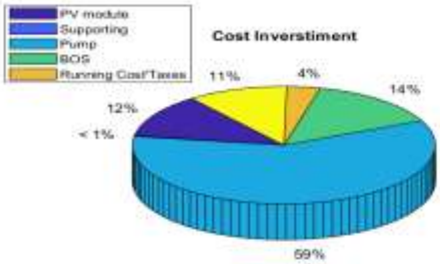

Figure 4-1: Cost repartition in term of percentages

The solar PV modules are assumed to work within 20 years and the pump for 10 years. The running cost includes also the pump replacement after 10 years and the maintenance cost.

4.9.1 LIFE COST CYCLE

This method assesses the facilities ownership total cost. It takes into account all costs of acquiring, owning, and disposing of a system. It is determined by the present value of the current of the total cost of solar systems consisting of initial investment costs (IC) and long-term costs for maintenance and operational (M_{OC}). So, the life cycle costs in this study can be calculated with the following formula [94]:

$$LCC = IC + M_{OC} \qquad (4-12)$$

4.9.2 NET PRESENT VALUE

The difference between the present value of all future returns and the present value required to make an investment is the net present value for the investment. The present value of the future returns can be calculated through the use of discounting rate of return which are future benefits and cost streams can be converted to their present value. The interest rate was assumed as the discount rate for discounting purpose [95].

Solar PV for Water pumping in this work (n) is assumed for 20 years operation. The discount rate (i) used to calculate the present value in this study is estimated to 10%.

Therefore, the current value (present value) for the maintenance and operational costs during the project life of 10 years with a discount rate of 11% is calculated using Equation 4-13 [94]:

$$NPV = M\left[\frac{(1+i)^{n-1}}{i(1+i)^{n}}\right] \tag{4-13}$$

Therefore

$$\mathrm{NPV} = \$1{,}069.4\left[\frac{(1+0.10)^{10}-1}{0.10(1+0.10)^{10}}\right] = \$\,6570.19$$

This is the amount of money which could be obtained in 10 years of operating and maintenance cost referring to the pump life span and replacement.

By substituting the value in Equation 4-12, the Life Cost Cycle in 10 years is $36,513

Based on the above data, in DRC, 1 cubic meter of water costs $0.7 while having the probability to pump 6935 cubic meters per year, then the cost sale in ten years is calculated as following:

$$CS = Q_p * n * W_{cost} \tag{4-14}$$

Where Q_p quantity of water produced per year, n number of years and W_{cost}, the water cost per cubic meter based on the country standard.
Therefore, the water sold in ten years is $ 48,545.

Solar powered has a higher initial cost comparing to Diesel powered and other pumping methods . Besides, the other costs for solar powered are very lower than those of diesel powered the maintenance, operation and replacement costs are lower and there is no energy cost needed in PV system.

4.10 CHAPTER CONCLUSION

This section was conducted by the best understanding of the system by putting together all data collected from the field and internet to carry out a design hand calculation of the system we are developing all along with this dissertation, a simple economic analysis was done to see how performance the design was.

Chapter 5 : RESULTS AND DISCUSSION

5.1 INTRODUCTION

In this chapter, we will be been comparing different results obtained from the simulation tools: PVsyst, and Matlab/Simulink. A System rated at 4 kWp was designed for both tools to see the performance of the system. We will see how sufficient is the system based on different parameters and different components chosen by taking into account some characteristics.

5.2 PVSYST VERSION 6.8

PVsyst tool has been used to find the most fitting power requirement for Minova area to supply drinking water. PVsyst is a comprehensive Photovoltaic system analysis and design program. Historically the software was developed in the year 1978 by the University of Geneva [96] It calculates the size of PV system considering the specific location, the specific loads, and the designer selects the different components afterwards the results are automatically given. This software allows the user to estimate energy production that accounts for losses due to weather and climate. This tool is very useful for PV pumping system with hydraulic storage and therefore, the following result was gotten during the simulation. Adding on this, the tool presents some mismatch which was related to the subsystem design such as a converter, pumps wires, pipes, etc [96].

5.2.1 PRESENTATION OF THE RESULTS

The present section we will be presenting the results from PV Syst software and discuss them by comparing with the one we got from the hand calculation. as shown Figure 5-1, the first thing to do is to set the climate data of the site selected for the software to recognize the site, however, if the data is not very well set or is wrong the user might be working on the wrong site which can wrong the output result as well.

	Horizontal global irradiation	Temperature
	kWh/m².mth	°C
January	86.8	21.1
February	87.4	22.0
March	90.5	21.8
April	95.5	20.6
May	104.8	20.3
June	110.8	19.2
July	107.0	18.9
August	103.7	19.4
September	102.2	19.8
October	92.5	20.8
November	89.4	20.2
December	90.1	20.9
Year	**1160.7**	**20.4**
	Paste	Paste

Horizontal global irradiation year-to-year variability 2.4%

Figure 5-1: Meteorological data of Minova site

The output power as related in section 2 of this work is the subject of some parameters such as the angle at which the panel modules are tilted, the area and the transposition of the area, Figure 5-2 represent the input variant based on the PV panel position

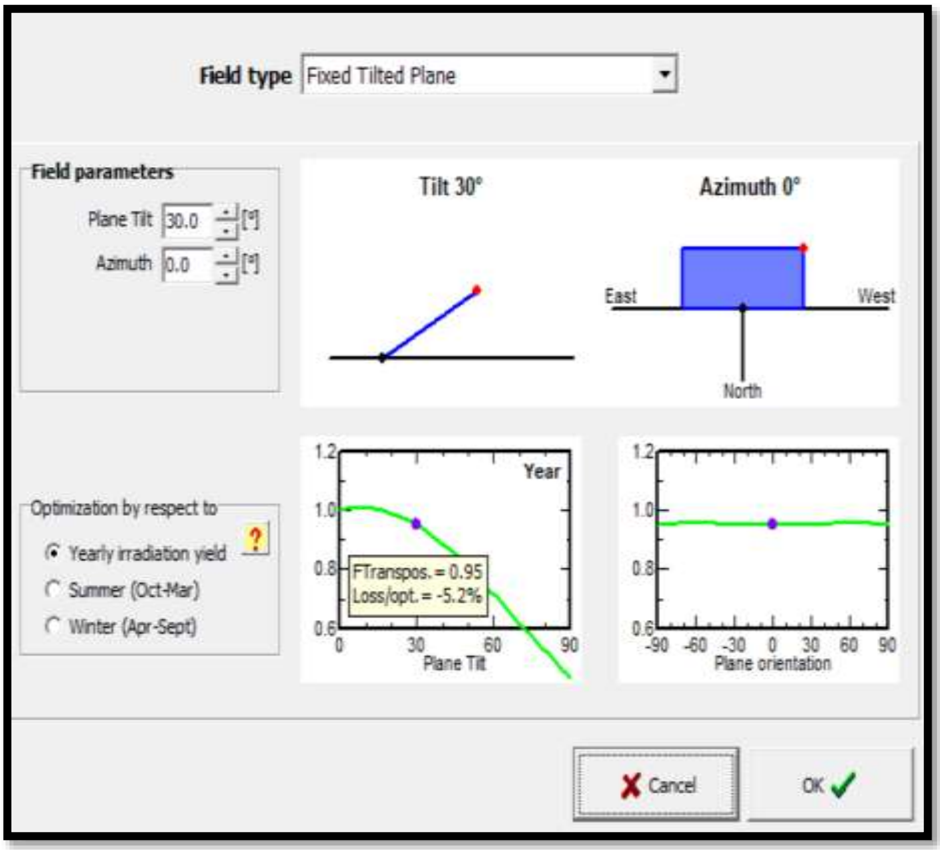

Figure 5-2: Input variant for the module transposition

Figure 5-2 represents the suited orientation for PV modules or losses rate due to the orientation. This is designed by taking into account the geographical coordinates such as latitude and longitude and here we set the tilt angle to 30 degrees based on the 29 degrees for longitude and we found the transposition factor based on the meteorological data such as irradiation from the site was 0.95, the above parameters and values have been set yearly.

