ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

PHOTOVOLTAIC-POWERED WATER PUMPING APPLICATIONS IN RURAL VILLAGES

M.Sc. THESIS

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Department of Electrical Engineering

Electrical Engineering Programme

Thesis Advisor: Assoc. Prof. Dr. Ramazan ÇAĞLAR

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KIRSAL YERLEŞİMLERDE FOTOVOLTAİK ENERJİ İLE ÇALIŞAN SU POMPALAMA UYGULAMALARI

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To my parents, I thank you for not telling me what I could and could not do, or, what I should and should not do. Your willingness to embark on new adventures will always amaze me. Your prayer for me was what sustained me thus far,

FOREWORD

Solar Photovoltaic Water Pumping systems have the potential to provide clean drinking water to millions of unserved people in distant places that are far away from electricity around the world. The abundant solar energy resources and ground water availability in Somalia can be combined to make much needed potable water available to remote areas and communities and can provide a clever solution. In my thesis work, PVsyst version 6.0, which PC software package for the study, sizing and data analysis of complete PV systems is used to looks at the feasibility of solar photovoltaic water pumping system in the selected site. The designed system is well capable of providing a sufficient quantity of water for daily use in Afgoye region. If diesel generator is used instead of solar photovoltaic water pumping system, to provide the same average daily water for the selected community, the costs of water without any subsidy are much higher than solar-powered system (SPV) pumps. A life cycle cost analysis method is also carried out for economic comparison between solar PV and the diesel pumping system. The results of this study are encouraging the use of the PV system for drinking water supply in the remote areas of the country.

The big advantage of the solar pump is that there is no battery necessary to back-up the solar power. The pump is connected to solar panels, so water is pumped from low to high level in case the sun shines. The water is buffered in the tank that is mounted at a higher level than the taps. In this way there is pressure on the taps and there is water available if the sun is not shining. The function of the water tank is comparable to the function of the battery. I would like to first acknowledge my advisor, Associate Assoc. Prof. Dr. Ramazan Caglar, for his support and advice throughout my graduate program. His Reliability Power System Analysis courses and his dedication to his students gave me the best experience during the program. I would also like to express my sincere appreciation to my other thesis committees, for review of this thesis in detail and their important feedback. I would like to thank my colleague and friends. A number of ideas generated from our numerous discussions and his feedback are incorporated in this thesis. Also, thanks to my other good colleagues, Khurram, Shabbir, Burak karaman, Isse SH nor, Ecem Karakoc, all other technicians for their support and willingness to help me out during various stages of my project.

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ABBREVIATIONS

SPV	: Solar Photovoltaic
PV	: Photovoltaic
°C	: Temperature
MPPT	: MaximumPowerpoint Tracker
DC	: Direct Current
AC	: Alternative Current
W	: Watts
V	: Voltage
A	: Ampere
UN	: Unite Nations
T	: Time
Gpm	: Gallons per minute
TDH	: Total Dynamic Head
Psi	: Per square inch
Ft	: Feet
D	: Diode
D_c	: Duty cycle
L	: Length
R	: Resistance
C	: Capacitance
PI	: Proportional and Integral
W	: Speed
hrs	: Hours
KWh	: Kilo Watt hour
Rs	: Series resistance
Rp	: Parallel resistance
Isc	: Short-circuit current
N(n)	: Ideality factor
rpm	: Rate per minute
Go	: Is the nominal value of irradiance
T_{ref}	: Reference temperature
Voc	: Open-circuit voltage
SPPS	: Solar-powered pumping systems
NGOs	: Non Government Organizations
GIS	: Geographic Information System

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PHOTOVOLTAIC-POWERED WATER PUMPING APPLICATIONS IN RURAL VILLAGES

SUMMARY

This study presents a design and simulation of a simple but efficient photovoltaic water pumping system for Afgoye, Somalia. PVsyst v6.0 software is used to design and perform simulation of water pumping system. The solar data, well characteristics, water demand and storage tank size are input to PVsyst. In addition, the cost and lifetime of PV module, solar pump and controller are input to the software. The output of the software includes the amount of water delivered for daily use to users in Afgoye region, amount of missing water, the excess (unused) PV energy and the system efficiency (performance ratio) during the year. The simulation results have shown the percentage of pump efficiency of the water pumping system and System efficiency of the water pumping system The life cycle cost analysis of pumping water shows that the SPV water pumping system is more economical and feasible compared to Diesel system. The results also indicate that more SPV systems can be installed in the country, replacing the existing more expensive Diesel systems, which would play significant role in achieving the country's Millinium Development Goal (MDG) targets.

The consumption of fossil fuels has an environmental impact, in particular the release of carbon dioxide (CO2) into the atmosphere. CO2 emissions can be greatly reduced through the application of renewable energy technologies, which are already cost competitive with fossil fuels in many situations. Good examples include large-scale solar water heating, and off-grid stand-alone PV systems.

Especially, PV has a powerful attraction because it produces electric energy from a free inexhaustible source, the sun, using no moving parts, consuming no fossil fuels, and creating no pollution or green house gases during the power generation. Together with decreasing PV module costs and increasing efficiency, PV is getting more pervasive than ever.

A water pumping system needs a source of power to operate. In general, AC powered system is economic and takes minimum maintenance when AC power is available from the nearby power grid. However, in many rural areas, water sources are spread over many miles of land and power lines are scarce. Installation of a new transmission line and a transformer to the location is often prohibitively expensive.

Pumps that use PV systems are normally powered by BLDC motors. These motors use the DC output from the PV panels directly. Alternating current (AC) motors are sometimes used, but they require more complex control systems. They also result in less total energy availability due to the electrical losses caused when an inverter is used to convert the BLDC to AC electricity. Because BLDC motors do not require an inverter, utilize a less complex control system, and result in more total energy availability, they are most commonly paired with solar-powered pumps.

Uses for Solar Water Pumps in Somalia Solar pumps are very cost-effective for remote applications, particularly where utility interconnect costs more than $5000. That is usually about one-third to one-half mile from the grid. Specific applications include:

• Off-grid homes and cabins;

• Livestock watering: pond and stream protection, rotational or prescribed grazing, and remote pasturing;

• Aquaculture: circulation

• Irrigation: best for small scale applications.

A typical solar water-pumping system that is installed for a grazing operation includes the PV array, the controller, the pump, and accessories. The size of the array and the pump will be determined by several factors. In this section, the methodology used to determine the size of the system is described along with the general procedures used during installation.

Solar water pumps can provide simple and low labor watering options for farms that require water in remote areas. Several general points to keep in mind about solar water pumping include:

• Water storage in metal or plastic tanks is used instead of power storage in a battery. This reduces costs and makes the system simpler. A float switch turns the pump off when the tank is full.

• An electronic pump controller is used to smooth out the current to the pump. It acts like an automatic transmission in the sense that it helps the pump to start and to operate in low light conditions.

• As with the turtle and the hare, slow and steady wins the race. Many solar pumps are made to pump slowly over the course of the day, which allows water to be pushed over considerable distances and vertical rises. Slow pumps can use small diameter piping, reducing the installed cost. Slow pumps require less power and allow the use of limited water resources, such as a slowly recharged well.

• To reduce the cost of a system, water conservation must be practiced. PV modules are expensive, and reducing water use in any manner will save on the installed cost.

• Solar pumps are generally most competitive in smaller systems where combustion engines are least economical.

• Solar pump systems are low maintenance. With automatic shut off from a float valve, they require only occasional inspection.

Photovoltaic modules have been around for more than 50 years and have been mass produced since 1979. Due to improvements in manufacturing technology and economies of scale, the cost of PV has fallen by 90% since the early 1970s.

PV modules are now readily available in a wide range of sizes from several well established companies. The reliability of PV is such that 20- to 25-year power warranties are typical, with life expectancies beyond 30 years. PV arrays are installed so that they maximize the amount of direct exposure to the sun. That usually means placement in an area clear of shading from buildings and trees, and at an angle equal to the latitude of the location.

Analysis of the monthly average radiation at the 32° tilt angle shows that the average monthly radiation in Afgoa Somalia is sufficient for the development of solar PV power project. Further, solar PV water pumping systems require energy mainly during the months. Since the periods of low solar radiation in Somalia coincide with the availability of rainfall (May to August), the availability of sufficient solar radiation to energies the solar PV pumping system is ensured.

PV modules, to run the pump, and sun¬light value is determined by the nearest latitudinal coordinate of the well location (between 25° and 30° in Afgoa Somalia). When you insert this value, Insolation at given latitude 5.784 kWh/day. Daily Water Requirement 4000 liter/day (with multiplier) three day.

Finally, wishes that this thesis serves the interests of other students who are interested in power electronics for PV applications and provides encouragement towards more advanced senior project or master's thesis research.

KIRSAL YERLEŞİMLERDE FOTOVOLTAİK ENERJİ İLE ÇALIŞAN SU POMPALAMA UYGULAMALARI

ÖZET

Bu çalışma Afgoye Somali için basit ama etkili bir fotovoltaik su pompalama sistemi için dizayn ve simülasyon sunmaktadır. PV syst v6.0 yazılımı su pompalama sistemini dizayn etmek ve simülasyon uygulamak için kullanılmaktadır. Solar veriler, uygun nitelikler, su gereksinimi ve depolama tank ölçüleri gibi veriler PVsyst için girdidir. Bunun yanında PV modülün maliyeti ve kullanım ömrü, solar pompası ve kumandası yazılım için birer veri girdisidir. Yazılımın veri çıktısı Afgoye bölgesinde ki kullanıcılara günlük ulaştırılan su miktarını, eksik kalan su miktarını, artan (kullanılmayan) PV enerjisini ve yıl boyunca sistemin verimliliğini (performans oranını) içerir. Simülasyon sonuçları su pompalama sisteminin pompalama verimlilik yüzdesini ve su pompalama sisteminin sistem verimliliğini gözler önüne sermiştir.

Su pompalama yaşam döngüsü masraf analizi sonucunda SPV su pompalama sistemi Dizel sisteme oranla daha ekonomik ve fizıbıldır. Bu sonuçlar ülkeye daha çok SPV sistemlerinin kurularak mevcut olan daha pahalı Dizel sistemlerle yer değiştirmesi gerekliliğine işaret etmektedir. Ki bu da ülkenin Milenyum Gelişme Hedefine (MGH) ulaşmasında önemli ölçüde büyük bir rol oynayacaktır.

Fosil yakıtlarının tüketimi çevresel olumsuz etkilere sahiptir. Özellikle atmosfere yapılan karbon dioksit (CO2) salınımı. CO2 emisyonu, birçok durumda zaten fosil yakıtlarla masraf yönünden rekabet edebilen yenilenebilir enerji teknolojilerinin uygulanmasıyla büyük ölçüde azaltılabilir. Büyük ölçekli solar su ısıtıcıları ve sebekeye bagli olmadan calisabilen (off-grid) PV sistemleri sozkonusu durum icin verilebilecek güzel örneklerdir.

Özellikle PV'nin güçlü bir cazibesi vardır. Çünkü bitmeyen kaynak olan güneşten ücretsiz elektrik enerjisi üretmektedir. Güç üretimi esnasında hiçbir hareketli parça kullanmaz, fosil yakıt tüketmez ve hiçbir kirlilik veya sera gazı üretmez. PV modül maliyetlerinin düşmesi ve verimliliğinin artmasıyla birlikte PV hiç olmadığı kadar daha yagın hale gelmektedir.

Bir su pompalama sistemini çalıştırmak için enerji kaynağına ihtiyaç vardır. Genel olarak AC ile beslenen güç sistemi ekonomik ve düşük bakım maliyetine sahip olduğundan, yakında AC enerji sağlayan elektrik şebekesi mevcut ise sistem AC ile beslenir. Ancak birçok durumda özellkle kırsal alanlarda su kaynakları kilometrelerce alana yayılmış durumdadır ve çoğu durumda enerji hatları yok denecek kadar azdır. Bölgede yeni bir iletim hattı ve yeni transformatörleri devreye almayı gerektirecek ve dolayısıyla çok pahalı bir çözüm olacaktır.

PV sistemlerinde kullanan pompalar hem DC hem de AC çalışan tiptedirler. Kırsal alanlarda küçük güçlerde DC ile çalışan fırçasız doğru akım (BLDC) motorları sıklıkla kullanılmaktadır. Bu motorlar PV panellerinden aldıkları Doğru Akımı (DC) doğrudan kullanırlar. Dalgalı akım (AC) motorları daha karmaşık kontrol sistemlerine gereksinim duyarlar. Bunlarda aynı zamanda elektriği DC den AC ye dönüştürmek için inverter kullanıldığından, bu dönüşüm nedeniyle oluşan elektrik kaybı toplamda mevcut enerjinin daha az olmasıyla sonuçlanmaktadır.

Çok yaygın olarak güneş enerjili pompalarla birlikte eşleştirilmiş BLDC motorlu sistemlerde invertere ihtiyaç duyulmadığından ve daha az karmaşık kontrol sistemleri kullandığından, toplam mevcut enerjinin daha fazla olmasi imkani vardır.

Fotovotaik su pompalarının Somali'de kullanımlarının uzak erişimli bölgelerdeki uygulamalar icin ozellikle alt yapı hizmet bağlantıları $ 5000 doları aştığı yerlerde çok uygun maliyetli olacağı aşikardır. Ekseriyetle şebekeden uzaklıkları yaklaşık üçte bir ila yarım mil olan bölgeler uzak erişimli olarak kabul edilebilir. Bu uzak bölgeler için ozel uygulamalar şunları kapsar:

• Sebekeye bağlı olmayan evler ve kulübeler.

• Hayvancılıkta sulama: gölet ve akarsuların korunması, dönüşümlü veya öngörülmüş otlatma ve uzak meralarda otlatma.

• Su ürünleri: sirkülasyon

• Sulama: küçük ölçekli uygulamalar için en iyisidir.

Otlatma işlemi için kurulmuş olan tipik bir güneş enerjili su pompalama sistemi, PV donanımını, kontrol ünitesini, pompayı ve aksesuarlarını kapsar. Donanımın ve pompanın ölçüsü birçok etken tarafından belirlenir. Bu bölümde sistemin büyüklüğünü (ölçek ve boyutları) belirlemek için kullanılan yöntem kurulum sırasında kullanılan genel işlemler boyunca anlatılmaktadır.

Solar enerjili su pompaları uzak alanlarda su ihtiyacı olan çiftliklere basit ve az işçilikle sulama seçenekleri sağlayabilir. Solar enerjili su pompalamayla ilgili unutulmaması gereken genel bazı konular şunları içerir:

• Su depolama metal tanklar yerine plastik tanklarda yapılmaktadır. Bu masrafları azaltır ve sistemi daha basit hale getirir. Yüzen bir anahtar (şamandıra) tank dolduğunda pompayı durdurur.

• Bir elektronik pompa kontrolörü pompa akımını düzeltmek için kullanılır. Düşük elektrik durumunda pompanın çalışması ve işlemesi için adeta otomatik transmisyon işlevi görür.

• Adeta kaplumbağa ve tavşan orneginde oldugu gibi yavaş ama kararli olan yarışı kazanır. Çoğu güneş enerjili pompalar, gün boyunca suyun ciddi mesafelere ve dikey yüksekliklere itilmesini sağlamak amaciyla, yavaş hızda pompalamak için yapılmıştır. Kurulum maaliyetini azalmak amaciyla yavas pompalarda küçük çaplı borular kullanilir. Yavaş pompalar düşük enerjiye gereksinim duyar ve geri dolması zaman alan kuyular gibi sınırlı su kaynakların kullanılmasına olanak tanır.

• Sistemin maliyetini düşürmek için mutlaka su tasarrufu yapılmalıdır. PV modülleri pahalıdır ama su kullanımının herhangi yolla azaltılması tesis masraflarını da azaltacaktır.

• Solar enerjili pompalar, genellikle ekonomik olmayan içten yanmalı motorların kullanıldığı küçük sistemler göz önüne alınacak olursa daha rekabetçidirler.

• Solar enerjili pompa sistemlerinin bakım maliyetleri düşüktür. Sistemi otomatik durduran yüzen şamandırayı sadece ara sıra yoklamak gerekliliğini yerine getirmek yeterlidir.

Fotovoltaik modüller nerdeyse 50 yıldan fazla bir süredir hayatımızdadır ve 1979'dan bu yana da seri üretimleri yapılmaktadır. Üretim teknolojilerindeki gelişmelerden dolayı ekonomik ölçeklere göre PV maliyetleri 1970'li yılların başlarından itibaren %90 oranlarında düşüş göstermiştir.

PV modüllerin mevcut birçok iyi donanımlı şirketler tarafından her ölçekte ve boyutta üretimi yapılmaktadır. PV modüller için özellikle 30 yıldan fazla ömür tahmini altında, güvenirliğinin 20 ila 25 yıl arasında garanti edilmesi tipik bir durumdur.

PV dizilimi güneş ışınlarını azami derecede yakalayabilecek şekilde inşa edilir. Bu genelde binaların ve ağaçların gölgesinden uzakta ve kurulduğu bölgenin enlem açısına uygun bir yere yerleştirmek anlamına gelir.

32 derecelik eğim açısına sahip aylık ortalama radyasyon analizleri Afgoa Somali'de ki aylık ortalama radyasyon değerlerinin PV enerji projesi geliştirmek için yeterli olduğunu göstermektedir. Dahası güneş enerjili PV su pompalama sistemleri genellikle yağışlı aylarda daha çok enerjiye ihtiyaç duyar. Düşük güneş radyasyon dönemlerinin yağışlı mevsimlere (Mayıs Ağustos arası) rastladığı için PV solar enerjili pompalama sistemlerinin ihtiyaç duyduğu güneş radyasyonları yeterli derecede mevcuttur.

PV modülleri pompalarının çalışması için gereken güneş ışığı değeri kuyu konumuna en yakın enlem koordinatları tarafından belirlenir (Afgoa Somali'de 25° ila 30° derece arasında). Bu değerler girildiginde verilen enlemde güneşlenme m2 basina 5.784 kWh/gun. Günlük su ihtiyacı 4.000 liter/gün (çarpanla birlikte) üç gün.

Son olarak bu tezin PV uygulamaları için guc elektroniğine ilgi duyan diğer öğrencilerin çalışmalarına hizmet etmesini ve daha gelişmiş ileri projelere veya yüksek lisans tez araştırmalarını teşvik etmesini temenni ederim.

1. INTRODUCTION

1.1 Purpose of Thesis

There are few forms of energy in the world, like sound, heat, speed, potential energy, electrical energy and so on. Of them electricity is a versatile form of energy. In this day electricity has become an essential part for human. The way we are living our life has been possible due to electricity. There are uncountable numbers of machines and gadgets run on electricity. Although a big amount of the electric energy comes from diesel and fossil fuel running generators. The problem of diesel and fossil fuel is that they contaminate the nature in a large scale. In addition electricity is not available on all the area. So they have to rely on diesel and fossil fuel based generators. And as diesel and fossil fuel is decreasing day by day, we have to think about an alternative which is available everywhere. Therefore, renewable energy sources like wind, solar, biomass, hydropower, geothermal are potential sources to meet the energy needed. By using renewable sources energy demand can be met and it causes less environment pollution.

Energy is one of the key drivers in the development of any country's economy. As the post-conflict situation in Somalia have eased, and the country is relatively becoming in a stable state, the development of the energy sector plays an important role in giving the economy a kick-start and in ensuring its sustained development. It is widely accepted the access to affordable and reliable enerygy will not only improve the economy and the environment, but the solar energy systems could significantly improve quality of life in rural communities; water supply for consumption, irrigation, and livestock.

Water is essential for living. Every living thing on earth requires water. Water is not only used for drinking, it is used for irrigation, food production, cleaning, sanitation and other domestic and industrial purposes. A large number of world populations living in rural area, where modern technology and infrastructures are limited. In order to meet the necessities rural population needs maintenance. Shortage of pure

water can cause severe problems like nutrition, sanitation and economically that affects people. As water resources are sustainable, consumption of water is not bigger than natural replacement.The most important is the supply of pure drinking water for consumption of human being, domestic animals. Unfortunately in some regions of world people have to walk several kilometers to get the daily water usage.
Utilization of solar energy for drinking water supply pumping is a feasible solution especially for remote villages and homes far from power grid. Using photovoltaic (PV) pumps has predominant advantages where grid connection is not available, good solar conditions exist, and distances from transport facilities are long. In solar powered pumps, pumping and transporting water from the source to end user requires a lot of energy. The energy required for pumping and transporting water can be obtained from solar powered pumps. The overall objective of this thesis is to study the feasibility of solar powered pump for drinking water supply in rural areas of Somalia and to compare the economics of photovoltaic pump with diesel generator powered pump. Preference is given to the drinking water of Afgoye town. This thesis also covers the design process and the components of a SPPS when used with a well and submersible pump. A significant amount of detail is directed towards selecting a pump when solar power is selected as the appropriate technology.

1.2 Literature Review of PV Water Pumping Technology

Water pumping worldwide is generally dependent on conventional electricity or diesel-generated electricity. Solar water pumping minimizes the dependence on diesel, gas or coal based electricity. The use of diesel or propane based water pumping systems require not only expensive fuels, but also create noise and air pollution. The overall upfront cost, operation and maintenance cost, and replacement of a diesel pump are 2–4 times higher than a solar photovoltaic (PV) pump. Solar pumping systems are environment friendly and require low maintenance with no fuel cost [1]. Keeping in view the shortage of grid electricity in rural and remote areas in most parts of world, PV water pumping is one of the most promising applications of solar energy. The technology is similar to any other conventional water pumping system except that the power source is solar energy. PV water pumping is gaining importance in recent years due to non-availability of electricity and increase in diesel prices. The flow rate of pumped water is dependent on incident solar radiation and size of PV array. A properly designed PV system results in significant long term cost savings as compared to conventional pumping systems. In addition, tanks can be used for water storage in place of requirement of batteries for electricity storage [2].

Agricultural production in developing countries is largely dependent on rains and is adversely affected by the non-availability of water in summers. However, maximum solar radiation is available in summers as such more water can be pumped to meet increased water requirements. Urban water supply systems are also dependent on electricity to pump water in towns. There is a wide scope to utilize PV pumping systems for water supplies in rural, urban, community, industry and educational institutions. Solar water pumping is found to be economically viable in comparison to electricity or diesel based systems for irrigation and water supplies in rural, urban and remote regions. The investment payback for some PV water pumping systems is found to be 4–6 years. The recent Somalia incentives for PV pumping and policy initiatives for the promotion of solar water pumping in developing countries are also discussed. A solar PV water pumping system consists of a PV array, a DC/AC surface mounted/submersible/floating motor pump set, and electronics. The PV Array is mounted on a suitable structure with a provision of manual or automatic tracking. Water is pumped during day and stored in tanks, for use during daytime, night or under cloudy conditions. The water tank acts as storage and generally battery is not used for storage of PV electricity; however, for specific reliable requirements it can be used. The components used in the PV water pumping system should conform to the national/international specifications, whichever is applicable in a country [2]. Direct coupled DC solar pumping was first introduced in the field in the late 1970s. Earlier PV water pumping systems have limitations of overall performance of the system due to lack of proper design. Since then, manufacturers have refined their products to improve the performance and reliability. The steady fall in prices of solar photovoltaic (PV) panels have resulted in making solar pumping economically viable for an increasingly wide range of applications. Direct coupled DC solar pumps are simple and reliable [3] but cannot operate at maximum power point of PV generator as the solar radiation varies during the day from morning until evening. However, adding a maximum power point tracker (MPPT) and controls/protections improve the performance of a PV pump. PV water pumping systems have shown significant advancements in the last decade. The first generation

PV pumping systems used centrifugal pumps usually driven by DC motors and variable frequency alternating current (AC) motors, with proven long-term reliability and hydraulic efficiency varying from 25% to 35%. The second-generation PV pumping systems use positive displacement pumps, progressing cavity pumps or diaphragm pumps, generally characterized by low PV input power requirements, low capital cost and high hydraulic efficiencies of even 70% [4].

The current solar pumping technology uses electronic systems, which have further increased the output power, performance of the system and overall efficiency of the system. The controller provides inputs for monitoring storage tank levels, controlling the pump speed and uses maximum power point tracking technology to optimize the water. Advancement has taken place in the tracking mechanism of PV arrays from manual tracking to dual axis automatic tracking systems by microcontroller programming. Tracking the sun reduces the physical size of PV panel area required for a given output, improves power yield, overall efficiency of the system and return on investment. Tracking of a solar pumping system extends the time for peak water yield. The solar pumps available in the market can lift water from 5 m to more than 200 m with outputs of up to 250 m^3/day. For the past 15 years, significant improvement has been done in helical motor pumps (positive displacement pumps) which are submersible, last for many years and are powered by similar motors as used for centrifugal pumps. Advancement has been in the field of controllers for large size PV arrays in the order of 25 kW with 100 kW controllers expected to be developed in near future [5]. PV module costs have significantly declined and are available at a rate of US$ 0.59/Wp in 2014 as compared to around US$ 1/Wp in 2012 in India [6] . This significantly affects the overall cost of the pumping system since PV modules represent 60–80% of the total cost of a PV system. The steady increase in cost of diesel and gasoline prices over the years and decrease in PV system costs make PV pumping attractive from financial perspective also. Furthermore, crystalline PV modules with high efficiencies of 16.84–21.5% are available in the International market in 2014 [7] and [8]. In the following section, an overview of solar water pumping technology is presented.

1.3 Motivation

Energy is used in all steps of water supply and treatment. The amount is dependent on which technology is used for which purpose. Generally the water supply problem is a matter of local energy shortage to conduct the extraction and supply of water from source to place of water consumption. The solution for this could be introducing off-grid systems of energy production. Electrical and diesel based water pumping systems are widely used for cultivation around the world. The problems above about the conventional energy sources have created an interest in choosing renewable sources for water pumping systems. Water pumping systems were introduced many years ago. Then water was pumped manually or by animal traction. Now this technology is obsolete and water pumping systems use diesel generators mostly. The price of diesel and the pollution it makes have caused to find an alternative. Water can also be pumped using wind energy. But wind flow is not same all time, and in some areas it is not efficient to setup one because of low wind flow. The term refers to wind mills that use wind to mechanically extract water from well. Solar pumps are new and less popular. But PV pumping systems is becoming the interesting and cost effective. Solar water pumping systems is on all over the world. It greatly enhances lives in rural areas. A solar water pumping system does not have to use batteries to provide the power as the pump will operate during the day by pumping water into a tank for use at night and following table 1.1 comparision.

Table 1.1: Comparison between diesel, solar and wind powered pumps

Pumping systems	Advantages	Disadvantages
Diesel powered pump	• Moderate initial cost • Portable • Easy to install	• Fuel is expensive • Noisy and creates fumes that is harmful for environment • As there are rotating parts lubrication is needed.
Wind powered pump	• High power output from certain wind speed • Low maintenance • No fuel needed	• Depends on location • It creates much noise • Affects the view of landscape
Solar powered pump	• Low maintenance • No fuel needed • Easy to install • Long lifetime	• Relatively high capital cost • Lower output in cloudy weather

1.4 Scope

The necessity for optimizing the utilization of this system has become an emerging issue. For that reason it is necessary to study these types of systems to improve.
The subject of this thesis is to design a solar water pumping system for Somalia in an efficient way. The focus of this thesis is to study the environment of the site and designing the system according to water necessity for the use of household and livestock.

1.5 Methodology

In this thesis the method adopted is a conventional method. We used PVsyst software to gather the methodological data of the selected site. Then panels and pumps are selected according to water usage. A water storage tank used to store the water for later use.

Design of solar pump system starts with a survey of needs and location data with this result, a most appropriate pump and solar panel combination is obtained to design the right system configuration. Then the following methods can be used in the design process for a PV-powered water pump system.

These procedures will help us ensure that the system functions properly and that water is supplied for the operation in the amounts and at the locations required. Designed pumping and storage system, the system's total water storage capacity should be sufficient for a minimum of three days water use. This minimum storage capacity is calculated below using the water requirement. The direct coupled photovoltaic water pumping system studied consists of the PV array that provides the minimum energy requirement to run the pump, DC motor, centrifugal pump. Total Dynamic Head (TDH) for the Pump calculated, vertical lift, pressure head, friction loss, a storage tank that serves less than a polycrystalline solar panel for the same wattage. If you are limited on size and want to get the most energy possible, monocrystalline panels are the better choice.

Looks: In terms of looks, monocrystalline panels have a nice uniform color and have a more circular cell shape. Polycrystalline cells are in squares and have inconsistencies in the color sort of like granite.

Longevity: Even though a monocrystalline panel has the potential to last up to 50 years, most warranties only go up to 25 years which polycrystalline panels are able to reach just fine.

Overall, the production process for monocrystalline silicon is mature, and the process for polycrystalline in still maturing. As purity and process tolerances for polycrystalline Si improves, the performance gaps between the two are narrowing.

The flotation switch is used in the tank to turn off the pump when the tank is full. The pump should be specifically designed for solar power. It is strongly recommended to have the pump controller purchased from the same manufacturer as the pump. To use another manufacturer could cause several unforeseen problems and even invalidate the pump's warranty. If the pump does not contain a built-in check valve, one should be installed in the system to keep the water from flowing back into the well. Very few pumps can handle reverse flow without reducing the life expectancy of the pump. The pumps that are designed to drain during non-operation are meant for extremely cold conditions to keep water from freezing in the lines. The pump should be no deeper than 2 feet above the bottom of the well to help prevent heavy silt and sand from entering the pumps intake and causing it to seize. The storage tank should be sized to hold at least three day's worth of water demand to account for evenings and cloudy days. A security fence should be placed around the PV modules and controller. If the controller is not attached to the array mounting bracket it can be placed in a secure shed or pump house, preferably water tight and dust free. See the following figure for a schematic diagram of a typical system [5]. Following methodology has been adopted for present feasibility study and comparative analysis of the solar powered pumps. Water supply demand analysis based on population data and national standard water provision of the country.

To determine the energy required from the source and the size of photovoltaic module; Economic analysis of the system in general and cost comparison of different energy sources. The initial survey is about pumping techniques and other systems related to our project. Any work without planning is like story without any end. Planning is a very necessary and important step before starting a project. The method used here to build solar powered water pumping system is cost effective comparatively to an electrically operated hydraulic pump. Since here non-conventional energy is used to achieve the required head. The reciprocating pump built by us is built with the help of simple and easily available materials still we have successful to demonstrate the worth of a reciprocating pump. This device serves its purpose to some extent, but with proper course of actions, it can perform still better.

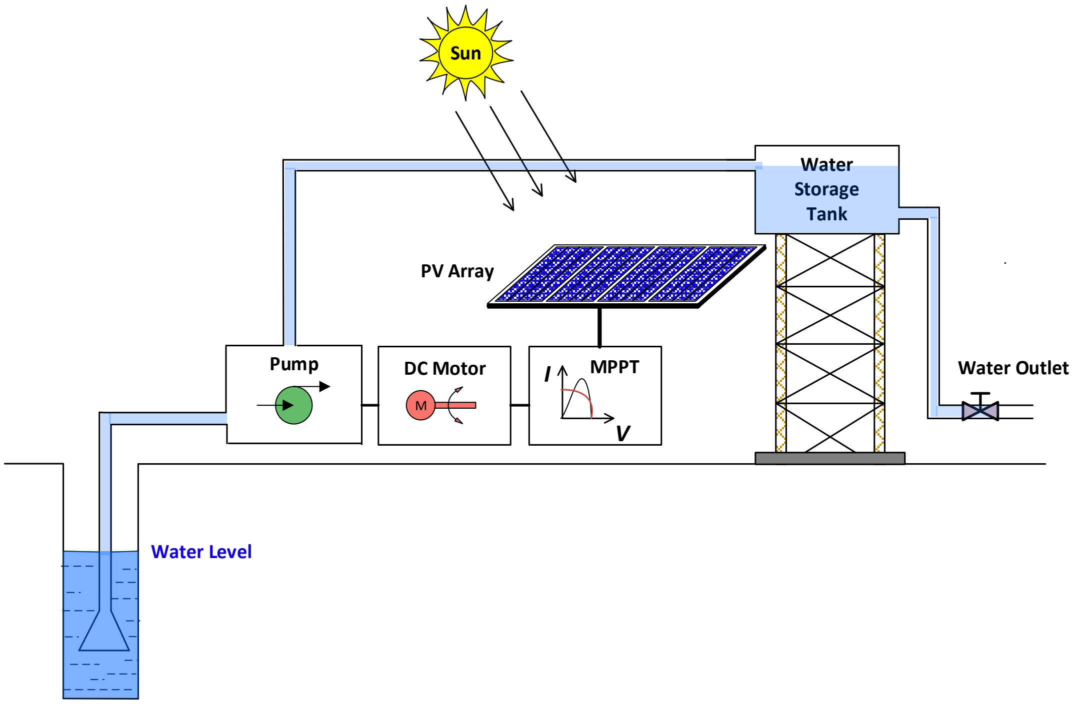


Figure 1.1: Schematic diagram of a typical system

Solar water pumps are pumps that work with an electric motor whose power comes from photovoltaic cells located on solar panels that capture power from the sun's light. These pumps are often directly connected to a tank supplying a miniature water network or standpipes. The pumps used are generally centrifugal force or suction-force pumps.

2. LIVESTOCK WATER DEMAND

Many livestock producers allow their animals' free access to the rivers, streams and creeks that run through rural Tennessee. Along these surface water sources are areas commonly referred to as riparian zones. A well vegetated riparian zone establishes a buffer between agricultural land and surface water sources. These buffer strips filter and purify water as it moves across the riparian zone, reduce sediment loads and support soil stability while providing additional benefits such as improved wildlife and fisheries habitat. Over time, allowing livestock access to these buffer areas can lead to poorly vegetated riparian zones with unstable, erosion-prone stream banks.