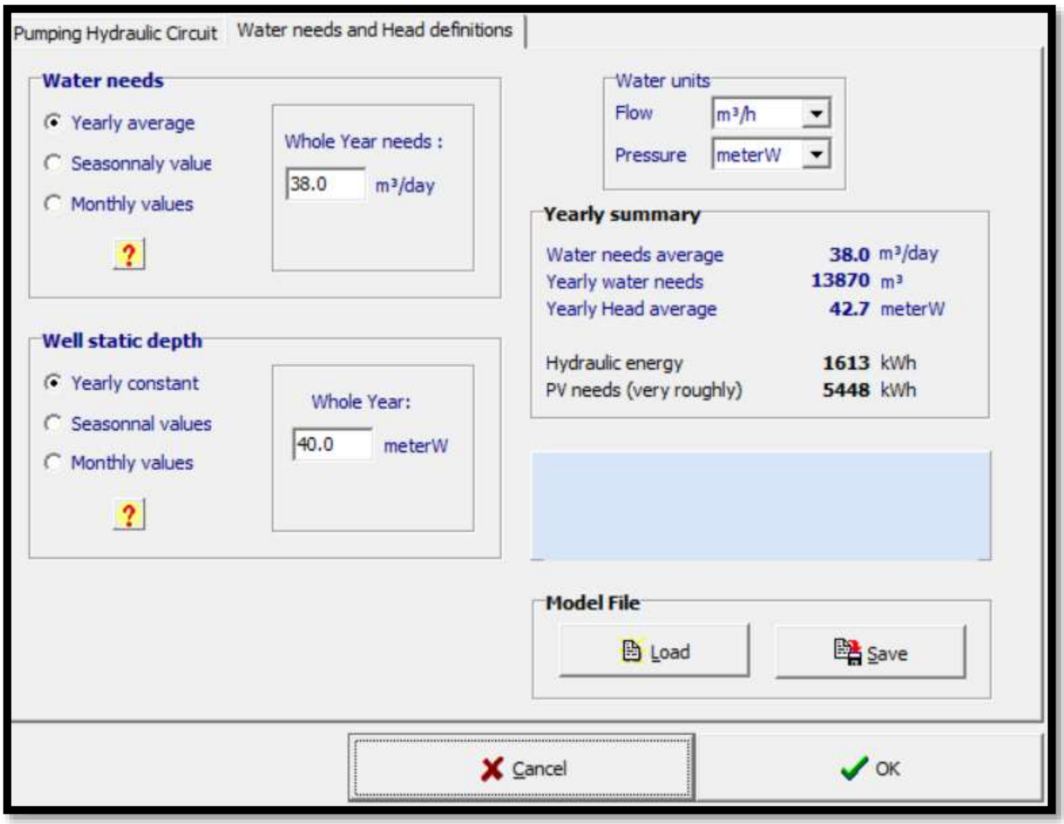

Figure 5-3:Hydraulic input data based on water need

Based on the water need and the geological data we collected from Minova, the static level is set at 40 m and the water need at 38 cubic meters per day by calculating the average yearly water needs to be gotten 13870 cubic meters at the total head of 40 m this difference of 2.7 is shown because of the drawdown value which varies seasonally that is why the yearly average head of 42.7m as shown Figure 4-3 and the hydraulic energy estimated at 4.4 kWh/day with electrical energy from the PV of 14.9kWh/day.

Figure 5-4 shows the system design by choosing different parameters from PV to the pumps manufacturers. Therefore, here JAM5 72- 200 (L) (BK) from JASolar manufacture,1MPPT-DC converter from LORENZ were used based on the water flow this makes the difference between hand calculation and the simulation tools in which the database is limited and to get a datasheet for a desire component was not easy. we were running 3000W centrifugal multistage PS2-1800 C-SJ5-12 in which a brushless motor is incorporated with 4.1 to 7.7m^3/h flow rate range at the head range of 20-70m. However, we had to configure two pumps in parallel to increase the flow rate up to 11. 7m^3/h.

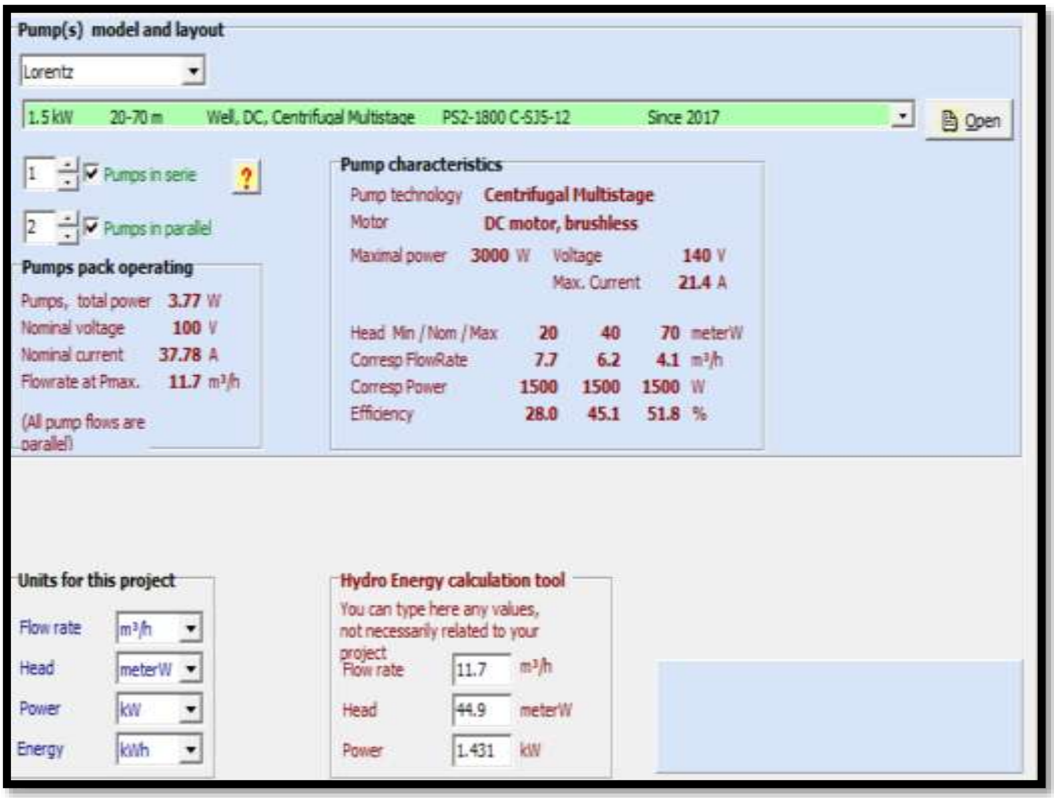

Figure 5-4: system Pump model and layout

The PV modules were selected based on their electrical characteristics therefore 3 modules were configurated in series and 7 in parallel, this configuration was made to reach the operating conditions of voltage and current at different temperatures. However, the series modules helped to reach the voltage needed for our system which is rated at 114 V at 20 degrees, at 1000w/m^2 irradiance and 3.8 kW were gotten at the maximum operating power and the array nominal power at STC was 4.2kWp.Besides, Figure 5-4 shows how we set the flow rate of the chosen pump with a flow rate slightly low than the calculated one we realized that the flow rate varies indirectly proportional with the head. So, with a high-water flow rate, a small head. Here the pumps are coupled in parallel to get at least the desired water flow rate and this implies the loss in power which will be unused. Figure 5-5 shows that by using the flow rate of 15.2 calculated the power at the pump will increase as well this makes a clear understanding relationship between the power and the flow rate which are directly proportional.