2.1 Water Requirement Analysis

The daily livestock water requirement is one of the key factors in the design of the solar water pumping system. Size of the herd, pregnancy, lactation, animal weight, type of feed, physical activity and time of year all have to be considered when determining the minimum volume of water the solar pumping system must supply each day. The daily water intake by various types of beef cattle for each month of the year, shown in Table 2.1, gives a good estimate of the daily water needs that must be met by the solar pumping system, the pumping system must be designed to supply a maximum of roughly 4.000 liter per day. To determine the operation's water needs, use table 1.2 calculates the total water requirement for animals. We suppose that there are Camel 15, Horses 5, Sheep & Goats, 240 Catlle 20 and others are 10. So water requirement for a daily multiplied liter per day in each animals as showing the water requirement per day in liter [23], future plan to prouduce daily water demand for drinking liter per up to 5501 m3 per day [23]. Water quality is also important to consider as it can have an impact on the volume of water consumed. Foul odours or tastes, for example, may discourage animals from drinking. Depending on the cause, poor water quality can affect herd health, possibly leading to animal death and economic loss to the producer.

Assess water quality at both the point of use and the source. The contamination of watering devices by dust, spilled feed and fecal matter can lead to the growth of slime. Eventually slime organisms die and decay, creating foul odour and/or tastes.

Average daily demand (add) the total volume of water delivered to the system over a year divided days. The average use in a single day expressedin Litres per day.

Table 2.1: Average daily demand (ADD) for drinking (L/day)

Type of livestock	Number	Daily requirement (L/day)	Total daily requirements (L/day)
Camel	15	36.5	547.5
Horse	5	40	200
Cattle	20	41	820
Sheep & Goat	240	10	2.400
Others	10	10	100
Total			4.067.5

2.2 Water Storage

Solar energy is only available during the day, and can sometimes be absent during heavy winter days, which would require storage for some applications. For this reason, a lot of solar pumping applications favor the use of water storage instead; here water is pumped whenever sufficient solar power is available and stored in an elevated tank, form which water can be withdrawn whenever required. Water storage is very practical when the system is properly sized. During sunny days, the system provides enough water more than the daily requirements; water can be stored in water tanks that should be sized to ensure sufficient storage volume depending on climatic conditions and water consumption patterns. This is also called the direct drive system design. The capacity of tank is 12 m^3 liters, but daily water requirements 4.000 liter per day.

Tank shapes are calculated assuming exact geometric solid shapes such as cylinders, circles and spheres. Actual water and oil tanks may not be perfect geometric shapes or might have other features not accounted for here so, these calculations should only be considered estimates. For rectangular tanks, the filled volume is simply the same length and width with a shorter height. The new height is the fill height. Therefore, filled volume is equal to the length times the width times the fill height figure 2.1.

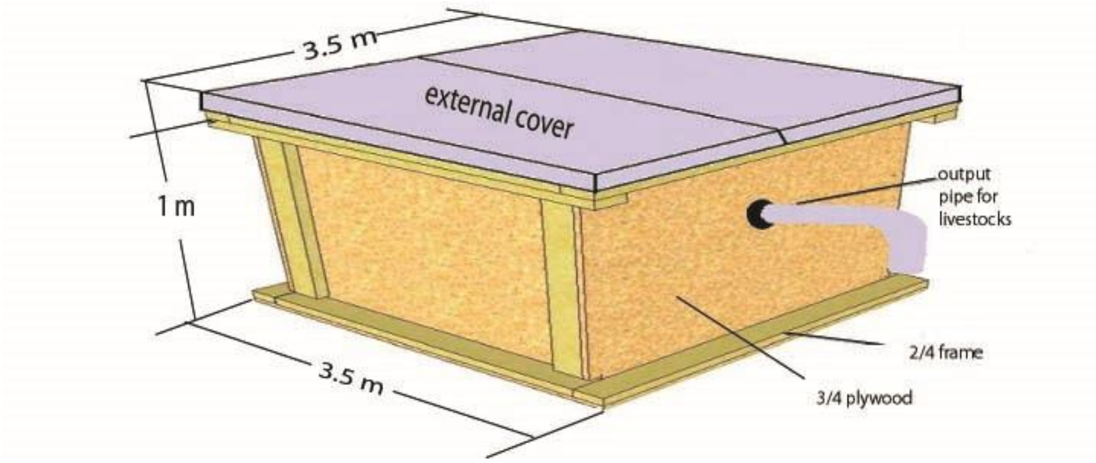


Figure 2.1: Storage tank of water need

Water tank is for storing the water for later use. The tank we used here is a rectangular shaped tank. The tank's width and length is 3.5 m and the height is 1 m. We know that the volume of a rectangle is the multiplication of width length and height.

$$\text{Volume} = \text{width x Length x Height} = 3.5 \times 3.5 \times 1 = 12.25\ m^3$$

So the tank volume is $12.25m^3$. As in 1 m^3 volume 1000 liter water is stored. For $12.25m^3$ water storage capacity is 12250l which is sufficient for water usage of 3 days. The tank should be sized for 3-5 days water storage. The tank is sized for 3 days autonomy for repair and other purpose. Water intake pipe is on top of the tank and water will come out for daily usage from the bottom.

Tanks are used to store water for use during the day or periods of cloudy weather. Tanks areusually large enough to hold 3 days of daily water output. If your application requires large amounts of water on a periodic basis, like watering a crop once aweek, divide the weekly requirement by 7 to arrive at an average daily requirement.

3. WATER PUMPING

3.1 Flow Rate

Water flow rate is the factor that indicates the amount of water pumped unit time. A pumps water flow rate usually rated as *l*/sec or m^3/sec. It means that the pump can move water to a certain head at a constant flow per unit time. So flow rate is amount of water pumped multiplied time. The bottom table shows the two pump's water flow rate corresponding to different power and head level. The Watermax AD pump water flow rate changes with change in head and input power of pump. The flow rate decreases as the head increases. But the increasing power is not sufficient to keep the flow rate constant. The change of flow rate with fixed head at different power levels can be seen in Lorentz_PS200_HR_04 maximum power point tracker with a fixed head the water flow rate increases with increment of power. The flow rate should be calculated during the year's driest times (July, August, September, and October) to ensure adequate water supply year-round; however, it may still by economically viable to develop the spring if you have an adequate flow rate for even six months of the year.

Measuring flow is accomplished by creating a makeshift dam below the spring outlet. A makeshift dam can be as simple as rocks and dirt clods formed across the flow with a small opening in the center. The flow across the opening can be used to roughly estimate flow rate. Flow rate can also be determined by measuring the time required to fill a known volume. An adequate spring flow would be one that yields the maximum amount of water needed per animal times the number of animals in the pasture at any one time. The provide estimates on the amount of water needed by animal growth stage and species. Location to develop a spring, there needs to be enough change in the elevation of the spring to a watering tank to provide gravity flow. If there is not, pumps will need to be used to transfer the water. There are solar-powered pumps that might be able to move the water effectively. .

The expected flow rates and minimum recommended solar panel sizes for a typical volt, positive-displacement, and diaphragm-type submersible pump are shown in

Table 3.1. The choice of pump depends on water volume needed, efficiency, price and reliability.

Table 3.1: Estimate the flow rate

Watermax AD (Afgoye)			**Lorentz_PS200_HR_04_MPPT (Kismayo)**		
Power (W)	Flow rate (l/sec)	Head (meterW)	Power (W)	Flow rate (l/sec)	Head (meterW)
130	0.2611	10	62	0.0292	60
161.6	0.2528	20	101	0.0678	60
192	0.2444	30	143	0.1069	60
223.2	0.2375	40	188	0.1489	60
			235	0.1800	60

3.2 Pumping Deep Well Wystem

Many solar pumping systems are of the "Deep Well" type, i.e. made of a submersible pump placed in the bottom of a borehole. The borehole is usually sunk by specific machines; with a diameter of about 12 to 20 cm. Special submersible pumps are designed for being inserted in such boreholes. They should of course lie below the water level, and are connected to the surface by a pipe for the water, and the feeding/control electrical wires. The water is pumped into a storage tank, according to sun availability. Remember that the Pressure or Head is mainly related to the difference between the input and output levels. The pump has to provide a total head resulting of several contributions [21]. In PVsyst it takes reference to the ground level.

$$\boldsymbol{HT = HG + HS + HD + H} \tag{3-1}$$

Where:

HT is total head

HG is head due to the height of the outlet pipe above the ground (assuming that outlet pressure is negligible).

HS is static head due to the depth of the water level in the well, in absence of any pumping.

HD is dynamic "drawdown" head: in a borehole well, the effective water level is dynamically lowered by the water flow extraction in figure 3.1.

HF is friction losses in the piping circuit, which depend on the flow rate.

Deep well dewatering systems are used when large volumes of groundwater must be pumped, highly permeable soils result in rapid recharging of the aquifer, A deep well system consists of an array of bored wells, each fitted with a multi-stage electric submersible borehole pump. As water is pumped from each well, the groundwater is lowered creating a cone of depression or drawdown around itself. Deepwell dewatering is suited to deep excavations and where soil permeability is moderate to high. Deepwell systems also work well where artesian groundwater pressures threaten base stability.

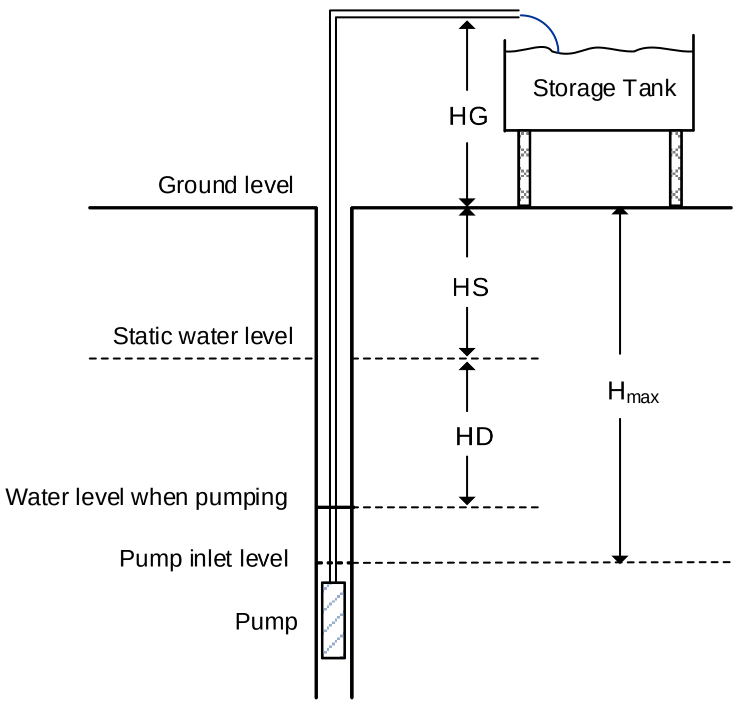


Figure 3.1: Schematic drawing of total dynamic head of a submersible pump

Total Dynamic Head, or TDH, is a very important factor in system design. TDH is the effective pressure the pump must operate against. TDH is expressed in FEET. TDH is the sum of 4 factors:

1. Pumping level: this is the level of the water in the well while pumping at the required flow. The standing water level water is also called the "static" (at rest) water level.The drawdown, measured in feet, is the difference between the static water level and the pumping level.

2. Vertical rise: It is the amount of rise between the pump discharge pipe and the point of use. It could be a small rise to the top of a holding tank or a large rise to the top of a hill.

3. Friction loss: It is measured in equivalent feet, is the pressure required to overcome friction in the pipes from the pump to the point of use. The friction is based on: rate of flow, the length, diameter, and type of pipe, and also the number and type of pipe fittings used. The higher the flow rate the more the Friction. In most cases, calculating friction loss can be simplified. If the system storage tank is located close to the well, 30 feet or less, and the recommended pipe size is used, a simple rule can be used. Friction loss, in equivalent head, can be estimated at 5% of the total vertical lift. This will allow for a few straight runs of pipe and a few fittings. In cases where the tank is located far from the well, more than 10 meters (30 feet), more accurate calculations must be used for friction loss. Friction loss is based on the size and length of the pipe, the number and type of fittings, and the flow rate. the friction loss by adding the length of all piping in the system to express the friction loss from fittings in equivalent length of pipe, the total of fitting losses to pipe losses.

Using the total equivalent length of pipe, and the flow rate, find the head loss in meters per meter of pipe, or feet per foot of pipe, the friction loss in meters or feet of head. When the system design is complete, the actual daily output of the chosen pump and array, recalculate the flow rate, and review the friction loss calculations. If necessary, recalculate the friction loss and the total dynamic head and double-check your pump and array choice.

4. Tank pressure: It is expressed in equivalent feet of head, is the operating pressure of the storage tank. Each pound of pressure (PSI) is equal to 2.31 feet. Tank pressure tank pressure is specified from other system needs. When a pressurized tank is used, convert the cutoff pressure to meters or feet of head. If the water is allowed to flow free into an open or vented tank, the tank pressure is zero, use a value of zero when calculating total dynamic head. To convert pressure to equivalent head, use the following formulas [31]:

Head (in feet) = Pressure (psi) x 2.31 Metric.

Head (in meters) = Pressure (kPa) x 0.102.

Storing water in a good sized cistern or stock tank has many advantages. It is less expensive and more efficient than storing energy in batteries, giving your system a flywheel effect over cloudy days and letting the pump work at a slower continuous pace over the day. As a rule of thumb, the tank should be able to store 3 or 5 days worth of water. Generally speaking, animals, plants and humans use less water on cloudy days. Conversely, the sunniest days are when we consume the most water and when the solar modules are providing the pump with the most power.

Total vertical lift to calculate total dynamic head it is best to make a sketch like

Solar pumping systems, unless connected to a battery, pump only when the sun is shining on the solar array. Cloudy weather will also affect the flow rate. The flow rate varies over the course of the day with the peak flow occurring at midday. Because our system design is not complete (a pump and array have not been selected yet), the total daily output can only be estimated. To estimate the flow rate,make a guess for the total daily output and use the following equations:

In US system: GPM (gallons per minute) = GPD (gallons per day) / 360

In Metric system: LPM (liters per minute) = LPD (liters per day) / 360

For example: Daily requirement = 4.067.5 liters per day and flow rate is found as 4.067.5 / 360 = 11 liters per minute

3.3 Pumping Borehole Modeling

A pumping test to charecterize the draw-down in boreholes is normally done by extracting water with portable engine-pump, and measuring the drop in level at a certain pumping rate after the water level has stabilized, then three data characterizes a borehole after the test: the static level (H_{ST}), the dynamic level (H_{DT}), and test flow rate (Q_T). For this system, in the "Pumping Hydraulic definitions" dialog requires to specify the static level depth with respect to the ground; this may be also given in seasonal or monthly values in the water needs, the borehole diameter (in cm), specific drawdown expressed in (m) and the maximum pumping depth in the tank, which corresponds to the inlet aspiration level. We consider the borehole as an impervious tube, when pumping the water level will drop as the flow rate Q [m3/h] divided by the whole section area Aw [m²] [21].

On the other hand, the re-filling of the well from the surrounding porous medium is a diffusive process. One can admit as a reasonable hypothesis that the refilling flow rate is proportional to the stress, i.e. the drawdown dynamic head. Under these hypotheses the real level in the well (or HD evolution) will obey the following equation:

$$\frac{dHD}{dt} = -\frac{1}{T}\ x\ HD + \frac{Q(t)}{Aw} \tag{3-2}$$

One can easily see that for steady-state conditions (dHD/ dt = 0), this equation leads to a drawdown height HD linear with the flow rate. Indeed, compared to a reference case. T is e recovery time. We have for any flow rate:

$$HD = Q \times \frac{HD_{ref}}{Q_{ref}} \tag{3-3}$$

Under this hypothesis, the ratio $\left(\frac{HD_{ref}}{Q_{ref}}\right)$ is a characteristics of the well, which we will call the "specific drawdown" expressed in [meter / (m3/h)]. This parameter is mainly related to the geologic properties of the surrounding ground (permeability, storage capacity), and the construction technique of the borehole. It may be measured rather easily, using a portable engine-pump and measuring the water depth and flow rate in stabilized conditions [21].

3.4 Borehole Parameter in PVsyst

As a matter of fact, a pumping test is often performed for measuring the borehole performance, which yields essentially 3 parameters: the static level (HStat), a reference flow rate available from the well Qref, and the corresponding dynamic level (HDref). Boreholes are normally pumped as a matter of a routine test, so that the information from the pump tests are commonly logged and stored in official records and can be later obtained by potential users. However it must be taken to into consideration that the excessive extraction rates on boreholes can damage the internal service below the water table and cause voids to be formed, which then lead to an eventual collapse of the bore. Then the maximum rate exists for each borehole. Information from the borehole pumping tests mentioned above is usually referred to as the maximum flow rate at which water can be extracted from it. In many African countries using borehole parameters in PVsyst as the bellow table 3.2 clearifying counteries using this parameters [21].