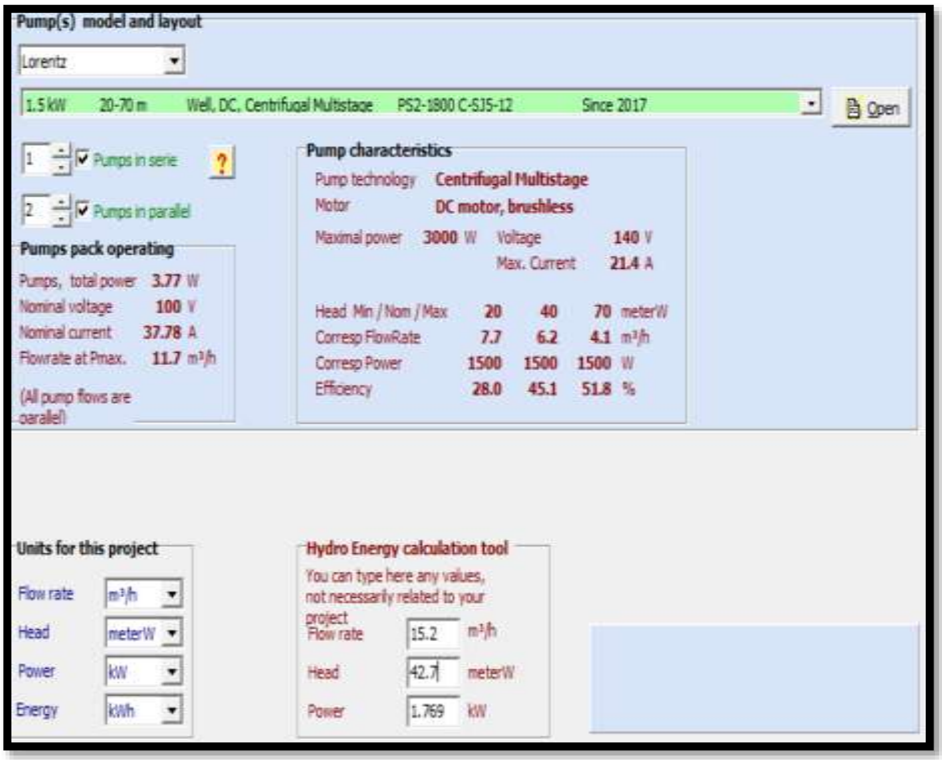

Figure 5-5: Pumps choice based on the flow rate

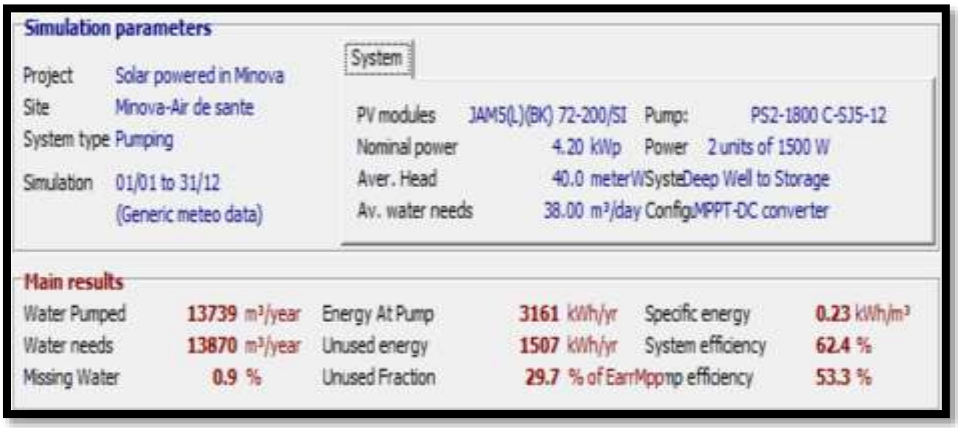

Figure 5-6: Summarized project parameter

The result presented on Figure 5-6 shows the yearly summary of the whole system which represents 99.1% of the water pumped with 3161kWh of energy at the pump which is 70.3% of the total energy used and the other 29.7 % can be used in another purpose. The system efficiency is 62.4% with pump efficiency of 53.3%.

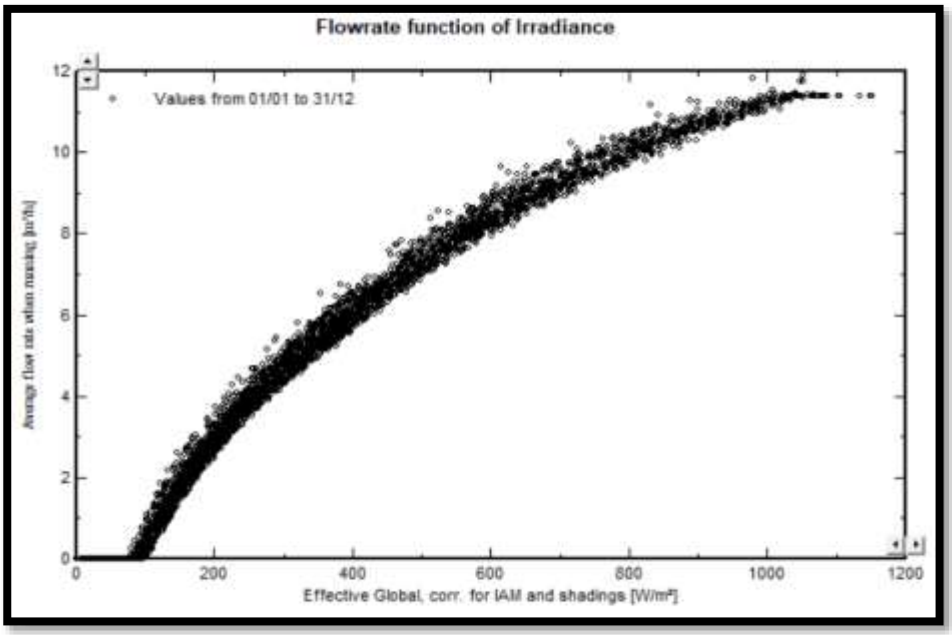

Figure 5-7:Flow rate Vs Irradiance

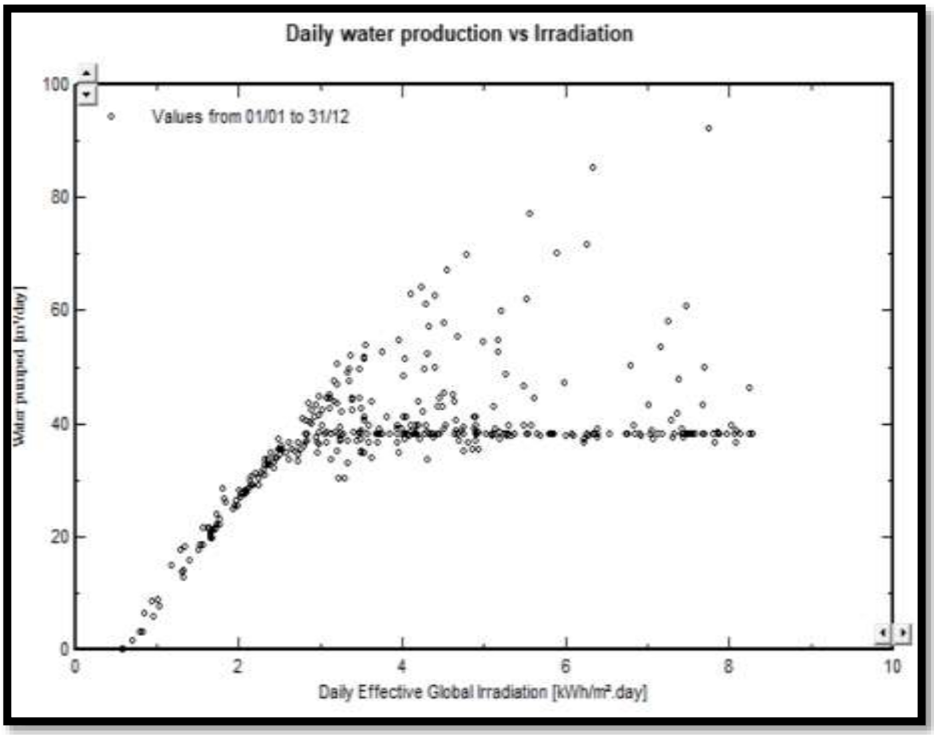

Figure 5-8: Daily water production concerning the irradiance

The flow rate and daily production are a function of the irradiation as illustrated Figure 5-7 and 5-8, there is much production during day time hours and during the night time, there is zero production because the pump can not run within the absence of the sun.

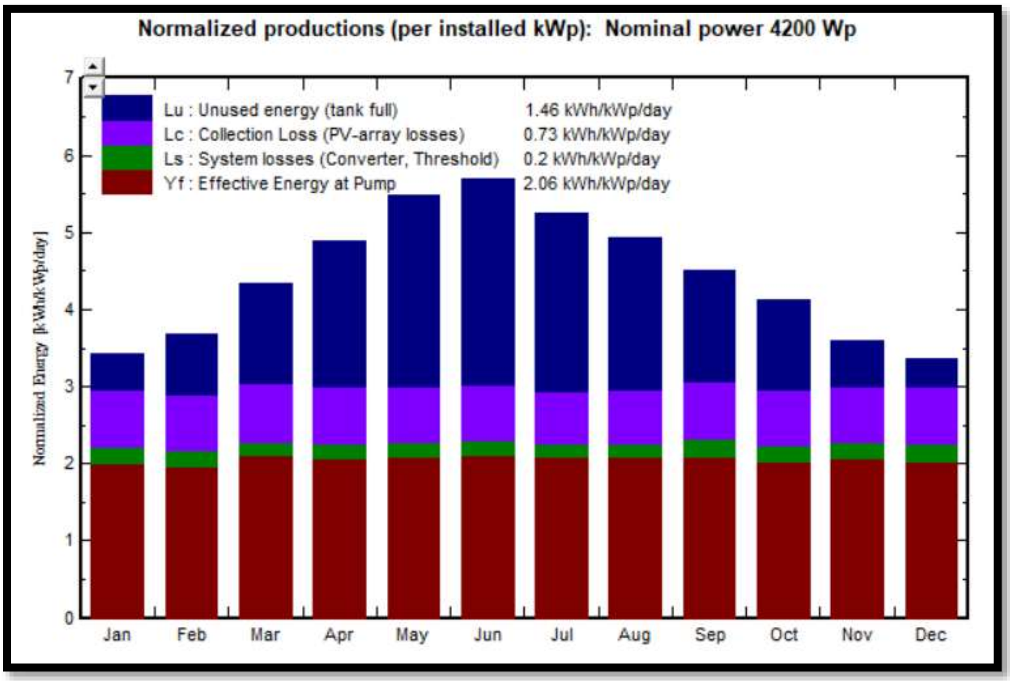

Figure 5-9: Production per installed capacity

We were kin to see that from April to August, the sun was in abundance and therefore the unused energy rate was very high because as detailed in the previous sections, the pumps controller will always stop running once the tank is full and also when the water level in the well in low.

5.2.2 MAIN RESULT PRESENTATION FROM THE PV SYST

Table 5-1 summarized the overall system and we realized that from March to August the water pumped per day were used 100% this is explained by the factor than those months listed are the most with sunshine and in that period the scarcity of water is very remarkable. The average yearly data of the global efficiency based on the irradiance is third of the Array energy at MPP.

Table 5-1: Summary of the main result from PV syst

New simulation variant Balances and main results								
	GlobEff kWh/m²	EArrMPP kWh	E_PmpOp kWh	ETkFull kWh	H_Pump meterW	WPumped m³/day	W_Used m³/day	W_Miss m³/day
January	98.3	334.9	261.0	43.6	44.21	36.87	36.03	1.970
February	95.8	322.2	231.5	63.6	44.15	36.42	36.60	1.397
March	125.5	418.8	273.8	113.6	45.01	38.20	38.00	0.000
April	138.1	453.7	261.7	158.4	44.86	37.45	38.00	0.000
May	160.7	522.9	272.9	212.3	45.26	38.20	38.00	0.000
June	161.7	528.0	266.6	224.3	44.98	38.38	38.00	0.000
July	153.5	510.4	271.5	203.8	45.32	37.95	38.00	0.000
August	144.0	482.1	271.9	177.4	45.33	37.82	38.00	0.000
September	126.9	419.3	263.5	120.3	44.81	37.80	37.73	0.267
October	118.8	399.8	262.8	103.3	44.88	36.75	37.73	0.268
November	99.9	343.2	260.5	52.0	44.52	38.32	37.25	0.754
December	95.9	329.6	264.6	32.8	44.39	37.44	37.52	0.483
Year	1519.1	5064.9	3162.4	1505.4	44.79	37.64	37.58	0.422

5.3 MATLAB/SIMULINK TOOL

This section describes the MATLAB model illustrated in Figure 5-10 used to simulate the system behaviour. It contains solar PV array represented by PV plant with the variants inputs, DC-DC boost converter controlled by MPPT technics based on P&O algorithm, a brushless motor bloc which is run the pump, IGBT switch which alternatively feeds two motor windings through signals which come from the sensors controller bloc, where the speed is maintained stabilized by PID controller. Moreover, there are also some measurement blocs such as efficiencies, currents, power and voltages.

5.3.1 GENERAL BLOC USING CONSTANT LOAD

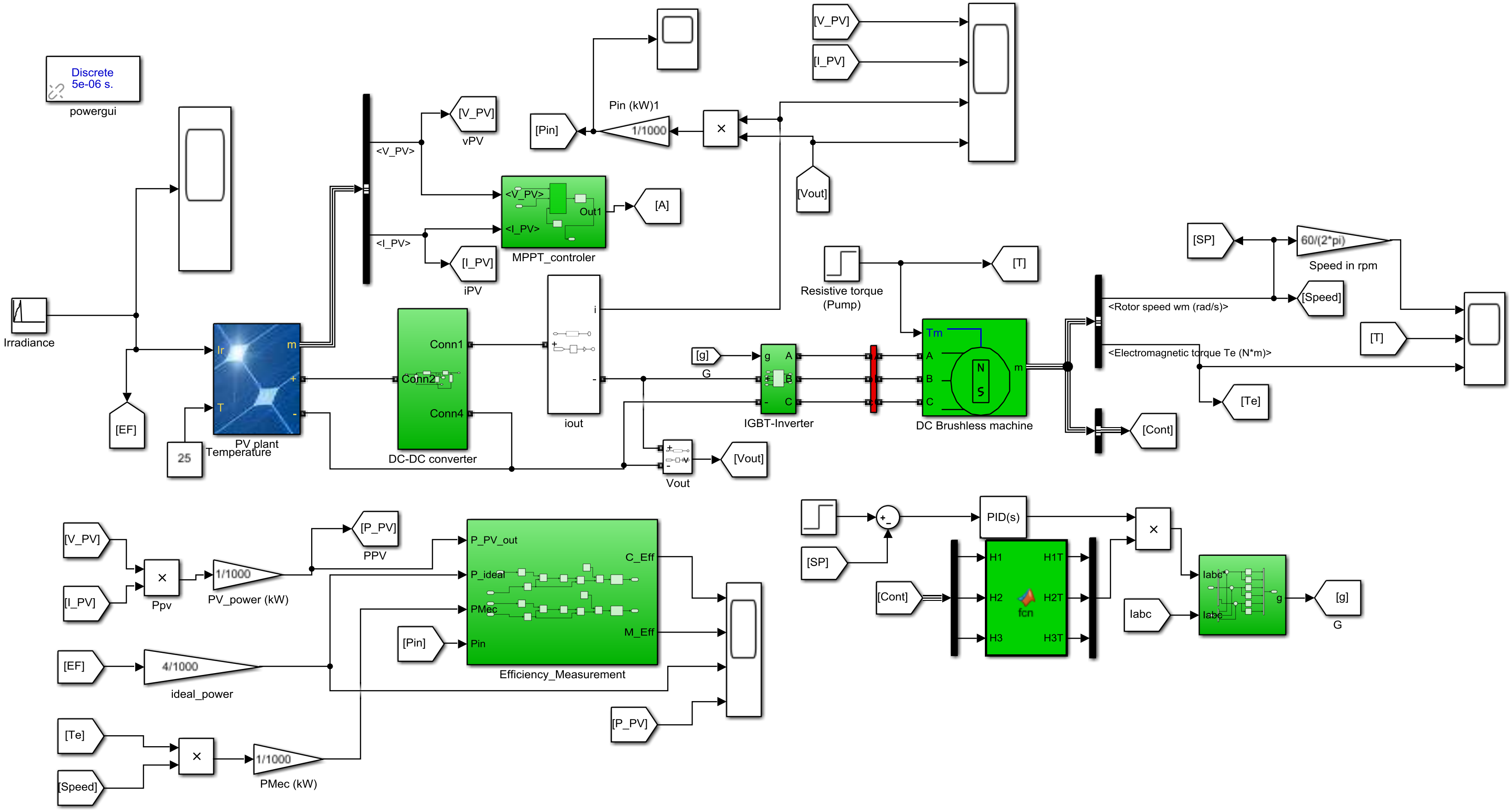

Figure 5-10: Solar pumping system model using Matlab

5.3.2 PRESENTATION OF THE RESULTS

The system model altogether based on Simulink is represented in Figure 4-10. All the system components have been set and combined to be simulated. The above bloc shows the complete system using a PV array of 4kWp at a 25 degree of temperature. A boost converter is commanded by MPPT to track the maximum power. The command signal of the IGBT is obtained through a comparator having as inputs a square signal of frequency f = 20,000 kHz and the duty ratio d supplied by the MPPT control algorithm, respectively. Theoretically, the maximum values of the current and voltage generated by the PV generator are 17.4 A and 242.2 V respectively.

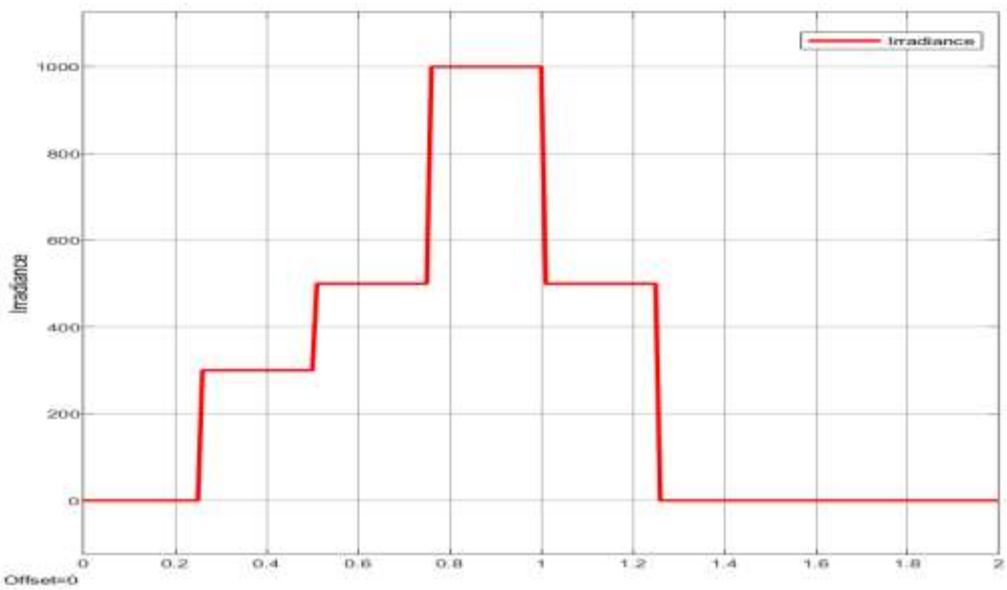

Figure 5-11: Solar irradiance concerning the temperature

Figure 5-11 represents the variation of the irradiance from 0 to 1000W/m^2. However, the following results will be been depending on this variation such as the output power, output currents, output voltage as well as efficiencies as the resistive torque has been set at a constant value.