Table 3.2: Characteristics of some borehole in Africa [Navarte, 2000]

Country	Hstat [m]	HDred [m]	Qref [m^3/h]	HDred/Qref [m/m3/h]
AngolaRotunda	20	25	7.2	3.5
Chamaco	12	20	6.9	2.9
Lupale	20	24	5	4.8
Morocco Abdi	13	22	21.6	1
Ourika	17	2	10.8	0.2
Iferd	10	50	38	1.4

We can observe from these examples that the Dynamic contribution is not to be neglected. The recovery time τ (corresponding to a 1/e re-filling) is easily calculated from the steady state conditions:

$$\boldsymbol{\tau} = \mathbf{Aw} \times \frac{\mathbf{HD_{ref}}}{\mathbf{Q_{ref}}} \tag{3-4}$$

For example, in the case of a borehole of diameter 0.15 m in Rotunda, this is about 4 minutes. Therefore this dynamic model describes the short term behaviour of the well. Long term variations are likely due to modifications of the phreatic water level along the seasons. They may be introduced in PVsyst by specifying a monthly profile of the static head HStat. Long-term exhausting effects caused by an excessive water drain (climate change) involve complex (and not sustainable) phenomena which are not modelled here in PVsyst. Finally, the simulation (as well as the real system regulation) should take the maximum head Hmax, i.e. the inlet level of the pump, into account for stopping the pump, avoiding dry-running.

3.5 Pumping Piping Circuit

The pipes circuit produces friction head losses, which have to be kept at a reasonable value. The "Hydraulic Circuit Definition" dialog asks for the choice of a Pipe type (including diameter), and a total piping length. It allows inclusion of a number of elbows, as well as eventual other friction Loss factors for diverse hydraulic singularities, valves, etc. The overall friction head loss appears on the little graphical tool (below the green line), as a function of the flow rate. It should be kept negligible at nominal flow rates of the system, by choosing the appropriate pipe diameter [21]. The motor technology is not crucial in PVsyst. This specification will be mentioned in some result outputs. Brushless DC motors seem to have the higher efficiencies. The only relevant information used by the program is whether the motor is AC or DC.

3.6 Hydraulic Power and Energy

The mechanical power of a Hydraulic flow is basically the product of the fluid flowrate, by the head at which it is transferred. When using usual units in PVsyst:

$$\boldsymbol{P\ hydr}\ [\boldsymbol{W}] = \boldsymbol{FlowR}\ [\boldsymbol{m^3/h}] \times \boldsymbol{Head}[\boldsymbol{Bar}] \times \frac{\mathbf{1000}}{\mathbf{36}} \tag{3-5}$$

$$\boldsymbol{P\ hydr}\ [\boldsymbol{kW}] = \boldsymbol{FlowR}\ [\boldsymbol{m^3/h}] \times \boldsymbol{Head}[\boldsymbol{Bar}] \times \frac{\mathbf{1}}{\mathbf{36}} \tag{3-6}$$

In the same way, the energy is related to the total water volume transferred

$$\boldsymbol{E\ hydr}\ [\boldsymbol{kWh}] = \boldsymbol{Flow}\ [\boldsymbol{m^3/h}] \times \boldsymbol{Head}[\boldsymbol{Bar}] \times \frac{\mathbf{1}}{\mathbf{36}} \tag{3-7}$$

$$\boldsymbol{E\ hydr}\ [\boldsymbol{MJ}] = \boldsymbol{Flow}\ [\boldsymbol{m^3}] \times \boldsymbol{Head}[\boldsymbol{Bar}] \times \frac{\mathbf{1}}{\mathbf{10}} \tag{3-8}$$

In solar pumping systems, Head is usually expressed in units of Level difference [meter or feet]. The pressure at the basis results of the water column weight. Physically, passing to pressure units involves multiplying the height by the water density (1000 kg/m³) and the gravitation constant (g = 9.81 m/s²) [21], and for getting [bar] we have to divide by 100'000 [Pa/bar].

3.7 Pumping Hydraulic Losses

In the losses flow (as shown on the Loss diagram) of non-battery pumping systems, we have chosen to account for all electrical losses even when the pump is stopped for hydraulic reasons [21]. In this situation the ELowLev and ETkFull contributions are referred to the EPmpAv(Available useful energy at pump) energy. An alternative way would be to refer the hydraulic ELowLev and ETkFull losses to the EArrMPP energy, and to consider the system as "not running" during these situations. In this case the hydraulic arrow losses would come upstream of the other losses, with increased "virtual" energy hydraulic losses referred to EArrMPP.

The results are equivalent, the account of the effective hydraulic losses being transferred from the Array and Converter to the EArrMPP quantity. The results are equivalent, the account of the effective hydraulic losses being transferred from the Array and Converter to the EArrMPP quantity.

3.8 Friction Loss Factor

In hydraulic engineering practice, it is frequently necessary to estimate the head loss incurred by a fluid as it flows along a pipeline. For example, it may be desired to predict the rate of flow along a proposed pipe connecting two reservoirs at different levels. Or it may be necessary to calculate what additional head would be required to double the rate of flow along an existing pipeline. Loss of head is incurred by fluid mixing which occurs at fittings such as bends or valves, and by frictional resistance at the pipe wall. Where there are numerous fittings and the pipe is short, the major part of the head loss will be due to the local mixing near the fittings. For a long pipeline, on the other hand, skin friction at the pipe wall will predominate. Some examples of the Friction Loss Factor values, for piping circuits (may be added for several singularities), for piping circuits table 3.3 used the friction loss factor value 0.35.

Table 3.3: The Friction Loss Factor values, for piping circuits [21]

45° elbow, standard	0.35
90° elbow, standard	0.75
90° elbow, long radius	0.45
Tee, along run, branch inactive	0.4
Tee, used as elbow	1.5
Gate valve, open	0.17
Gate valve, ¾ open	0.9
Gate valve, ½ open	4.5
Gate valve, ¼ open	2.4
Diaphragm valve, open	2.3
Diaphragm valve, ¾ open	2.6
Diaphragm valve, ½ open	4.3

4. PHOVOLTAIC PUMPING TECHNOLOGY

The solar water-pumping technology has-proven record of reliability, require, minimal skilled manpower once in operation, and operation and maintenance cost is also very minimal and affordable. The photovoltaic pumps have many advantages including they operate on freely available sunlight and therefore incur no fuel or electrical costs. They are also environmentally friendly, reliable and have a long working life [1]. The advantage of using solar energy for pumping the water is that major quantities of water are required during day time and that too during time when the sun is on top of our head, and during these times the PV panels produce maximum energy and hence the water quantity. These solar pumps can be installed in locations which are not connected to national electric grid [2].

Photovoltaic water pumping systems (PVWPS) are conceptually divided into three parts:

1. The PV array, which converts solar radiation energy to DC electrical energy

2. The motor and pump subsystem in which the array electrical output is converter into mechanical and then hydraulic energy.

3. The hydraulic system, which delivers water to its point of use

Various degrees of sophistication may be incorporated into the system such as, a maximum power point tracker (MPPT) to maintain the highest power output from the PV array in varying conditions of insolation. An inverter has to be used in the case where DC motor is used to power the pump. One major difficulty facing the use of PV pumps is that the energy required for pumping a certain quantity of water is not available on demand and does not necessary coincide with the peak water demand. Solar irradiance varies continuously, which means that for some locations with successive cloudy periods it may be prudent to consider storage of surplus of water pumped on clear periods, for use on cloudy days.

Another way of tackling the problem of non availability of solar energy when mostly needed, is to incorporate a battery bank in the system to store electrical energy to be used when necessary enabling the system to start pumping any moment including at night. However, electrical energy storage has proved to be very demanding in maintenance time and costs. In addition, batteries can increase considerably the overall initial system cost. Although PV water pumping systems cannot yet compete with efficient conventional central generating plants such as diesel units, gas turbine generators units, the vast majority of PVWP installations to date have been for relatively low-power applications (less than 2 kW) in locations, which do not have complete access to a mains electricity grid. In such cases, PV has been selected because it offers a secure and reliable power supply, and is often the cheapest power option.

4.1 Main Solar Water System Components

Photovoltaic power systems are generally classified according to their functional and operational requirements, their component configurations, and how the equipment is connected to other power sources and electrical loads. The two principal classifications are grid-connected or utility-interactive systems and stand-alone systems. Photovoltaic systems can be designed to provide DC and/or AC power service, can operate interconnected with or independent of the utility grid, and can be connected with other energy sources and energy storage systems [2].

a. The Source: Water sources can be deep drilled wells, streams, springs, ponds, rivers, etc. The main variables, in addition to initial cost, that factor into system design are the recharge rate of the source and the volume of the source reservoir. Ideally, the source should recharge faster than pump can take water out of it. For example, if the pump will produce three gallons per minute, the source should be able to recharge at a rate that is equal to or greater than three gallons per minute. If the pump takes water away faster than the source can recharge, the reservoir can run dry, the pump will then be run dry, and that should be avoided to prevent damage to the pump.

b. The pump: This is the heart and soul of the solar water pumping system. Pumps fall along a spectrum of high-flow/low-head to low-flow/high-head. In other words, for a given power input, the pump produces a unique combination of flow and pressure. When selecting a pump you are selecting that combination of performance characteristics. Solar pumps are rated according to the voltage of electricity that should be supplied. A 12-volt pump is a small one, 24 volt is more the norm, while 48 volts and upwards will require more power and might pump more water. Smaller wire sizes can be used in higher voltage systems without sacrificing power output from panels to pump. Some pumps require certain accessories to function optimally. These include filters, float valves, switches, etc.

c. Photovoltaic (PV) panels: The photovoltaic panels make up most (up to 80%) of the systems cost. The size of the PV-system is directly dependent on the size of the pump, the amount of water that is required (m^3/d) and the solar irradiance available. A panel is rated in watts of power it can produce. The SPV water pumping system should be operated with a PV array capacity in the range of 200-Watts peak to 5000-Watts peak, measured under Standard Test Conditions (STC). Sufficient number of modules in series and parallel could be used to obtain the required PV array power output. The power output of individual PV modules used in the PV array, under STC, should be a minimum of 74 watts peak, with adequate provision for measurement tolerances. Use of PV modules with higher power output is preferred. Indigenously produced PV module(s) containing mono/ multi crystalline silicon solar cells.

d. Motor pump-set:

- Following types of motor pump sets could be used in the SPV water pumping systems.
- Surface mounted DC motor pump-set
- Submersible DC motor pump set
- Submersible AC motor pump set
- Floating DC motor pump set

Mounting structures and tracking system: To enhance the performance of SPV water pumping systems, it is desirable to use a tracking system. Manual, passive and auto tracking are permitted. The PV modules will be mounted on metallic structures of adequate strength and appropriate design, which can withstand load of modules and high wind velocities up to 150 km per hour. The support structure used in the pumping system will be hot dip galvanized iron (G.I). The G.I. structures for mounting the Solar panels could be so designed, that these can be manually/ auto adjusted for optimal tilt throughout the year [2].

Controller: The purpose of the controller is twofold. Firstly, it matches the output power that the pump receives with the input power available from the solar panels. Secondly, a controller usually provides a low voltage protection, whereby the system is switched off, if the voltage is too low or too high for the operating voltage range of the pump. This increases the lifetime of the pump thus reducing the need for maintenance.

Inverter: It changes the direct current from the solar panels into alternating current for the pump. The supported power range of inverters extends from 0.15 to 55 kW and can be used for larger irrigation systems. However, the panel and inverters must be sized accordingly to accommodate the inrush characteristic of an AC motor. The water distribution system: In many countries of the world, trenches are dug to gravity feed water through an intricate network of irrigated plots or holding tanks. Here farmers tend to use black polyethylene piping. Whatever the system is to get water from A to B, there important thing to consider is the smaller the diameter piping and the longer the piping run, the harder a pump has to work and the more pressure the pump must create.

4.2 Photovoltaic (PV) Panels

Photovoltaic technology is a modular non mechanical technology. A photovoltaic solar cell is used to produce electricity directly from sunlight. They are made up of a series of solar cells, as shown in Figure 4.1, below. Each solar cell has two or more specially prepared layers of semiconductor material that produce DC electricity when exposed to sunlight. A single, typical solar cell can generate approximately 3 watts of energy in full sunlight [30].

8.33 8.65MSG Gallium265 Watt Solar Panel Module 8.33 Solar mono crystalline PV modules with gallium enriched cells are our best performing modules yet; excellent up 16.14% efficiency and industry leading power output guarantees. 95% power output guarantee within 12 years and 90% within 25 years. Manufactured for maximum yield and robust long-life performance. Mono crystalline PV modules with gallium enriched cells are less susceptible to damage by solar radiation and decay slower over their lifetime. Combined with highly transmissive glass, the result is a highly efficient solar PV module that delivers higher power output than alternative standard mono crystalline PV modules. High quality standards: ISO 9001, IEC, CE, and MCS certification; Accredited by TUV SUD. Key Benefits Efficiency up to 16.14% Power tolerance: 0 ~ +3% 10 years product warranty 95% efficiency within 12 years 90% efficiency within 25 years Free module recycling via ceres.

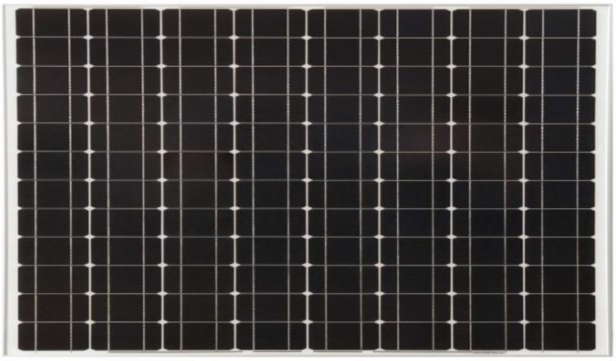


Figure 4.1: Solar cell, PV solar panel, and PV panel array

8.33 Solar Gallium 265 Watt Solar Panel Module power output and efficiency. The graph below shows the typical power produced (in Watts) for the 8.33 Solar Gallium 265 Watt Solar Panel Module at maximum available sunlight (irradiance). The 8.33 Solar Gallium 265 Watt Solar Panel Module has a maximum output of 265 watts. The graph below also shows the efficiency of 8.33 Solar Gallium 265 Watt Solar Panel Module. Efficiency is an important thing to look at when comparing solar panels, since it affects how much power can be captured from the sun. The 8.33 Solar Gallium 265 Watt Solar Panel Module has a module efficiency of 15.55% % as shown in following figure 4.2 [30].

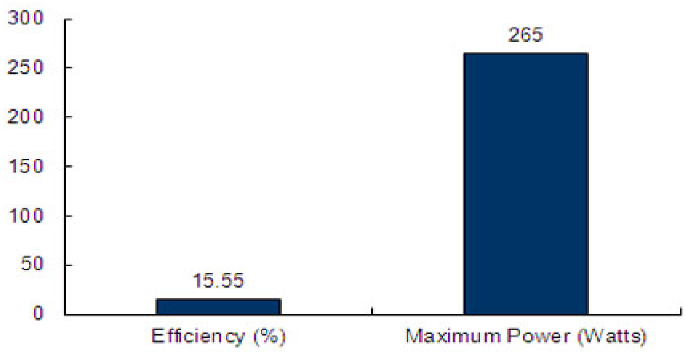


Figure 4.2: Solar Panel Module has a module efficiency

A measure of how much of the solar energy that hits the solar module is converted into electricity under Standard Test Conditions (STC)following table 4.1 and 4.2.

Table 4.1: Electrical Data Standard Test Condition

Factor	8.33 Solar 8.265MSGB (Afgoye)
Maximum power Pmax	265 Wp
Open circuit voltage Voc:	60.10 V
Short circuit current Isc	5.73 A
Maximum power point voltage Vmpp:	49.40 V
Maximum power point current Impp:	5.36 A
Module Efficiency	15.55 %

Note: Standard Test Conditions: Air mass 1.5; Irradiance = 1000W/m2; cell tempeture 25C as shown in following figure 4.3 [30].

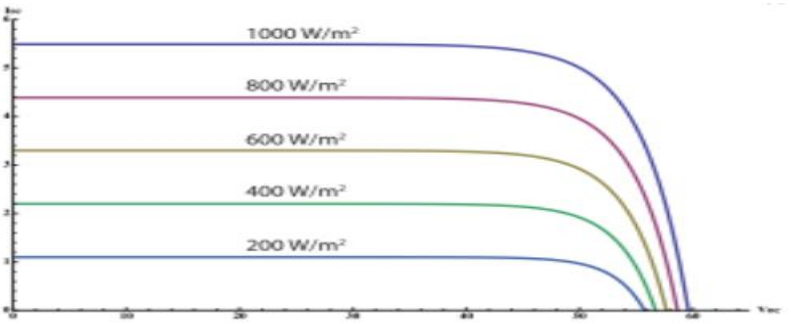


Figure 4.3: I-V standard characteristic 1000W/m2; cell temp. 25°C

Table 4.2: Electrical Data Standard Test Condition

Factor	**Tenesol TE130-36P**
Maximum power Pmax	130 Wp
Open circuit voltage Voc:	21.7 V
Short circuit current Isc	8.100 A
Maximum power point voltage Vmpp:	8.100 V
Maximum power point current Impp:	16.90A
Module Efficiency	15.55 %

NOCT tests realized with a maximum power (in Wp), junction temperature 45 °C; irradiation 800 W/m²; Am 1,5 ; Ambient temperature 20 °C as shown in following figure 4.4.

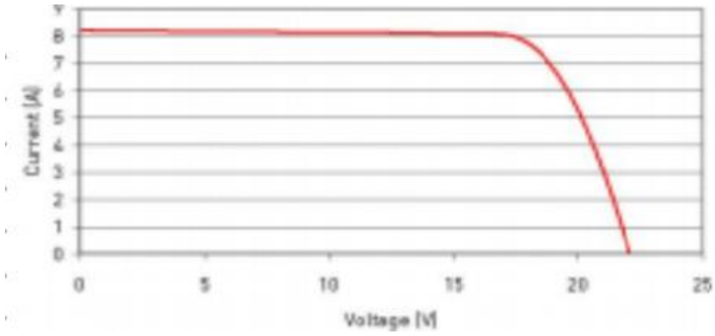


Figure 4.4: Typical I-V curve with irradiation 800 W/m²; at 25 °C.

Declination angle: It is the angular distance, north (or south) of the equator of the point, when the sun is at its zenith [28]. When the sun is directly overhead at any location during solar noon, the latitude of that location gives the declination. Declination is denoted by δ and d is the day number of which declination angle will be determined. The values of 'd' varies from 1 to 365.

$$\boldsymbol{\delta = \sin^{-1}\left[\sin(23.45) \times \sin\left\{\frac{360}{365}(d-81)\right\}\right]} \tag{4-1}$$

For January 1, d=1. And for any year and for the same date declination angle is same. So declination angle for January 1 is

$$\delta = -22.986°$$

Hour angle: It is the angular displacement of the sun east or west of the local meridian due to the rotation of earth on its axis at 15° per hour.

$$\text{Hour Angle (HRA)} = 15° \text{ (Local Solar Time} - 12) \tag{4-2}$$

So at noon HRA is 0.

Elevation angle: Maximum elevation angle an important parameter in the design of photovoltaic systems. It is the maximum height of the sun in the sky at a particular time of year. This maximum elevation angle occurs at solar noon and depends on the latitude and declination angle. It is denoted by α.

$$\boldsymbol{\alpha = \sin^{-1}(\sin\delta \times \sin\varphi + \cos\delta \times \cos\varphi)} \tag{4-3}$$

Here, δ is declination angle, and φ is latitude.

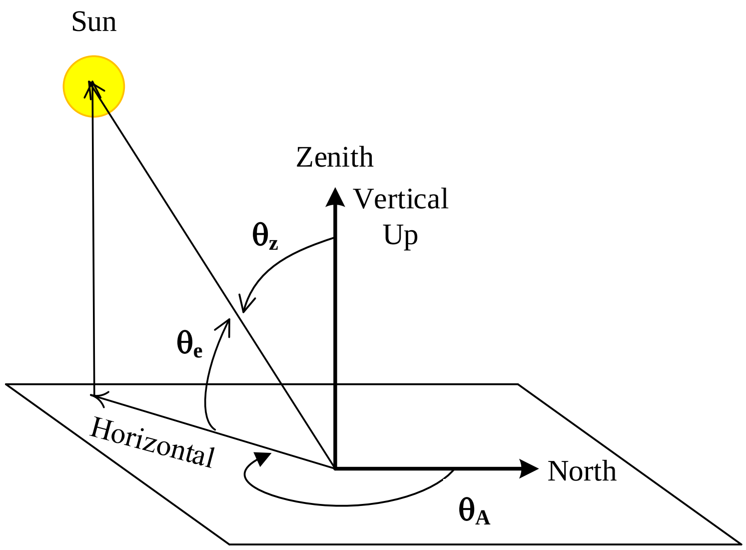
So for $\delta = -22.986°$ and $\varphi = 2.14\text{(Afgoye)}$, and 0.4(Kismayo)

the elevation angle is $\alpha = 64.874°$ (Afgoye), and $66.614°$ (Kismayo)

Azimuth angle: It is the angle on the horizontal plane measured clocwise direction from north to the horizontal projection of the sun's direct rays. East of south is taken as negative and west of south as positive.

$$\boldsymbol{Azimuth} = \mathbf{cos^{-1}}\left(\frac{\boldsymbol{sin}\boldsymbol{\delta}\times\mathbf{cos}\boldsymbol{\varphi}-\mathbf{cos}\boldsymbol{\delta}\times\mathbf{sin}\boldsymbol{\varphi}}{\boldsymbol{cos\alpha}}\right) \quad (4\text{-}4)$$

So putting the above calculated values of declination angle, latitude and elevation the azimuth of both areas are found 180° as shown in following figure 4.5



Elevation angle or θ_e, measured up from horizon

Zenith angle or θ_Z, measured up from vertical

Azimuth angle or θ_A, measured clockwise from North

Figure 4.5: Solar angles

Tilt Angle: Solar panels or PV arrays are most efficient, when they are perpendicular to the sun's rays. The tilt angle of the photovoltaic (PV) array is the key to an optimum energy. The tilt angle means the angle that solar panel gives most energy with horizontal plane. Efficiency is one of the most important factors that should be considered in overall performance. A good way to improve it is adjusting the tilt angle of the solar panel to maximize the power output and thus the amount of water pumped every day. The equator line passes through southern Somalia and Afgoye is located about 20 miles south of the equator in Somalia and has relatively dry and hot climate. The altitude is about 87 meters above sea level, which has relatively dry or hot climate mostly similar with the rest of southern regions in Somalia [28].

Afgoye geographically located at latitude (2.14 degrees) 2° North of the Equator and longitude (45.24 degrees). When the earth orbits the sun the relative tilt changes with an angle of about 0° between the extreme points, which occurs December 21st and June 21st. Afgoye location 2.14 ° north of the equator means that the solar angle will be 2° north of the perpendicular line to the horizontal plane at solar noon the 21st of March and 23rd of September. Since solar time and real time differs a bit noon at solar time for Afgoye is about 12.30. The sun's position in the sky throughout the year, the maximum amount of solar insolation on a surface at a particular tilt angle can be calculated as a function of latitude and day of the year. These calculations are also essential in using experimental data from sunshine hour recorders. The following animations calculate the daily solar irradiance, the solar insolation and the number of hours during the day which the sun is shining. They do not include local weather effects and so these theoretical graphs are not used in system sizing or prediction of operation. A description of each graph is given figure 4.6 in the caption underneath. The systems design. Lower efficiency signifies lower levels of water pumped therefore a reduction in [28].

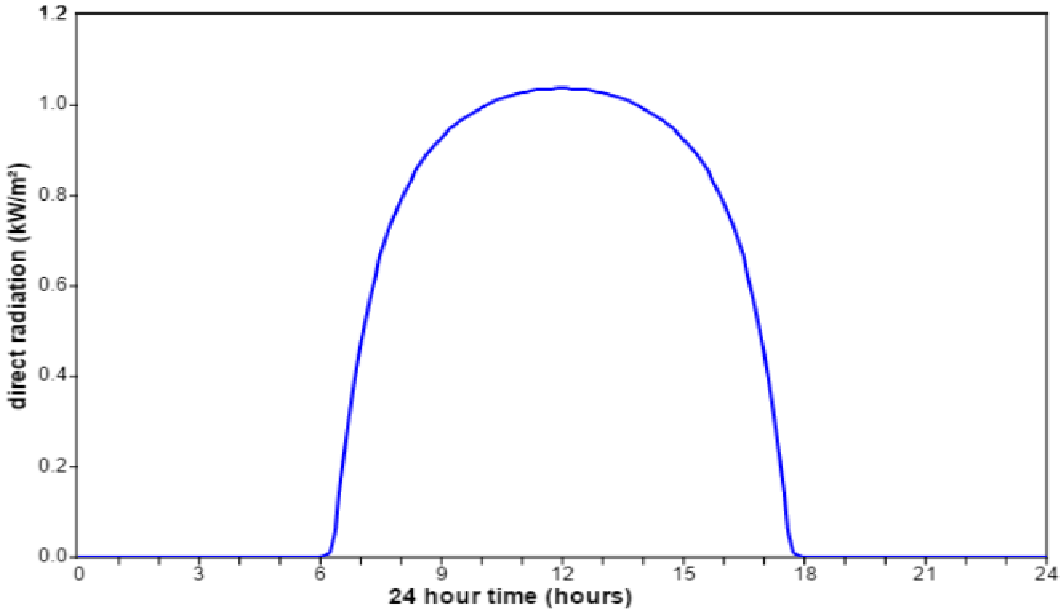


Figure 4.6: Direct radiation (KW/m^2) and 24 hours

The graph shows the intensity of direct radiation in W/m² through out the day. It is the amount of power that would be received by a tracking concentrator in the absence of cloud. The time is the local solar time. Set the latitude to your location

and then adjust the day slider to see how much radiation there is for each day of the year. Sunrise: 6:3 Sunset: 17:56, Latitude: 2° North and Day: 365 (Dec 31).

The average daily solar insolation as a function of latitude. The three curves are the incident solar insolation, the horizontal solar insolation and the solar insolation on a titled surface as defined. he daily insolation is numerically equal to the number of sun hours in a day. The module is assumed to face the equator so that it faces South in the northern hemisphere in North in the southern hemisphere. As the latitude is adjusted through zero going across the equator, the module faces in the opposite direction. the graph changes suddenly at the equator since the module is now facing in the opposite direction, Latitude: 2° north and array tilt: 0° [28]. The number of hours the sun is shining each day that is the number of hours between sunrise and sunset each day. In latitude is 2° the sun shines for 24 hours during part of the year. When averaged over the year, the sun shines an average of 12 hours per day. The equations to generate the above plots are given below. These equations are calculated in solar time, and not in local time. The correction between local solar time and local time is given the number of sun hours is simply the time between sunrises [28].

4.3 Solar Insolation and PV Panel Location

Appropriate data should be used to determine the amount of solar insolation (peak sun hours) available at the site. In order to maximize the solar-powered system's energy production, the panels should be south facing with no significant shading in their vicinity in order to achieve full sun exposure. However, partial shading (e.g., shadows from tall trees) in the distance during the early morning or late afternoon may be unavoidable. The effects of any shading present should be considered when determining the amount of available solar energy.

The site location plays a major part in the feasibility of a solar-powered pumping systems (SPPS). Peak sunlight hours (PSH) differ widely across the globe. The PSH is based on the number of equivalent daily hours that provide solar irradiance equal to 1 kW/m2. If a graphical plot of sun radiation versus hours of the day is created and the area under the curve is integrated and divided by 1,000 W/m2, the resulting value would be PSH. Also consider the potential effects that the slope and aspect of future shading due to continued tree growth may have. The solar array should be placed as close to the pump as possible to minimize the electric wire length (and thus any energy loss), as well as installation costs. An example of a proposed system layout is provided in Figure 4.7 below:

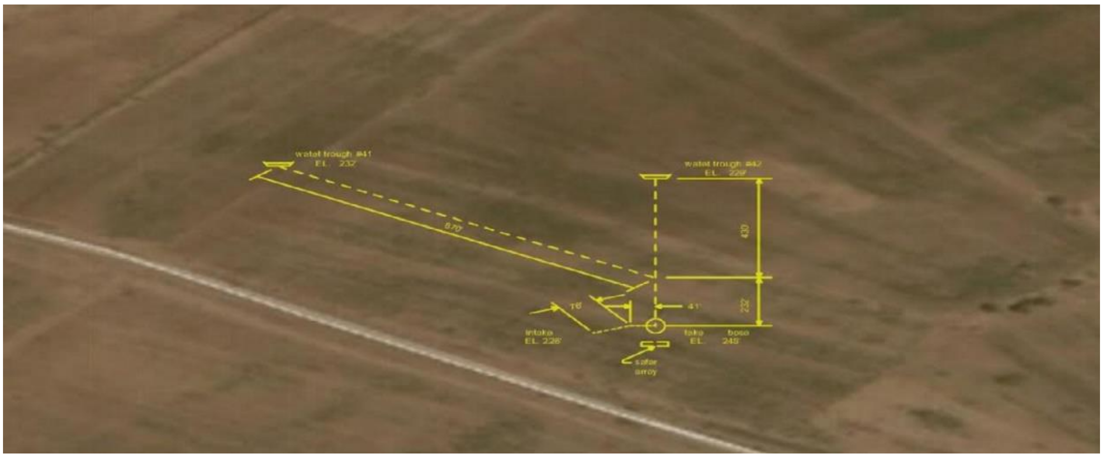
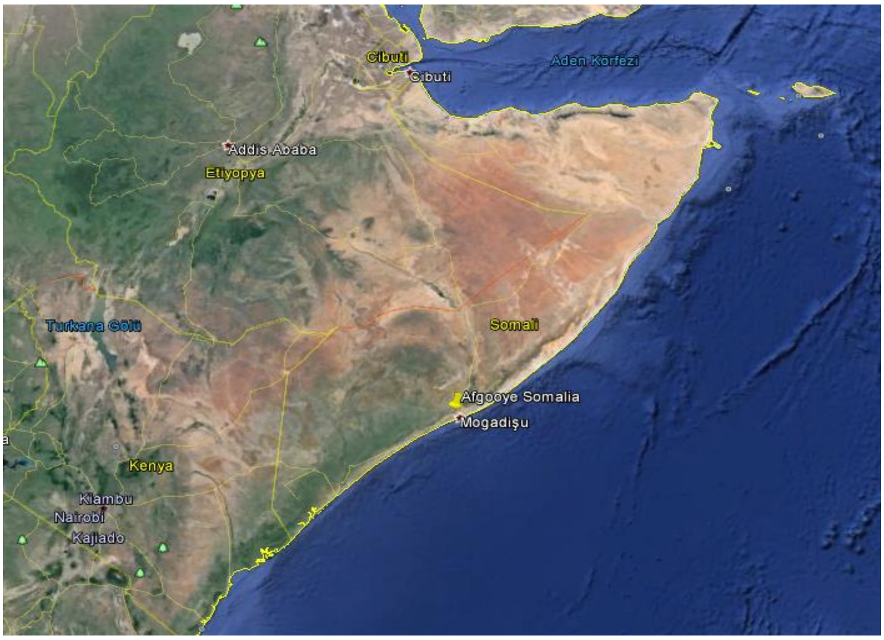


Figure 4.7: An example sketch of watering system with a storage tank and PV array

This design is specific solar watering system for Afgoa it has two way drinking tanks Therefore added more storage tanks distance apart in my calculation and design in order to minimize animal crowd and to seperade big and small animals not cause damage them selvies and to human.

A water storage tank is normally an essential element in an economically solar powered water pump system. A tank can be used to store enough water during peak energy production to meet water needs in the event of cloudy weather or maintenance issues with the power system. Ideally, the tank should be sized to store at least a three-day water supply. Multiple tanks may be required if a very large volume of water is to be stored.

Topography of Somalia is an integral part of Somalia Geography. Although the Topography of Somalia is marked by little variation, there are highlands, plains and plateaus in the landscape. Somalia experiences a semi-arid type of Climate. The temperature of all parts of the country remains almost hot in all through the year except for the highland areas. We chosed the is specific area called Afgoa, as it shows the bellow two fgures 4.8 (a,b) maps. The first is for the whole country's map and the second figure bellow is the is specific area of Afgoa's map. Solar water pumping system it's very import tha area because it is agricultural and livestoks area and the people who live there are in need of PV water pumping system.



(a)

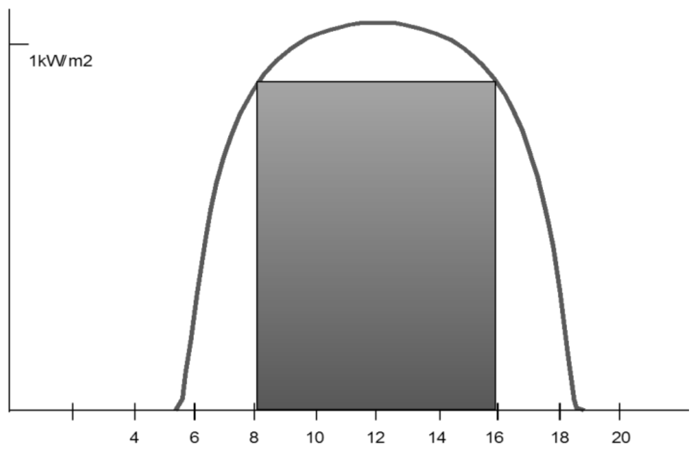
(b)

Figure 4.8: Somalia geographic location in Afgoa

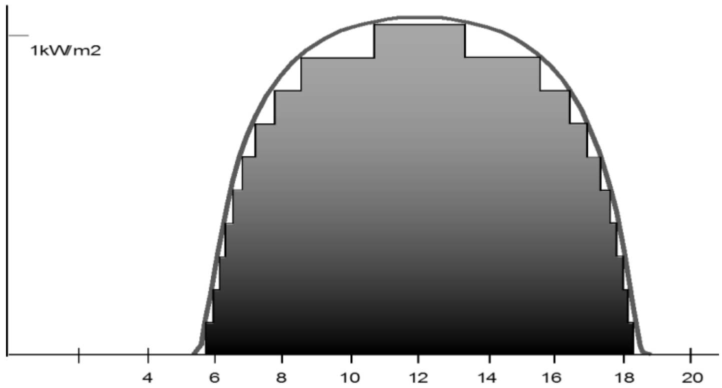
4.4 Conventional solar irrigation system

Solar PV modules produce direct current (DC) power. But alternating current (AC) motor-pumps are generally used for pumping purposes, therefore, an inverter is needed to convert power of solar panel from DC to AC. PV power output is non-linear and time-dependent that changes with change in solar irradiance throughout a day, as well as solar cell temperature [2]. The pump runs only when the available photovoltaic power is sufficient to drive the motor and compensate for inverter losses. If, for a low light condition, the PV power output falls short of the power requirement by the motor, the motor stalls. Since the optimal performance of a pump driven by a motor depends on the PV panel configuration [7], a 30 to 40 percent overcapacity of solar panels is generally maintained so that pumping can be continued during low insolation, even though it is by far the most expensive component in a PV pumping system. In such a system design, the excess solar power available at times can only be utilized by storing the energy in a battery and using the stored energy when there is lack of available solar power. Addition of batteries increase investment cost and adds to maintenance cost. Performance of a solar PV system is affected by availability of solar radiation [29].