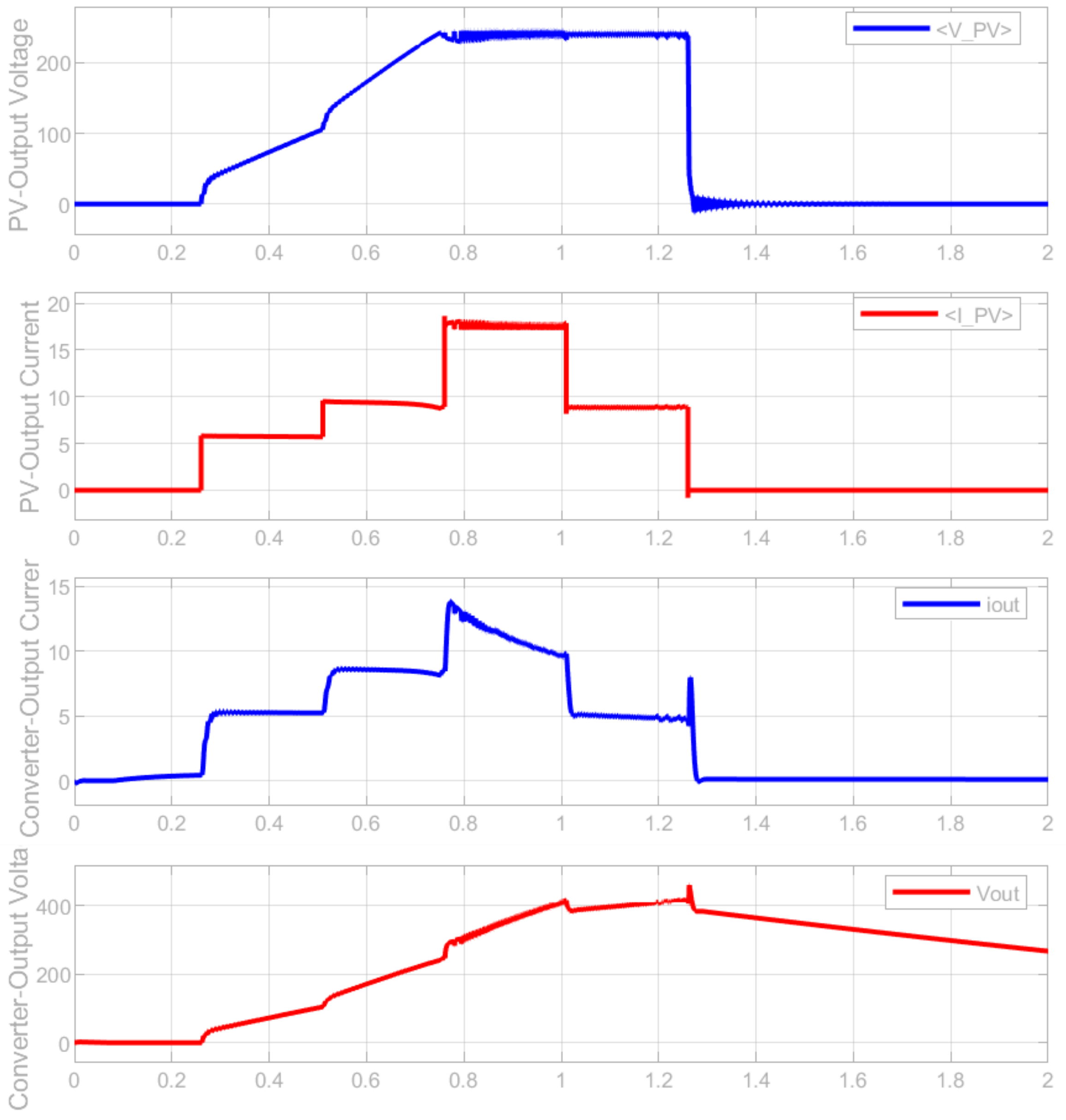

Figure 5-12: Input and Output currents and voltage

Figure 5-12 describes the PV outputs voltage and current and converter outputs voltage and current. Where it is seen that as long as there is a variation of irradiation, as shown in Figure 5-11 the highlighted results vary as well. At the irradiance of 0, they are also 0 and at the maximum irradiance, the results are also at their maximum values. These graphs shapes (currents and voltages) show that for any variation of the solar input i.e. irradiation, envolves a variation at each of equipements (converter, motor,pump) parameters employed in the system. Therefore, the following graphs shape will be depending on the highlighted explainations.

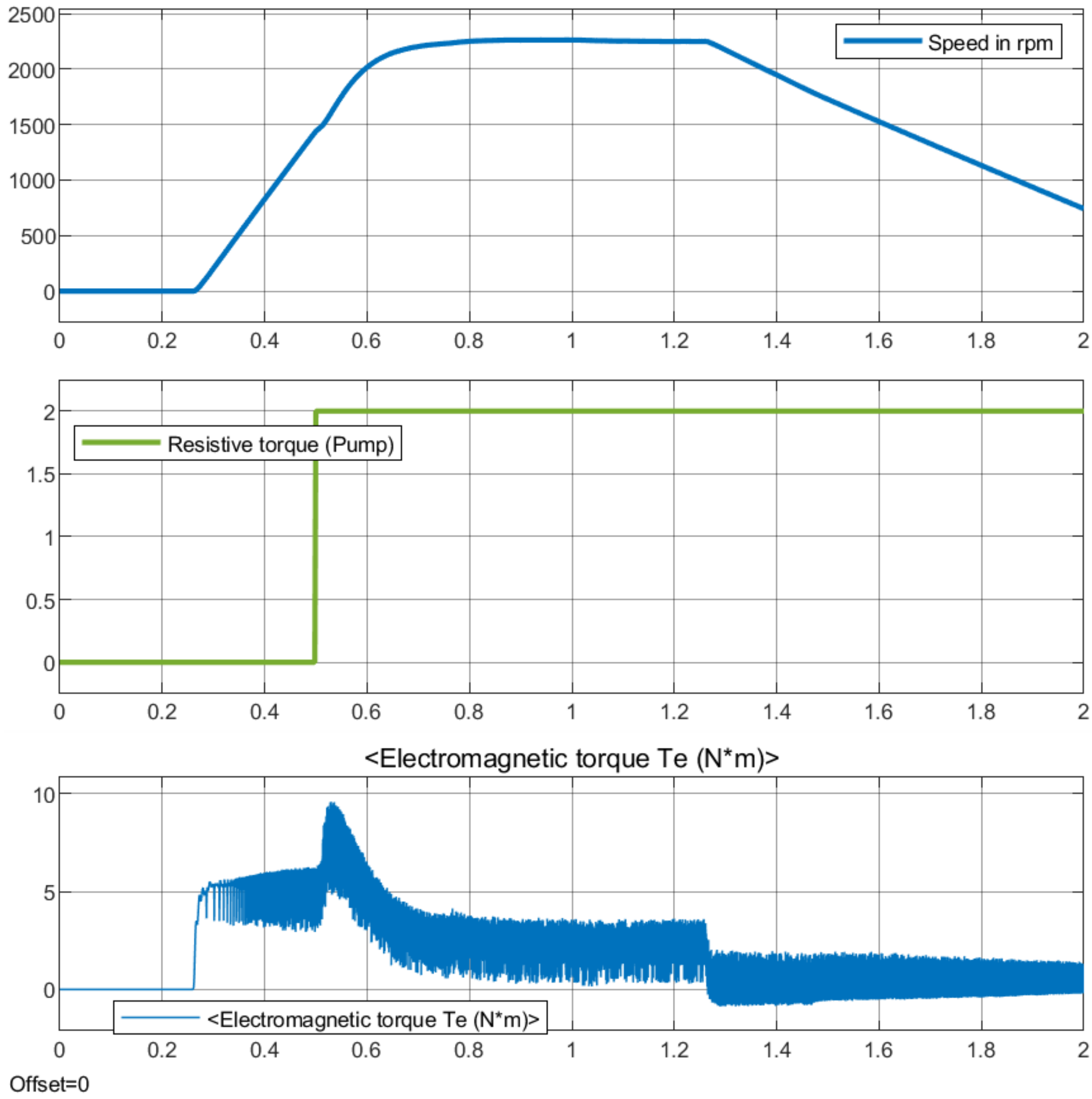

Figure 5-13: Motor characteristics

Motor mechanical characteristics are described in Figure 5-13 such as the motor speed, resistive torque and electromagnetic torque. It is seen that these characteristics or their values are linked with the previous results shown in Figures 5-11 and 5-12. When the irradiation is 0 (0 to 0.25sec) then the speed and electromagnetic torque are also 0. From (0.25 to 0.6) sec, the irradiation is varying from 0 to the maximum value where the voltage is risen and allow the motor to start then the electromagnetic torque rises. Hence, the load which is the water flow rate represented by step bloc in MATLAB is added after 0.5 sec and remains constant up to thes set time 2 sec. From 0.6 to 1.3sec, as the input PV remains constant, the motor parameters such as speed and electromagnetic torque remain unchanged. However, these motor parameters decrease from 1.3 to 2 sec when the irradiation decreases.

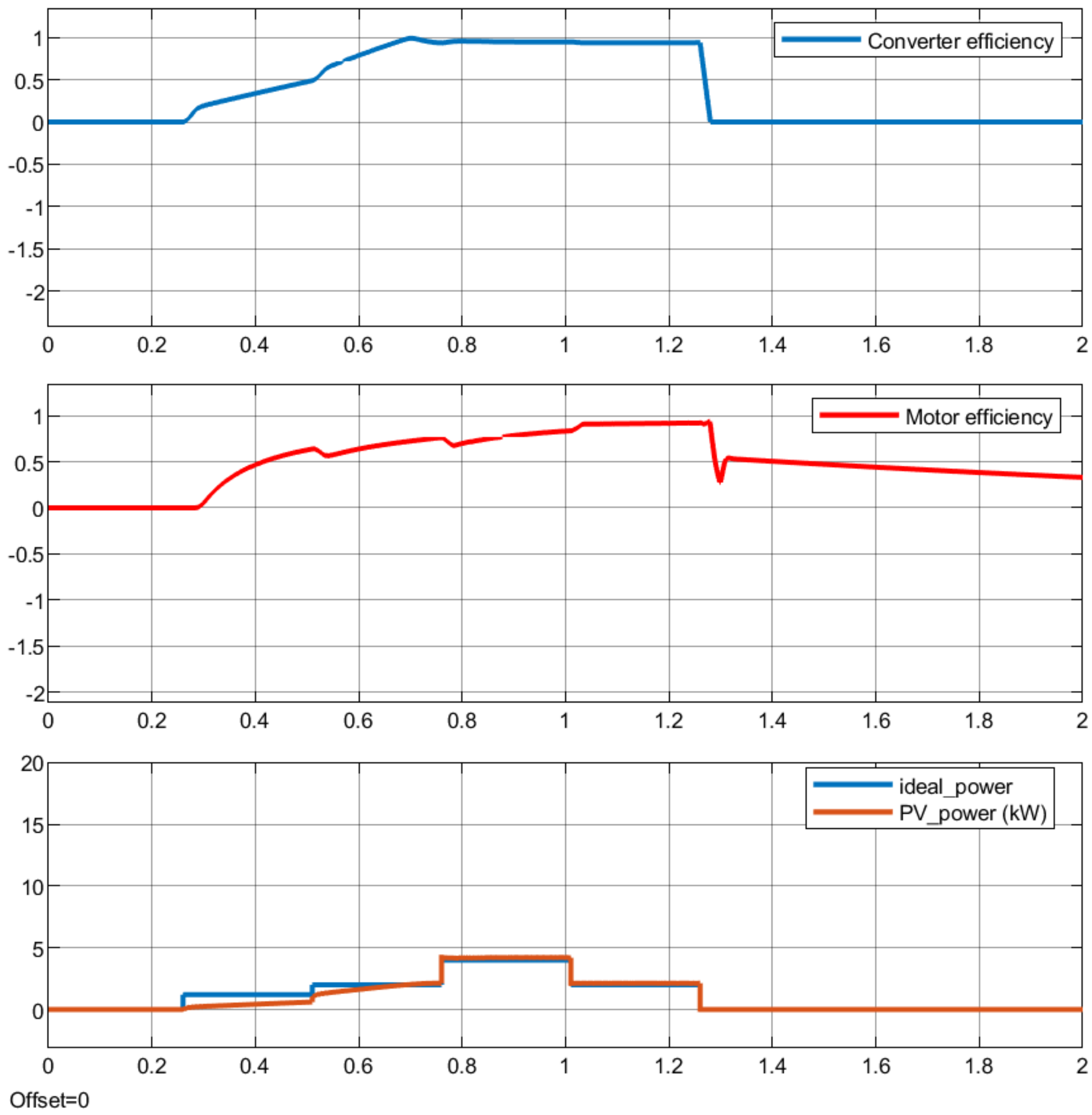

Figure 5-14: Converter and Motor efficiency

Figure 5-14 shows converter efficiency, motor efficiency, ideal power as well as the PV power. The efficiencies are directly proportional to output power which means that when the output power increases, the efficiencies increase as well with the output power depending on the irradiation. The ideal power is the power received directly by PV cells from the sun therefore, it is linearly depending on the irradiation. However, the PV-power is the cells output power which is not linearly proportional to the irradiation due to some constraints related to the components.

5.4 CHAPTER CONCLUSION

This section consisted of the results presentations from the PV Syst and Matlab based on Simulink model in understanding the system behaviour with various components. The result interpretation and discussion were made as well.

6 : CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The use of solar energy in remote and isolated areas for different application such as water pumping presents an important interest, however, the PV generators have two major inconvenient which are low efficiency and a high investment cost this is verified on the I-V characteristic under the influence of different temperatures. The study of the PV generators has enabled to know and understand their behaviours in terms of temperature, irradiance and their effects on the electrical characteristics and hence on their efficiency.

To overcome to some issues related to water pumping, a study was made in order to design and analyze a PV system for water pumping purpose to supply Minova rural community with drinking water. This has led us to a result of a deep well solar powered water pumping system. The study of different electrical motors based on the excitation and their electrical characteristics shown that the DC motor coupled with a pump from LORENZ type presents a good behavior in term of the PV array power. The optimization of the proposed system used MPPT with P&O technics and the results show that the use of that controller improves the solar PV pumping system but the only one drawback of it is that when there is a sudden increase of sunlight, the power from the PV increases as well which has a very good impact on its robustness. However, there are other methods based on artificial intelligence which enable the optimization in real time of the system such as the fizzy logical and neurons networks. Finally, the simulation results have shown that the proposed system allow to improve the effectiveness of the system.

6.2 RECOMMENDATIONS

The United Nations (UN) consider that every person needs at least 20 litres of water per day to satisfy the elementary needs. That basic amount of water should be free of charge for poor people most in the rural and remote areas.

The water management in DR congo has been driven by only one water Utility supply in peri and Urbans areas,some rural area, the management is done by a community organization called ASUREP. Therefore, to ensure sustainability water supply in rural and remote areas of DR Congo, Authorities, policy and decision makers in DRC and most in rural area should think in favour of renewable energy such as solar powered water pumping system when provding water.

Futher research, the need of analyzing the cost and the environmental impact comparison between solar and other sources of energy in the pumping water process also to find an proper algorithm which can be used to control the motor and the pumps while running.

REFERENCES

[1] A. F. Hütz-adams, “Énergie et eau en République démocratique du Congo,” 2008.

[2] D. R. C. Urban, W. Supply, and P. Project, “The World Bank Implementation Status & Results Report DRC Urban Water Supply Project (P091092) Implementation Status and Key Decisions PDO Indicators by Objectives / Outcomes,” no. June, pp. 1–8, 2020.

[3] H. Tyagi, A. Kumar Agarwal, P. R. Chakraborty, and S. Powar, *Applications of Solar Energy, Environment, and Sustainability*. 2018.

[4] A. Alshamani, “Design and Modelling of a Large-Scale Solar Water Pumping System for Irrigation in Saudi Arabia,” no. May, 2018.

[5] T. Finance, “Water Supply and Sanitation in the Democratic Republic of Congo,” 2015.

[6] USAID, “Democratic republic of Congo, Water and Sanitation Profile,” no. March, p. 4, 2010.

[7] M. Martin and J. E. F. A, “A S YSTEMATIC L ITERATURE R EVIEW OF B IOFUEL S YNERGIES.”

[8] W. P. Limited, *No Title*. .

[9] C. A. K. Dikangala, “Democratic Republic of Congo At a glance The Democratic Republic of Congo has tremendous renewable energy potential and access to electricity is increasing , although its global level it still limited to 17 %,” pp. 4–7, 2019.

[10] D. R. C. Expression, O. F. Interest, and P. In, “DRC EXPRESSION OF INTEREST TO PARTICIPATE IN,” no. May, pp. 1–14, 2014.

[11] D. Republic and A. D. Bank, “FP096 : Democratic Republic of Congo (DRC) Green Mini-Grid Program,” no. November, 2018.

[12] G. Mthembu-salter, D. Mozersky, and S. Das, “Renewable Energy & UN Peacekeeping : Untapped Potential in the DRC.”

[13] H. Yu, D. M. Kammen, and A. Newman, “Renewable and Appropriate Energy Laboratory RAEL Report # 2019-S-2 Addressing Conflict and Inequity through Energy Access in the Democratic Republic of the Congo,” 2019.

[14] “Etudes pour 2 turbines hydroélectriques dans le Nord-Kivu,” p. 2020, 2020.

[15] P. Solaire, P. Eolien, P. Hydraulique, P. Agricole, R. N. Renouvelables, and Z. Prioritaires, “AT L AS DES EN E R G I E S R E N OU V E L A B L E S D E L A R É P U B L I Q U E D É M O C R AT I Q U E CONGO,” pp. 1–2, 2019.

[16] S. Shukla and B. Singh, “Reduced Sensor Based PV Array Fed Direct Torque Control Induction Motor Drive for Water Pumping,” *IEEE Trans. Power Electron.*, vol. PP,

no. c, p. 1, 2018, doi: 10.1109/TPEL.2018.2868509.

[17] *No Title*. .

[18] I. Bostan, A. Gheorghe, V. Bostan, I. Sobor, V. Dulgheru, and A. Bostan, *Resilient Energy Systems: Renewables: Wind, Solar, Hydro*. 2004.

[19] A. Tomar, “Techno-Economical Analysis for PV based Water Pumping System under Partial Shading / Mismatching Phenomena,” 2016.