The available solar radiation is a function time of the day and the site selected. Optimal performance of a solar PV system depends upon how well these two factors are considered while designing the system. The hourly variation of irradiance at a site is represented by a bell shaped curve as shown in Figure 1(a). In conventional solar irrigation system the pumps are selected according to the near-to-maximum sunshine availability. Therefore, under low sun shine condition, the pumps stand as over rated, hence, can not be operated. On the other hand, during high sun shine the extra solar power is unutilized. The proposed system overcome the problem by using multiple pumps with different capacities and by switching the pumps intelligently.



(a)



(b)

Figure 4.9: Solar energyy utilization of conventional and proposed pumping system (a) conventional, (b) proposed

Developed for the purpose. Based on the availability of sunshine the pump controller decides which set of pumps to operate. The availability of sunshine is measured indirectly by measuring the terminal voltage of the PV modules. The control algorithm requires that the combined pump-motor characteristics be known beforehand. The concept may be clarified more through an example. Considering a setup consisting of four pumps having rating of 1, 2, 4 hp. Depending on availability of solar power, e.g. in the early morning, only one pump with 1 hp motor may be operated. On the other hand at mid day when full sunshine may be available all pumps having a total of 7 hp can be operated. In the intermediate conditions, the number of pumps of varying capacity may be operated depending on the solar power available at a particular time so that the photovoltaic output of solar panel is utilized to the maximum. This results in the maximum possible water being pumped. But with the conventional system, the pump can be operated only a portion of the day and if one wants to increase the duration of use, one has to increase the panel size [29]. The solar energy utilization capability of the conventional and the proposed pumping system is shown qualitatively in Figure 1. For the proposed system, gain in pumped water output in a single day for the same amount of available solar power is estimated to be about 37.85%. For a cloudy day, the gain in pumped water output is expected to be much higher. In the proposed system almost all available solar power is utilized to pump the water. Consequently, the same amount of water pumped by the conventional system can be pumped by a smaller sized proposed system. The savings in solar panel is estimated to be about 50%. Since the increase in cost due to multiple pumps and pump controller in the proposed system will not be appreciable, overall cost savings will be very attractive. DC motors are used instead of ac motors as used in conventional solar irrigation system. Use of dc motors avoids system complexity by eliminating batteries and inverters. The motors are fed directly from the PV modules. The higher cost of dc motors over ac motors are more than compensated by the elimination of batteries and inverters. A microcontroller based switching circuit is used to switch the pumps on or off, with series parallel combination of solar panels. Solar Irradiance is a measure of how much solar power you are getting at your location. This irradiance varies throughout the year depending on the seasons. It also varies throughout the day, depending on the position of the sun in the sky, and the weather. Solar insolation is a measure of solar irradiance over of period of time - typically over the period of a single day. Irradiance, the power incident on a surface of a site is given by the following relation. The irradiance in Afgoye can be calculated using Eq. (4.5) and available data.

$$\textbf{Irradiance} = \frac{\textbf{Average Insolation}}{\textbf{Average daily brighy sunshine hours}} \ [\boldsymbol{W/m^2}] \qquad (4\text{-}5)$$

4.5 Climate data of Afgoye Somalia

Like the rest of Somalia, the climate in Afgoye city is hot and dry all year and the annual average temperature is between 26 and 28 degrees Celsius. The average temperature difference between the hottest months (from Decembe to March) and the coolest months (July and August) is only a few degrees, but it is somewhat greater in the inland areas than along the coast. In August, the temperature can drop to 16 degrees Celsius. The average maximum temperature per month is 35 degrees Celsius. The climate is primarily characterized by rainy seasons.

- Jiilaal, the long dry season, lasts from December to March. This is normally the hottest season.
- Gu, the long rainy season, lasts from April to June.
- Haggai, the short dry season, lasts from July to September. This is normally the coolest season.
- Dayr, the short rainy season, lasts from October to November.

  Monthly global solar insolation in Afgoye and monthly global solar insolation in Kismayo as shows following figures 4.10 and 4.11.

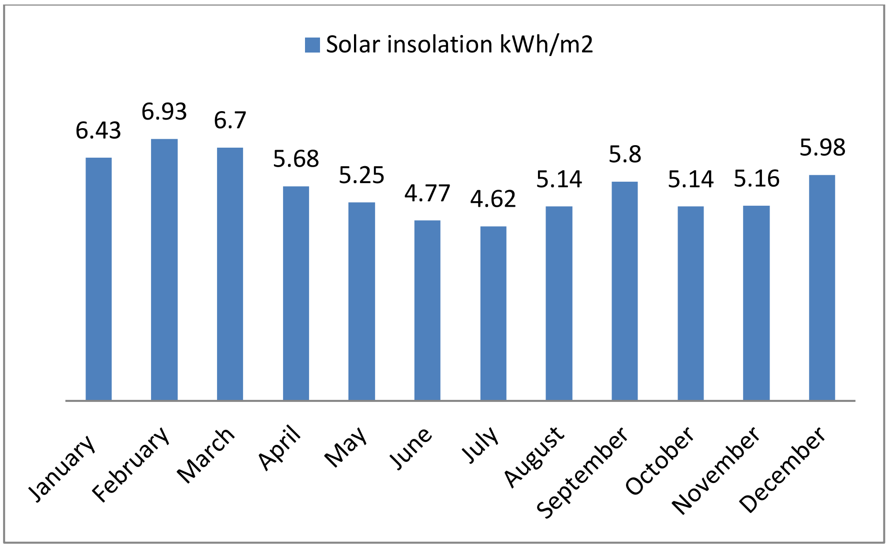


Figure 4.10: Monthly global solar insolation in Afgoye

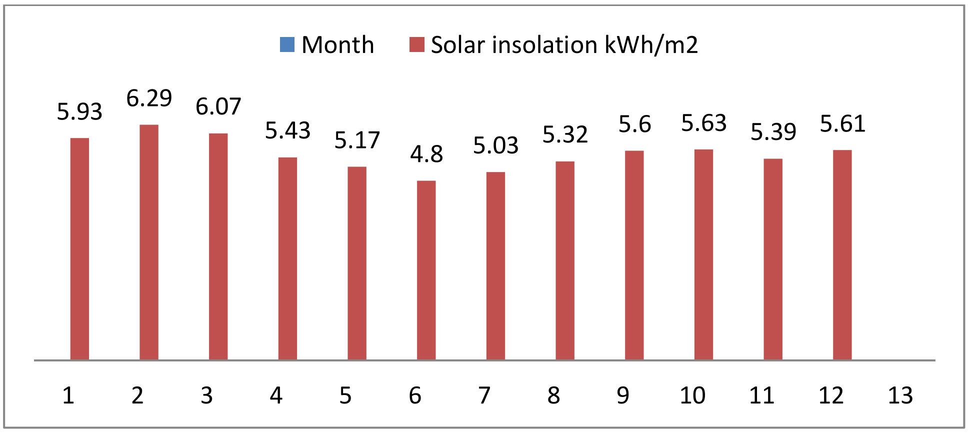


Figure 4.11: Monthly global solar insolation in Kismayo

Table 4.3: Daily average bright sunshine hours in Afgoye

Month	Daily mean, hr	Month	Daily mean, hr
January	8.7	July	5.1
February	9.1	August	5.8
March	8.8	September	6.0
April	8.9	October	7.6
May	8.2	November	8.6
June	4.9	December	8.9

The test system was set up on an agricultural field at the Hawa taako village in the Afgoye district. Pumps, the well and all control systems are housed in a room erected in the field. A special water delivery system is designed so that several pumps can be fed simultaneously from a single well. Each of the PV panels in the field is installed on a manually operated and easy to install three-axis movement stand. The panel stand is designed as a part of the project work installation and water discharge outlet. The test site selected is in Hawa taako, very near to the capital Afgoye. Afgoye is situated at 2.14^0 latitude and 45.21^0 longitudes. Daily average solar insolation in Afgoye aries between 5 to 6 kWh per square meter, the average being 5.24. Maximum amount of radiation is available on the month of March-April. Solar radiation energy received on a given surface area in a given time is defined as insolation and generally expressed in kilowatt-hours per square meter per day. The monthly global insolation and daily average bright sunshine hour in and around Afgoye are presented in Table 4.3 respectively [8]. Irradiance, the power incident on a surface of a site is given by the following relation.

4.6 Comparison solar global irradiation

This research, the feasibility of solar photovoltaic water pumping system was studied selecting one potential site from three administrative regions of Somalia. The regions selected are Afgoye and Kismayo regions. From the Afgoye region was selected (latitude 2.14º N, longitude 45.21º E and altitude 88 m a.s.l); from the Kismayo region was selected (latitude 0.4°N, longitude 42.6° E and altitude 7 m a.s.l). The solar radiation data for the three selected sites were collected from NASA-SSE satellite data [20] and then imported to PVsyst software database using its meteorological tool. Somalia enjoys bright sunshine throughout the year. The average daily solar energy received on a horizontal surface is about 5-7 kWh/m2. The daily average total solar radiation in parts of Somalia, calculated from the relative sunshine duration indicates one of the highest in the world. The solar energy distribution in Somalia is also almost uniform with modest gradients, not higher than 16% between zones with higher insolation and others with less insolation. This means that a Photovoltaic panel gives almost the same energy, disregarding the place or angle of installation. The average sunshine duration is estimated between 2900 – 3100 hours/year (8-8.5 hours / day). The temperature is not so high with yearly average of 27 °C that in turn adds to the operational life of solar PVs. All of these factors make Somalia as the most suitable place for wider application of solar technologies. The monthly average solar irradiation values on horizontal surface for the selected two sites.

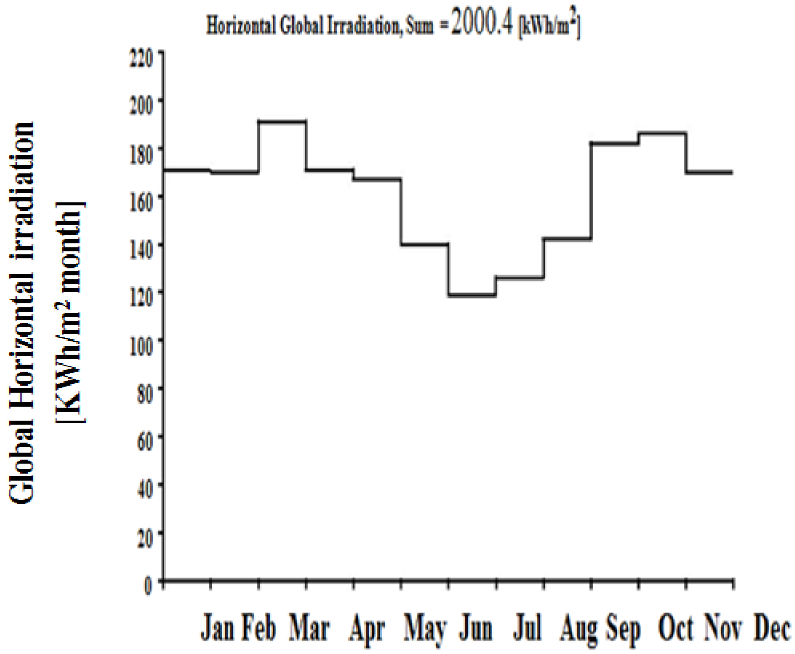


Figure 4.12: Year-long solar irradiation data for Afgoye.

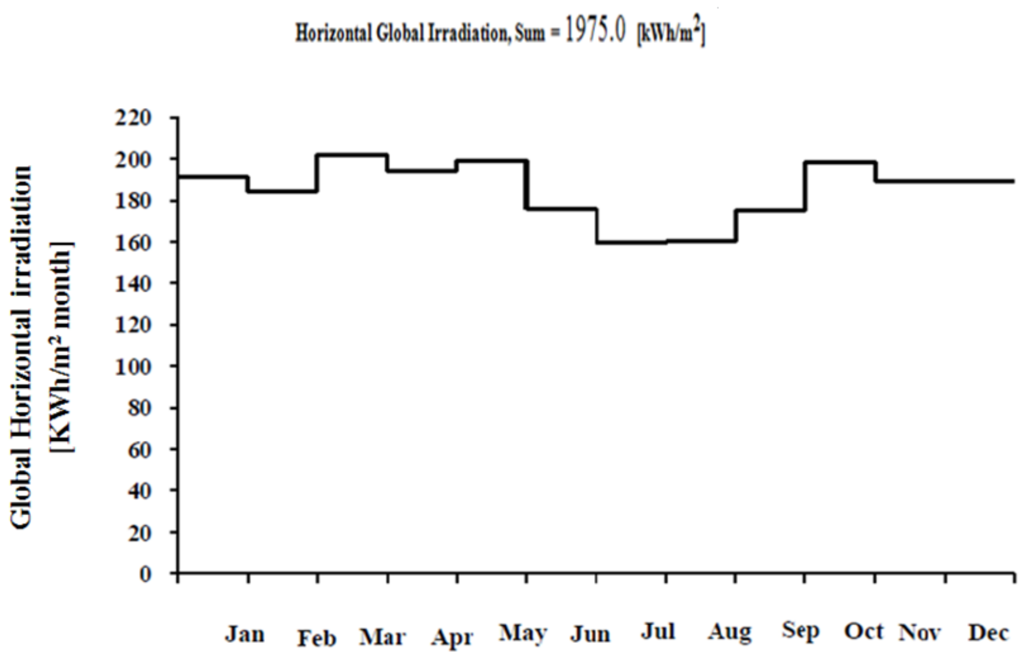


Figure 4.13: Year-long solar irradiation data for Kismayo.

Using the tabulated values above, there are several different ways toassess the number of peak sun hours to use when designing the system. For the purposes of this example, the average of all five months will be used since the values are relatively similar over the May through September period. This amount can be calculated as follows:INTRODUCTION**Error! Reference source not found.Error! Reference**

source not found.Error! Reference source not found. Pumps in parallel and in seriesRegulation Direct CouplingPumps in parallel and in series1 üst1 above

$$\frac{\mathbf{5.5+6+6.7+6.3+5.4}}{\mathbf{5}} = \mathbf{6}\ \boldsymbol{hour}$$

The decision of which approach to use to determine the peak sun hours to base the system design on is up to the discretion of the designer and should be based on good engineering judgment and solar paths at Afgoye as shows following figure 4.14.

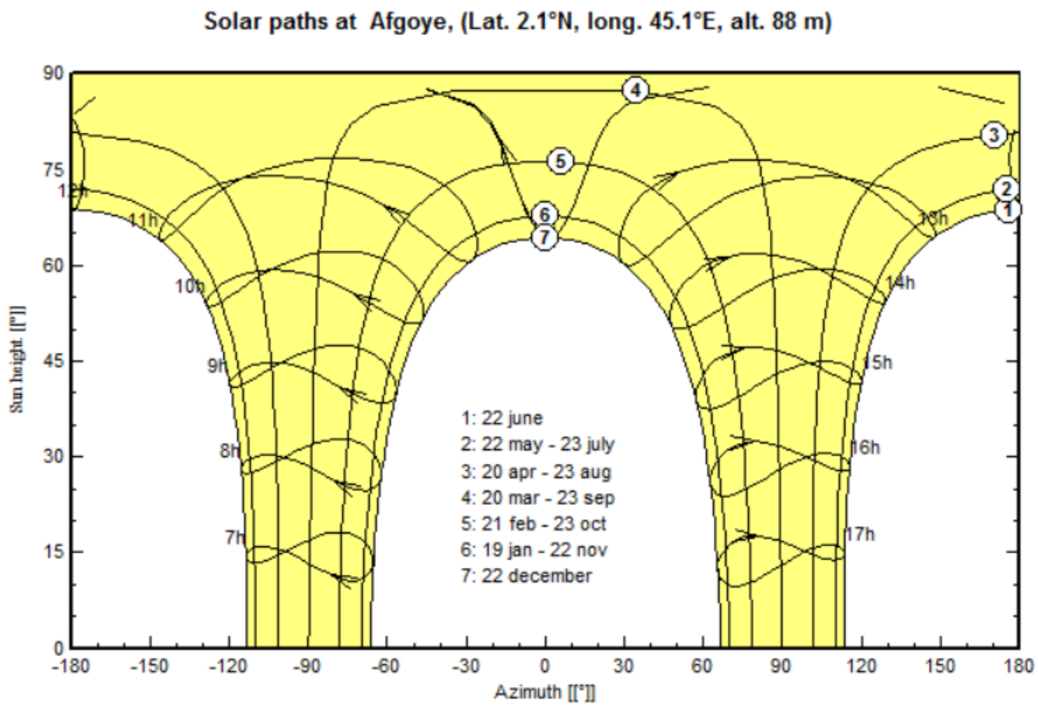


Figure 4.14: Solar paths at Afgoye

Somalia enjoys bright sunshine throughout the year. The average daily solar energy received on a horizontal surface is about 5.5-7.5 kWh/m2. The daily average total solar radiation in parts of Somalia, calculated from the relative sunshine duration indicates one of the highest in the world Some losses in the PV system are caused by an interaction between the environment, the inverter and modules, several types of losses are introduced the proposed method of analysis consists of a clear definition of these losses on basis of measured quantities. On the right hand side the various losses are mentioned, where the losses [in %] are presented against each previous measuring value.