[20] H. Partow, “Problématique de l ’ Eau en République Démocratique du Congo Défis et Opportunités,” pp. 4–90, 2011.

[21] M. Malik and K. N. Vagh, “Development and Testing of Solar Power Water,” vol. 6, no. Iv, pp. 42–47, 2018.

[22] A. Ingle, D. I. Sangotra, R. B. Chadge, and B. Link, “ScienceDirect Module configurations in photovoltaic system : A review,” *Mater. Today Proc.*, vol. 4, no. 14, pp. 12625–12629, 2017, doi: 10.1016/j.matpr.2017.10.072.

[23] A. K. Mishra and B. Singh, “Single Stage Solar PV Powered Water Pump with a Storage System,” *2018 8th IEEE India Int. Conf. Power Electron.*, no. Im, pp. 1–6, 2018.

[24] A. C. Technologies, *RENEWABLE ENERGY*. .

[25] A. Labouret and M. Villoz, *Solar photovoltaic energy*. 2010.

[26] N. Pushpraj, “Solar Energy Harvesting for Irrigation Water Pumping System,” *2017 IEEE Int. Conf. Power, Control. Signals Instrum. Eng.*, pp. 1398–1402, 2017.

[27] C. Guide, S. Water, and P. Solutions, “SOLAR-POWERED PUMPING IN LEBANON A Comprehensive Guide on Solar Water Pumping Solutions,” 2015.

[28] B. A. Bhayo, H. H. Al-kayiem, and S. I. Gilani, “Assessment of standalone solar PV-Battery system for electricity generation and utilization of excess power for water pumping,” *Sol. Energy*, vol. 194, no. October, pp. 766–776, 2019, doi: 10.1016/j.solener.2019.11.026.

[29] E. Engineering, E. Engineering, J. B. Joynal, N. T. Raka, H. M. Mithu, and L. T. Iqbal, “Design & Economic Analysis of a Solar Powered Water Pumping System for Crop Irrigation,” 2017.

[30] S. S. Patil and R. M. Zende, “Solar powered water pumping system,” *Proc. 2017 3rd IEEE Int. Conf. Sensing, Signal Process. Secur. ICSSS 2017*, no. January 2005, pp. 186–190, 2017, doi: 10.1109/SSPS.2017.8071589.

[31] H. Machrafi, *Green Energy and Technology*. 2012.

[32] A. K. Mishra and B. Singh, “Grid Interactive Single Stage Solar Powered Water Pumping System Utilizing Improved Control Technique,” *IEEE Trans. Sustain. Energy*, vol. PP, no. c, p. 1, 2018, doi: 10.1109/TSTE.2018.2890670.

[33] M. Ko, M. Demirta, M. Akta, and E. Di, “Performance analyses of sustainable PV / T assisted heat pump drying system,” vol. 199, no. February, pp. 657–672, 2020, doi: 10.1016/j.solener.2020.02.040.

[34] H. Rezk, M. Ali, and C. Ghenai, “Performance evaluation and optimal design of stand-alone solar PV-battery system for irrigation in isolated regions : A case study in Al Minya (Egypt),” *Sustain. Energy Technol. Assessments*, vol. 36, no. October, p. 100556, 2019, doi: 10.1016/j.seta.2019.100556.

[35] I. Odeh, Y. G. Yohanis, and B. Norton, “Influence of pumping head , insolation and PV array size on PV water pumping system performance,” vol. 80, pp. 51–64, 2006, doi: 10.1016/j.solener.2005.07.009.

[36] S. Feron, R. R. Cordero, and F. Labbe, “Rural electrification efforts based on off-grid photovoltaic systems in the Andean Region: Comparative assessment of their sustainability,” *Sustain.*, vol. 9, no. 10, 2017, doi: 10.3390/su9101825.

[37] S. Dubey, J. N. Sarvaiya, and B. Seshadri, “Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World A Review,” *Energy Procedia*, vol. 33, pp. 311–321, 2013, doi: 10.1016/j.egypro.2013.05.072.

[38] D. Uri and H. A. Aribisala, “IMPROVING THE EFFICIENCY OF SOLAR PHOTOVOLTAIC POWER SYSTEM,” 2013.

[39] S. T. Eshita and A. Hossain, “DESIGN AND SIMULATION OF A SOLAR PV SYSTEM,” pp. 1–46.

[40] W. Xiao, *Photovoltaic Power System*. Sydney, 2017.

[41] V. K. Garg, “A REVIEW PAPER ON VARIOUS TYPES OF MPPT TECHNIQUES FOR PV SYSTEM,” no. 5, pp. 320–330, 2014.

[42] L. Technologies, “WATER PUMP MOTOR.”

[43] K. M. Ã, S. Fletcher, and S. Ula, “Solar photovoltaic water pumping for remote locations,” vol. 12, pp. 472–487, 2008, doi: 10.1016/j.rser.2006.10.008.

[44] Schumacher Centre, “Practical Action of Solar PV Water Pumping,” vol. 44, no. 871954, pp. 1–9, 2012.

[45] S. S. Chandel, M. N. Naik, and R. Chandel, “Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies,” *Renew. Sustain. Energy Rev.*, vol. 49, pp. 1084–1099, 2015, doi: 10.1016/j.rser.2015.04.083.

[46] I. J. KARASSIK, W. KRUTZSCH., W. H. FRASER, and J. P. MESSINA, *Pump Handbook.*, no. (1976). 1976.

[47] “No Title.” https://www.google.com/url?sa=i&url=https%3A%2F%2Fmechanicalnotes.com%2Fcentrifugal-pump-definition-types-parts-working-and.

[48] A. Mettem, “Submersible pumps.,” vol. 716, no. January, pp. 1–3, 1988.

[49] Y. Engineer and S. G. To, "SOLAR WATER."

[50] "A Review on Solar based Induction Motor for Water Pumping," no. 8, pp. 7–12, 2018.

[51] M. Malik, "Development and Testing of Solar Power Water Pumping System for Domestic Purpose," *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. 6, no. 4, pp. 42–47, 2018, doi: 10.22214/ijraset.2018.4010.

[52] C. Protogeropoulos and S. Pearce, "Laboratory evaluation and system sizing charts for a 'second generation' direct PV-powered, low cost submersible solar pump," *Sol. Energy*, vol. 68, no. 5, pp. 453–474, 2000, doi: 10.1016/S0038-092X(00)00005-0.

[53] "Performance Analysis of Solar based Induction Motor for Water Pumping System," no. 7, pp. 20–28, 2018.

[54] R. Sharma, S. Sharma, and S. Tiwari, "Materials Today : Proceedings Design optimization of solar PV water pumping system," *Mater. Today Proc.*, no. xxxx, 2019, doi: 10.1016/j.matpr.2019.11.322.

[55] P. Zhang, X. Rong, X. Yang, and D. Zhang, "Design and performance simulation of a novel hybrid PV / T-air dual source heat pump system based on a three- fl uid heat exchanger," *Sol. Energy*, vol. 191, no. May, pp. 505–517, 2019, doi: 10.1016/j.solener.2019.09.024.

[56] S. Info, " Report generated: 3 Sep 2020," pp. 2–4, 2020.

[57] "No Title." .

[58] J. Solar, "Characteristics of a PV module," 2014.

[59] "GSA_Report_Minova." .

[60] L. Province, "Kapanga (https://elkap.org/index.php? Commission Européenne searchword = Commission searchword = SOFIA & ordering = & searchphrase = exact & Itemid = 330 & option = com _ searc searchword = électrification rurale & ordering = & searchphrase = exact & Ite," vol. 2019, pp. 1–2, 2019.

[61] J. Cronemberger, E. Caamaño-Martín, and S. V. Sánchez, "Assessing the solar irradiation potential for solar photovoltaic applications in buildings at low latitudes - Making the case for Brazil," *Energy Build.*, vol. 55, pp. 264–272, 2012, doi: 10.1016/j.enbuild.2012.08.044.

[62] S. Adhikari, "Control of Solar Photovoltaic (PhV) Power Generation In Grid-connected and Islanded Microgrids," 2013.

[63] R. Faranda, S. Leva, P. Milano, and P. Leonardo, "A Comparative Study of MPPT techniques for PV Systems," pp. 100–105, 2008.

[64] "Conférenciers," 2020.

[65] "Solar PV array." https://www.alternative-energy-tutorials.com/images/stories/solar/alt15.gif.

[66] "Chapter 2 Design and Modelling of the Solar," pp. 20–52, 2011.

[67] "Classification of converters." https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.researchgate.net%2Ffigure%2FClassification-of-the-DC-DC-converters_fig1_325487018&psig=AOvVaw2tJMALu_HwkX5PCTgzFyf0&ust=1601453438131000&source=images&cd=vfe&.

[68] T. Ramesh, "Solar Powered Based Water Pumping System Using Perturb and Observation MPPT Technique," *2018 IEEE Int. Students' Conf. Electr. Electron. Comput. Sci.*, pp. 1–6, 2018.

[69] W. Hart Danial, *Commonly used Power and Converter Equations*. 2010.

[70] "No Ti," [Online]. Available: https://www.google.com/url?sa=i&url=https%3A%2F%2Fcomponents101.com%2Farticles%2Fboost-converter-basics-working-design&psig=AOvVaw2V1AAgq04RirUtyaSaZaNF&ust=1601453932476000&source=images&cd=vfe&ved=0CAIQjRxqFwoT.

[71] "Buck converters electrical schematic." https://www.google.com/imgres?imgurl=https%3A%2F%2Fwww.electrical4u.com%2Fimages%2F2018%2Fjune18%2F1529672077.png&imgrefurl=https%3A%2F%2Fwww.electrical4u.com%2Fbuck-converter-step-down-chopper%2F&tbnid=j8j-.

[72] "Buck-buck converter image." https://www.google.com/imgres?imgurl=https%253A%252F%252Fbase.imgix.net%252Ffiles%252Fbase%252Febm%252Fpowerelectronics%252Fimage%252F2019%252F03%252Fpowerelectronics_3495_figure_01fan_formatted.png%253Fauto%253Dformat%2526fit%253Dcrop%2526h%25.

[73] F. Lin, *Advanced Dc / Ac Inverter*. 2004.

[74] "No Title." https://www.google.com/imgres?imgurl=https%3A%2F%2F1.bp.blogspot.com%2F-0jbNSvpMeQM%2FT3f-T1hYH8I%2FAAAAAAAAAZ4%2FlbGjxADwsqQ%2Fs1600%2F3.png&imgrefurl=https%3A%2F%2Felectricalsimplified.

[75] K. Terashima, H. Sato, and T. Ikaga, "Development of an environmentally friendly PV / T solar panel," *Sol. Energy*, vol. 199, no. November 2019, pp. 510–520, 2020, doi: 10.1016/j.solener.2020.02.051.

[76] M. R. Uddin, "Design , Implementation and Cost Analysis of a Solar Powered Water Pump for Multistoried Building."

[77] "SOLAR WATER PUMPING SYSTEMS SYSTEM DESIGN , SELECTION AND INSTALLATION GUIDELINES."

[78] J. Morales, T. D., & Busch, "Design of Small Photovoltaic (PV) Solar-Powered Water Pump Systems," *United States Dep. Agric.*, no. 28, 2010.

[79] J. B. Chishugi and Y. Xu, "Water supply and sanitation in the Democratic Republic

of the Congo," no. November 2015, 2010, doi: 10.1201/9780203859452-c15.

[80] M. Rosengrant and X. Cai, *World water and food to 2025*. 2002.

[81] 陳洋明, "No Title小学校体育の走り幅跳びにおける指導内容の体系化に関する研究　　リズムアップ助走を中心とした授業実践を通して," [Online]. Available: file:///C:/Users/youhe/Downloads/kdoc_o_00042_01.pdf.

[82] F. P. Oc, "The Irrigation Innovators."

[83] "PS2 Centrifugal Solar Pump Systems," vol. 49, no. 0, p. 24558.

[84] A. Thesis, "DESIGN AND SIMULATION OF PHOTOVOLTAIC WATER PUMPING SYSTEM," no. September, 2005.

[85] S. C. SMA, "Characteristics of a grid inverter," p. 1900, 2017.

[86] P. J. Tsochounie, "INSTALLATIONS ET CONSTRUCTIONS ÉLECTRIQUES Deuxième Licence Génie Electrique," 2018.

[87] "du référence."

[88] Á. Roca Rubí, "Design and Modelling of a Large-Scale PV Plant Escola Tècnica Superior d ' Enginyeria Industrial de Barcelona," Barcelona, 2018.

[89] R. Fu, D. Feldman, R. Margolis, R. Fu, D. Feldman, and R. Margolis, "U . S . Solar Photovoltaic System Cost Benchmark : Q1 2018 U . S . Solar Photovoltaic System Cost Benchmark : Q1 2018," no. November, 2018.

[90] L. Scenarios and M. Development, "Current and Future Cost of Photovoltaics Current and Future Cost of Photovoltaics."

[91] B. P. Guide, "Photovoltaics (PV)."

[92] I. Renewable and E. Agency, *RENEWABLE POWER GENERATION COSTS IN 2019*. 2019.

[93] M. Girma, A. Assefa, and M. Molinas, "Feasibility study of a solar photovoltaic water pumping system for rural Ethiopia," vol. 2, no. 3, pp. 697–717, 2015, doi: 10.3934/environsci.2015.3.697.

[94] R. A. Diantari, "Calculation Of Electrical Energy With Solar Power Plant Design," pp. 443–446, 2016.

[95] P. D. Narale, N. S. Rathore, and M. M. Lad, "Techno economic assessment of solar photovoltaic water pumping system," vol. 7, no. 1, pp. 1–6, 2014.

[96] A. Y. Moussa, P. Kuloba, and R. Kiplimo, "Assessment of Water Pumping System Powered By Solar Pump in Dry Areas," no. 4, pp. 2859–2866, 2019, doi: 10.35940/ijrte.D6950.118419.

APENDIX A: ELECTRICAL PUMPS CHARACTERISTICS

Centrifugal (C) Types

pump system		PS150	PS600 C	PS1800 C	PS4000 C
max. total dynamic head (TDH)	[M / ft]	20 / 65	25 / 80	100 / 330	170 / 560
max. flow rate	[m³ / h / 1,000 US gal./h]	5.0 / 1.3	11 / 2.9	51 / 13.5	70 / 18.5
solar operation: max.power voltage (Vmp)*	[V DC]	>17	>68	>102	>238
open circuit voltage (Voc)	[V DC]	max. 50	max. 150	max. 200	max. 375
voltage range	[V DC]	12-24	48-72	72-96	168-192
Battery operation: nominal voltage	[V DC]	24 and 48	48	96	n.a

Figure A-0-1: Lorenz DPS

Table A-1: motor-pump [83]

Controller and Pump Matching Method					
Controller Model	**Adaptable Pump**	**Max. Input Current (A)**	**Max. Open Voltage (V)**	**MPPT Voltage Range (V)**	**Working Temperature (℃)**
DF-12	Rated 12V Pump	15	<48	30-48	-15~+60
DF-24	Rated 24V Pump	15	<48	30-48	-15~+60
DF-36	Rated 36V Pump	15	<48	30-48	-15~+60
DF-48	Rated 48V Pump	15	<100	60-90	-15~+60
DF-72	Rated 72V Pump	15	<150	90-120	-15~+60
DF-110	Rated 110V Pump	15	<200	110-150	-15~+60

APPENDIX B : BRUSHLESS MOTOR ALGORITHM CODE

```
function [H1T,H2T,H3T] = fcn(H1,H2,H3)
H1T=0;
H2T=0;
H3T=0;
%% TH1
if(H1==0) &(H2==0) & (H3==0)
    H1T=0;
    H2T=0;
    H3T=0;
end;
%% TH2
if(H1==0) &(H2==0) & (H3==1)
    H1T=0;
    H2T=-1;
    H3T=1;
end;
%% TH3
if(H1==0) &(H2==1) & (H3==0)
    H1T=-1;
    H2T=1;
    H3T=0;
end;
%% TH4
if(H1==0) &(H2==1) & (H3==1)
    H1T=-1;
    H2T=0;
    H3T=1;
end;
%% TH5
if(H1==1) &(H2==0) & (H3==0)
    H1T=1;
    H2T=0;
    H3T=-1;
end;
%% TH6
if(H1==1) &(H2==0) & (H3==1)
    H1T=1;
    H2T=-1;
    H3T=0;
end;
%% TH7
if(H1==1) &(H2==1) & (H3==0)
    H1T=0 ;
    H2T=1 ;
    H3T=-1 ;
```

```
end;
%% TH8
if(H1==1) &(H2==1) & (H3==1)
    H1T=0;
    H2T=0;
    H3T=0;
end;
```

APPENDIX C : MPPT ALGORITHM CODE

```
function duty = MPPT_algorithm(vpv, ipv, delta)

%I used the MPPT algorithm in the MATLAB examples
%I only modify somethings
duty_init=0.1;

%min and max value are used to limit duty between
%0 and 0.85
duty_min=0;
duty_max=1;

persistent Vold Pold duty_old;
%persistent varable type can be store the data
%we need the old data by obtain difference
%between old and new value

if isempty(Vold)
    Vold=0;
    Pold=0;
    duty_old=duty_init;
end
P= vpv*ipv; %Power
dV= vpv-Vold; % Difference between old and new voltage
dP= P - Pold; %Difference between old and new power

%the algorithm in below search the dP/dV=0
%if the derivative equal to zero
%duty will not change
% if old and new power not equal
% &
%pv voltage bigger than 30V
%the algorithm will works
if dP ~=0 && vpv>10
    if dP < 0
        if dV < 0
            duty= duty_old - delta;
```

```
        else
            duty = duty_old + delta;
        end
    else
        if dV <0
            duty = duty_old + delta;
        else
            duty = duty_old - delta;
        end
    end
else
    duty = duty_old;
end

%the below if limits the duty between min and max
if duty >= duty_max
    duty = duty_max;
elseif duty < duty_min
    duty = duty_min;
end

%stored data
duty_old = duty;
Vold = vpv;
Pold = P;
```