In the following sections we describe the method in detail. Because there is a balancing item (mismatch losses) we start with calculating the system output, which are related to the inverter at the bottom of the Sankey diagram. Then we continue with the system input, i.e. irradiance measurements at the top of the diagram and the last item to be determined are the mismatch losses. To make a complete overview of the system behaviour we compare the measured values with the expected ones. This is done by a global characterisation of the various system components, using system loss factors. Inverter losses - E_{inv} the AC-energy from the inverter depends on the array power at the terminals of the inverter and the E_{inv} losses. These losses can be divided in: standby power; switching and ohmic losses in semiconductors. Resistance/ohmic losses - In small PV-systems the connection boxes are placed mostly near the inverter, otherwise they are grouped together nearby the PV modules. In addition to the cable resistance there are transition resistances in terminals, fuses and contactors/disconnecters. The instantaneous ohmic power losses can be rather accurately calculated by multiplying the cable resistance with the square of the 10 minute averaged DC-array current. The yearly energy copper losses are equal to the sum of all power losses during the year. Mostly the real array energy is not measured, because voltage sense leads are connected to the inverter input terminals. Temperature losses solar panel temperature is one of the important factors that affects how much electricity your panels will produce. It's ironic – but the more sunshine you get, the hotter the panels get and this in turns counteracts the benefit of the sun.

Depending on the solar and the type of mounting of the PV modules there is a temperature rise of the modules with respect to the ambient of 20 to 40°C at 1000 W/m². Low irradiance losses - The shape of the module efficiency as a function of the irradiance depends on the second diode model of the module (with two diodes, a effective series and shunt resistance). "Losses" related to the PV model: PV loss due to Irradiance level, low-light efficiency loss by respect to depends on the PV module parameters R_{series} and R_{shunt}.

5. MODELLING THE COMPLETE PUMPING SYSTEM

Any pumping system shows highly non-linear characteristics. We can mention the pump starting threshold, PV array pump electrical mismatch, converter efficiencies, well characteristics, operating limits, etc. This is why using "thumb rules", extensions of manufacturer partial data, or even the "Presizing Tool" described above, is not suitable for accurate performance evaluations or fine optimizations. Therefore a detailed study should involve a step-by-step hourly simulation over a realistic meteo period.

PVsyst offers the framework of such a simulation in hourly values, according to various meteo data and detailed modelling of components.

5.1 Pre-sizing tool: Early Quick Sizing and Evaluation

While a pumping system is a rather complex system, involving many variables and operating at very different conditions over the day and the year, component sizing is a rather difficult task. The customer usually specifies its water needs in volume, as well as the head (level difference) at which it should be pumped. He may also define a required autonomy duration and a time fraction during which he accepts that the water needs are not met by the system (empty tank). Starting from these requirements, and using rough, but quick yearly simulations, the program is able to determine the PV array, pump size and tank volume that are necessary to meet these water demand requirements. It also gives a very rough estimation of the costs [21].

This very simplified simulation runs over one year in daily values. It uses monthly meteo data as input, generates a random 365-days time series, and uses a well established meteo model to determine the irradiance on the PV plane. Then the pumping system's behaviour is calculated, on the basis of very general performance parameter (such as PV array efficiency, pump efficiency, coupling performances, etc) pre-defined for several pump, PV module technologies and regulation/coupling strategies. This simulation is repeated with different array and pump size arrangements, until matching the user's requirements. The results show the monthly yield of water (with respect to the specified needs), the missing water, and the excess PV energy (when the tank is full). Of course, this early layout proposition should be asserted by a detailed simulation, using real commercially available components, and taking all system features into account.

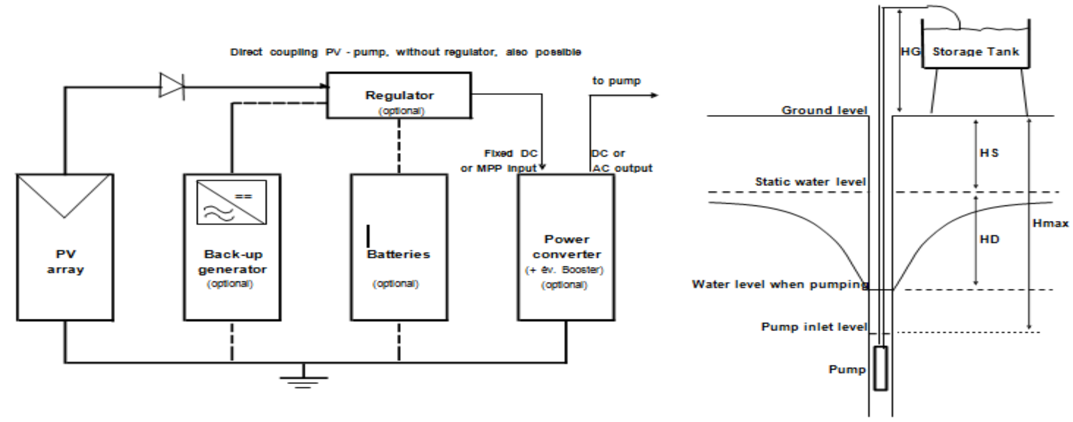


Figure 5.1: Global schematics of a pumping system with different conditioning/coupling options

As an example, figure 5.1 shows a typical layout of pumping system, with several regulating and coupling options. The parameter definition and the simulation process have to take the following aspects of the system into account:

• Definition of the user's water needs, which may be constant, in seasonal or monthly values,

• Characterization of the storage tank, if any,

• Dynamic behaviour of the well, with eventual drawdown limits,

• Photovoltaic energy yield (including meteo data, plane orientation, PV array characteristics, shadings, etc),

• Motor-pump device,

• Regulation and power converter strategy,

• Eventual battery storage or auxiliary back-up generator. In the present state, PVsyst treats 3 pumping system types, all with storage tank: deep well, pumping from a lake of river, and pressurization for water distribution. Moreover, there is a wide choice for the technology of these systems (power conditioning and transfer, regulation strategy). A main advantage of PVsyst is the ability of simulating several technological solutions for comparisons and optimisation [21].

5.2 Pumps in parallel and in series

Either on the electric side or on the hydraulic side, you are advised to **connect** all the pumps in parallel. At the moment PVsyst accepts electrical connections in series only for centrifugal pumps with DC motor. Other configurations don't make sense. The reasons are:

On the electric side, connecting two positive displacement pumps in series will prevent good starting conditions; after one pump has started, overcoming its peak starting current, the current will suddenly drop to the operating value; therefore the total current will be limited so that the second pump may never reach its own thresholds current.

On the hydraulic side, it is probably not a good practice to connect two pumps in cascade for obtaining a higher head in the same flow, as non-linearities in the pump behaviour, or electric feeding differences, may lead to very unbalanced heads. This is especially true for positive displacement pumps. It is far better to choose a pump model which undertakes the nominal foreseen head [21].

5.3 Regulation Direct Coupling

Direct coupling systems, owing to its simplicity. Many studies already reported the Array- Pump coupling and its unavoidable mismatch in the Current/Voltage characteristics [Roger, 1979]. Direct coupling is only possible with DC motor pumps. The simplified electrical layout is the following of DC pumps with the PV array is still widely used, especially in small pumping**.** Such a configuration implies in a very careful optimization. At any time, the operating point is the intersection of the two I/V characteristics: PV production and pump consumption. If the pump curve is too high (array current undersized), the pumping threshold will be high, penalizing the low irradiances (low season, bad days and morning/evening). If it is too low, the full potential power of the array is not used during bright hours. The optimal sizing is therefore depending either on the irradiance distribution (i.e. location, orientation, meteo), and on the periods at which the water needs are the more important. Due to high current (at low voltage) starting requirements, this type of systems is very inefficient by lower irradiances, using only a low fraction of the potential PV power. Use of PV tracking systems may slightly improve the situation. Moreover, the pump characteristic is strongly dependent on the head, displacing the I/V characteristics parallel to itself. Therefore, the sizing will also be dependent on the conditions of use, impeding using simple "thumb rules" valid for any system at any place, and often proposed by manufacturers. Absolute maximum ratings have to be respected: the pump should not be fed with dangerous voltages or over-powers whatever the irradiance conditions. This prevents over-sized PV-array, unless overload protections are implemented in the control device. At the system definition stage (choice of pump and PV array), PVsyst offers a contextual graph visualizing the effective behaviour of the system with the chosen [20].

5.4 Direct couple solar pumping system

In this study direct coupling method is used for the system power configuration. In direct-coupled pumping systems, electricity from the PV modules is sent directly to the pump, which in turn pumps water through a pipe to where it is needed. This system is designed to pump water only during the day. The amount of water pumped is totally dependent on the amount of sunlight hitting the PV panels and the type of pump. Because the intensity of the sun and the angle at which it strikes the PV panel changes throughout the day, the amount of water pumped by this system has also changed throughout the day [20]. Direct-coupled pumping systems are sized to store extra water on sunny days so it is available on cloudy days and at night. Water can be stored in a larger-than-needed watering tank or in a separate storage tank and then gravity-fed to smaller watering tanks. Water-storage capacity is important in this pumping system. Two to five days' storage may be required, depending on climate and pattern of water usage as shows following figure 5.2 [20].

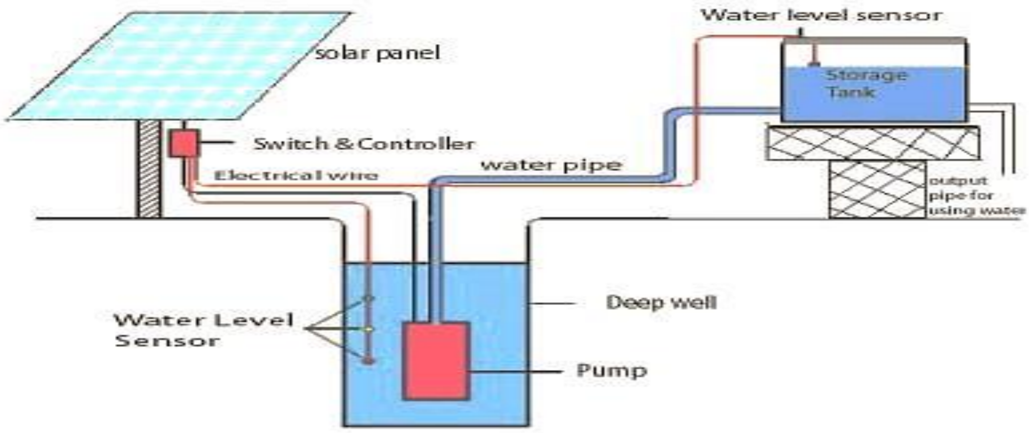


Figure 5.2: Schematic of a typical direct-coupled DC PV water pumping system

The various types of current configurations of direct coupled DC and AC solar water pumping systems being used worldwide are shown below figures 5.3, 5.4 and 55.

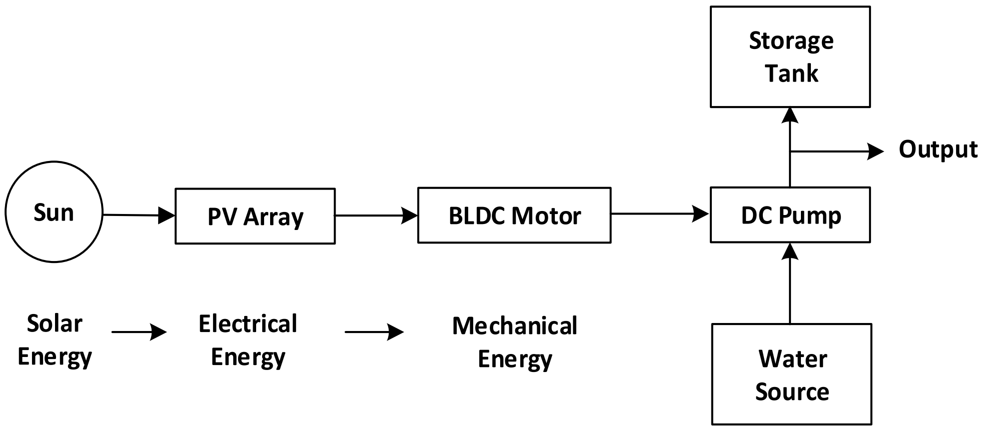


Figure 5.3: Block diagram of a direct coupled PV DC water pumping system

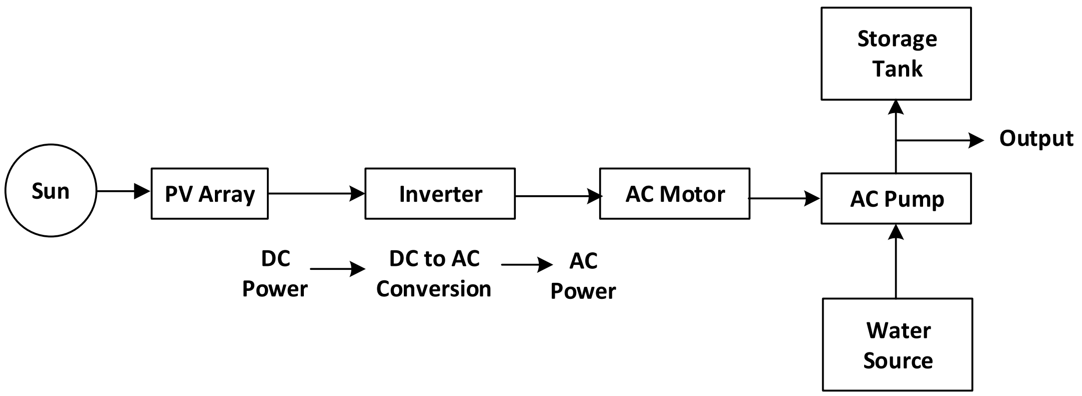


Figure 5.4: Block diagram of a PV AC water pumping system

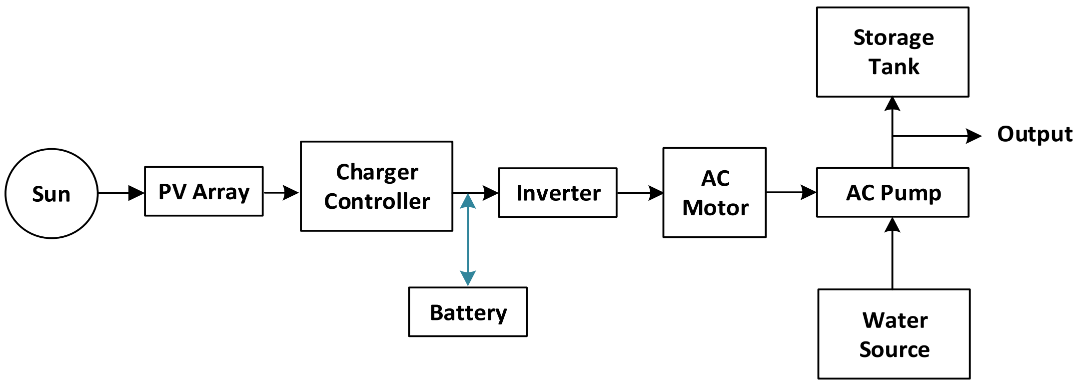
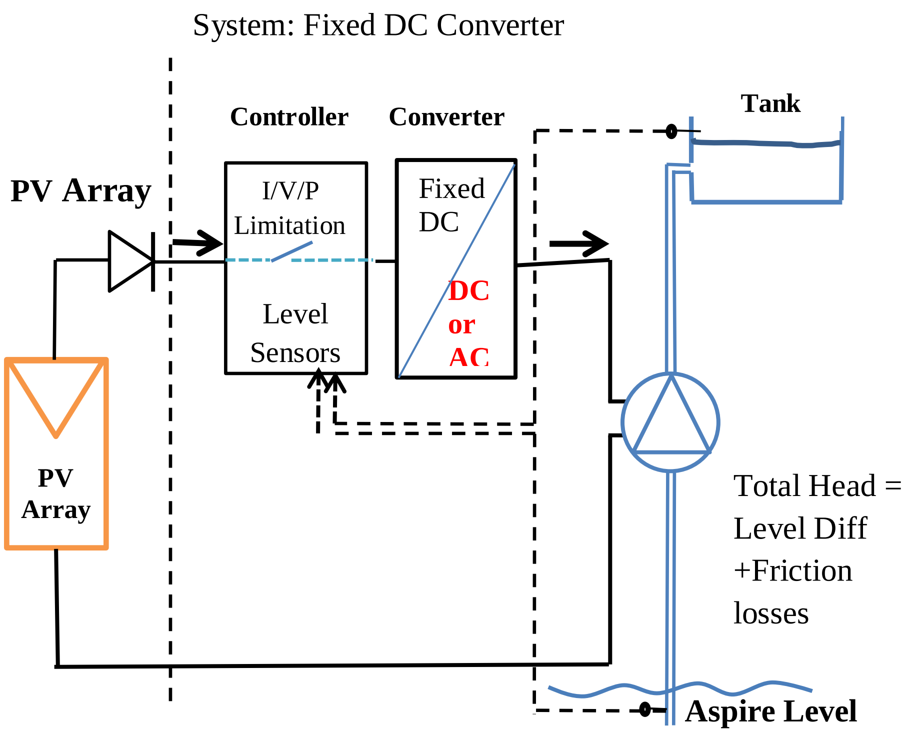


Figure 5.5: Block diagram of a PV water pumping system with battery storage

5.5 Power converter (MPPT or Fixed DC input)

Use of a DC-DC converter power conditioning unit (PCU) shows a much favorable figure than direct coupling. This (now cheap) electronic device absorbs the power of the PV array at an optimal voltage, and behaves as a current generator for feeding the dc motor of the pump. Most pump manufacturers propose now converters with



maximum power point tracking (MPPT) capabilities, adjusting continuously the input voltage at the optimum of the array system its fixed DC converter figure 5.6.

Figure 5.6: DC-DC power converter

But this is not quite necessary. A simpler (and cheaper) device with fixed voltage DC- input may show very good performances if the voltage is well adjusted. As in real conditions the MPP voltage is indeed very stable (it increases slightly with irradiance, but this increase is compensated by the module temperature effect), the fixed voltage can be chosen near this value. On most commercial DC-DC devices, the input voltage may be adjusted by hardware. PVsyst includes a specific tool for determining the optimal fixed DC voltage setting at a given site, performing a quick simulation over thr whole year, and threfore all siruation. This shows that the voltage optimum value is not very critical. The yearly performance is an important comperison for the PV systems. PVSyst 6 sofware has produced the yearly performance corve for a DC fixed operation given in the figure 5.7.

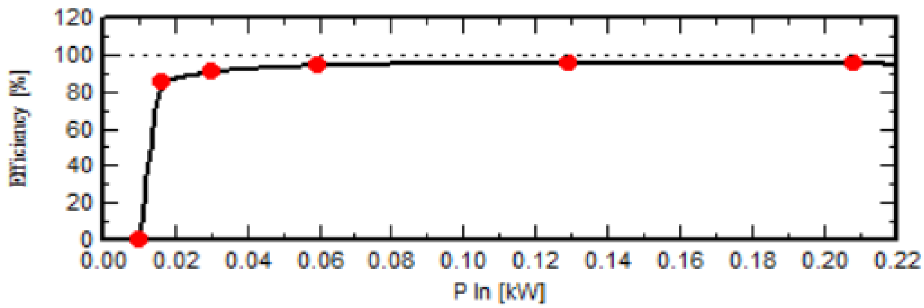


Figure 5.7: DC fixed operation yearly performance

When the converter definition is included in the pump's model, the electrical input definition of this converter motor pump aggregate is only based on the power. The only information on the input voltage/current behaviour is the MPPT or fixed VDC input parameters (minimum and maximum voltage of the tracking range, absolute maximum voltage). At the output side, the power is supposed to be transmitted to the motor at the optimal current/voltage point corresponding to the available power. For AC motor pumps, a Power Conditioning Unit (DC or MPPT inverter) suited for a given pump is usually proposed by the pump's manufacturer. It is supposed to fit the pump's requirements (voltage and frequency) for proper operation. With Power Conditioning Units, the overall performances of the pumping system are only related to the PV array power and meteo conditions. They don't depend anymore on the detailed pump electrical characteristics. The system sizing and the robustness of the design - is therefore much better.

5.6 Efficiency

Nowadays, the converter efficiency is usually of the order of 95% or more in the high power region. It drops toward low powers as other similar devices like inverters. It is treated as such in PVsyst an efficiency profile is constructed using the maximum and "euro" efficiency data, defined in a similar way as for inverters.

By the way, efficiency drop often arises at powers which are below the hydraulic threshold of the pump; therefore it doesn't affect much the normal running. Of course the DC-DC converter also plays the role of a "Booster". The starting high current is usually required under very low voltage, therefore low power. This is automatically provided by the converter.

5.7 Step-down technology

We have to point out here a special design constraint: most of the DC-DC converters operate on "step-down" principle. This means that they cannot deliver a voltage greater than the input voltage. Therefore the PV-array MPP voltage should be over the maximum voltage required by the pump at the maximum desired flowrate. This "step-down" limitation can be taken into account by the simulation only when the voltage behaviour of the pump is well defined. With pumps specified only by power curves, it is neglected [13].

5.7.1 DC – AC inverter

Pumps driven by an AC motor require of course a power converter (inverter) in any case. Manufacturers of AC pumps especially designed for solar use usually propose their own suitable inverter. In these cases, they don't specify the intermediate values (voltage, current, frequency) between the output of the converter and the input of the pump: the simulation process should consider the set converter-motor-pump as a whole [13].

5.7.2 DC – Dc Converters

The heart of MPPT hardware is a switch-mode DC-to-DC converter that converts a DC input voltage into a DC output voltage of lower or higher amplitude. In addition, DC to DC converters are used to provide noise isolation, power bus regulation…etc [13]. There are a number of different topologies for DC-DC converters. The most important are: boost converter (step-up converter), buck converter (step-down converter), buck- boost converter.

5.8 The step up converter (Boost converter)

Figure 5.8 shows the basic boost converter. This circuit is used when a higher output voltage than the input is required. It is made up of an inductor that is followed by a power switch, a diode and output capacitance. The circuit operation can be divided into two modes mode begins when switch SW (chopper) is closed for time t_1 (t_{on}), the inductor current rises and energy is stored in the inductor L. When the switch is opened for time t_2 (t_{off}), the energy stored in the inductor is transferred to the load through the diode D1 and the inductor current falls. As shows following figure 5.8

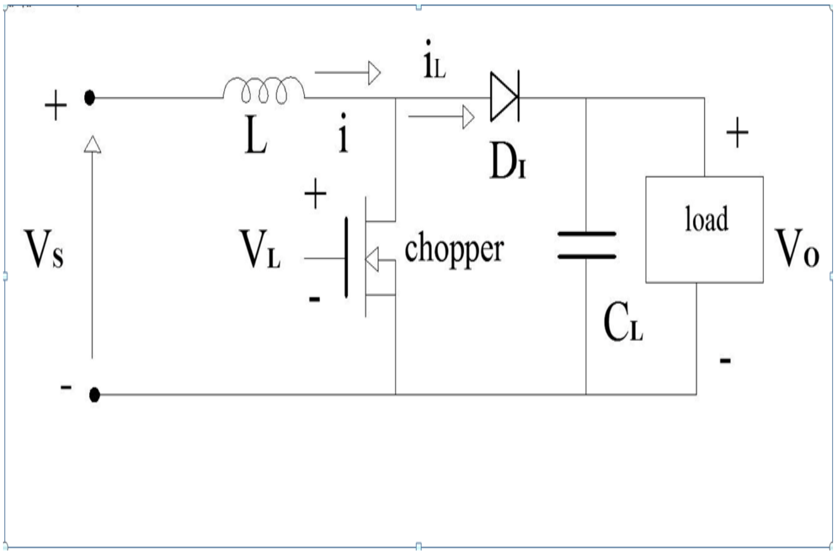


Figure 5.8: Shows the basic boost converter

When the converter is turned on, the voltage across the inductoris:

$$\mathbf{v_L = L\,\frac{di}{dt}} \tag{5-1}$$

$$\Delta\mathbf{I} = \frac{\mathbf{V_s}}{\mathbf{L}}\mathbf{t_1} \tag{5-2}$$

$$\boldsymbol{V_0 = V_s + L\,\frac{\Delta y}{t} = V_s\left(1 + \frac{t_1}{t_2}\right) = V_s\,\frac{1}{1-D_c}} \tag{5-3}$$

$$\boldsymbol{D_c = \frac{t_1}{T} = t_1 \times f} \tag{5-4}$$

$$\boldsymbol{V_0 = \frac{1}{T}\int_0^{t_1} v\,dt = \frac{t_1}{T}V_s = f t_1 V_s = D V_s} \tag{5-5}$$

$$\boldsymbol{\frac{V_0}{V_s} = D_c \quad , \quad V_0 = V_s \times D_c} \tag{5-6}$$

$$\mathbf{\frac{V_0}{V_s} = -\,\frac{D_c}{1-D_c} = -\,\frac{t_{on}}{t_{off}}} \tag{5-7}$$

Where:

T is the chopping period, F is the chopping frequency, and D_c is the duty cycle.

Because the large capacitor C_L is connected across the load, the output voltage is greatly switched and Vo becomes the average value Va. We can notice from equation (5-8) that the voltage across the load can be stepped up by varying the duty cycle D_c and the minimum output voltage is V_S when $D_c = 0$, however, the converter cannot be switched on continuously such that $D_c = 1$, for value of D_c tending to unity, the output voltage becomes very large and very sensitive to changes in D_c as shown in figure 5.9 There is a maximum duty cycle which has to be calculated for the protection of the system, Vo/Vs can not increase indefinitely. The maximum duty cycle is related to load characterististics [26].

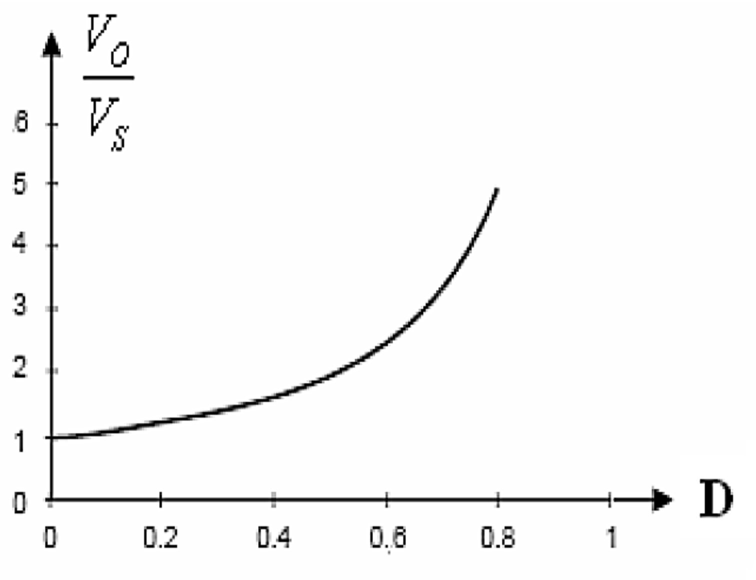


Figure 5.9: Output voltage dependency on duty cycle D for the boost converter

6. SIMULATIOM AND RESULTS

PVsyst software is able to import meteo data from many different sources as well as personnel data. The software consists of three main design steps [21]. The preliminary design option allows evaluating grid-connected, stand-alone and pumping systems, and using monthly values to perform a quick evaluation of system yield. For each project the location and the system to be used has to be specified. The program includes predefined values of locations of different parts of the world. The second one is project design option allows to create full-featured study and analysis of grid connected, stand-alone, pumping, and DC grid systems with accurately system yields computed using detailed hourly simulation data. Different simulation variants, horizon shadings, detailed losses, and real components can be added to make economic evaluations. Reports can be generated after the completion of the project and information can be exported to the clipboard. The last option includes meteorological data, components, solar toolboxes, and the analysis of actual data. Afgoye and Kismayo geographical comparison between two sites data as shows table 6.1.

Table 6.1: Geographical comparison between two sites

Factors	**Afgoye**	**Kismayo**
Latitude	2.1°N	0.4°S
Longitude	45.1°E	42.5°E
Altitude	88 m	7 m
Azimuth	0°	0°
Tilt	0°	0°

Figure 6.1 shows the functions of flow rate with respect to pump power. Since all graphs for all sites have similar behavior, the graphs of the Afgoye and Kismayo has been presented here.

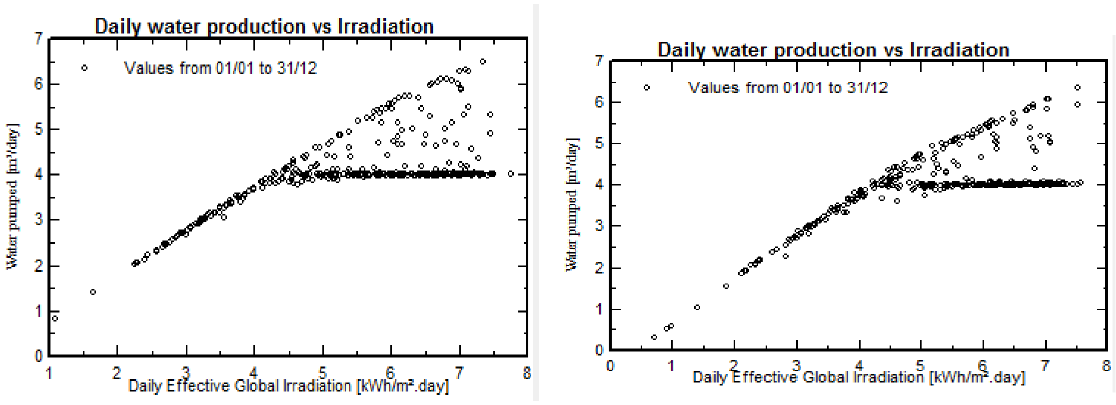


Figure 6.1: Daily water production vs Irradiation of Afgoye and Kismayo

Daily water pumped vs Irradiation shows a linear region. Because more irradiation increases the pump power and it will increase the water flow rate. And this follows a linear relationship. So water pumped is proportional to irradiation.

6.1 Project Sizing

We've designed both the systems considering the water needs. The daily water needs are 4000 L with 4 days of anatomy. The pump selected foctors table 6.2.

Pump: The pump selected is a Brushless DC motor pump. The pump was selected considering factors mainly water flow rate per hour, maximum head. The two motors selected for two sites. Watermax WD for Afgoye region and Lorentz PS20-HR-04 – MPPT for Kismayo region. Watermax WD is a submercible type motor and PS20-HR-04 – MPPT is Helical Rotor type. Submercible pumps pushes fluid to the surface on the other hand Helical rotor transfers fluid by means of the progress, through the pump, of a sequence of small, fixed shape, discrete cavities.

Table 6.2: The pump selected foctors

Factors	Watermax WD (Afgoye)	Lorentz PS20-HR-04 –MPPT (Kismayo)
Head	10-40 m	1-60 m
NominalVoltage	36 V	48 V
Voltage Range	10-40 V	24-60 V
Maximum Power	230 W	250 W
Maximum Current	6 A	5.5 A
Efficiency	41.3 %	39.3 %

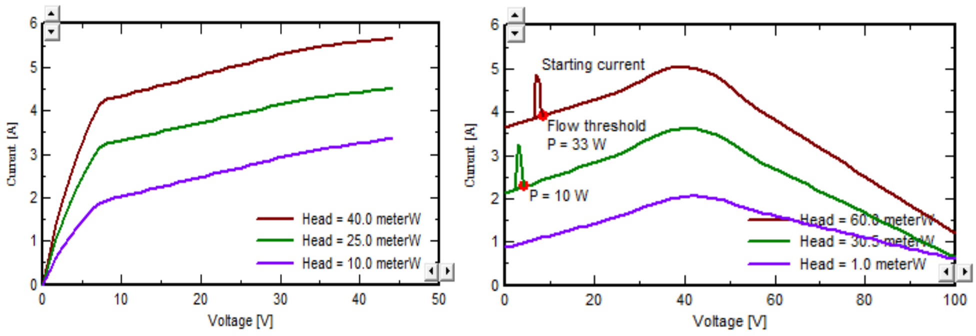


Figure 6.2: I-V Characteristic of Pump at different head level

6.2 Photovoltaic Array

Then comes the selection of solar PV panel. To meet the motor power requirements PV arrays are designed in terms of power and voltage. The panels are designed in a way that it can handle the large starting current. In Afgoye region the total number of panel is one . The required voltage and power is met by one panel. In Kismayo region to meet the output voltage two panels are connected in series and no panels are in parallel. So the total number of panels are two as shows table 6.3

Table 6.3: Comparison of PV panels

Facto	8.33 Solar 8.265MSGB (Afgoye)	Tenesol TE13036P (Kismayo)
Technology	Si-Mono	Si-Mono
Watt peak (W_p)	265.0	130
Open circuit Voltage (V)	60.10	21.70
Short circuit Current (A)	5.730	8.100
Voltage at Maximum Power (V)	49.40	16.90
Current at Maximum Power(A)	5.360	7.700

Nominal Voltage, Current & Power: Nominal voltage of MPPT charge controller is the output voltage of MPPT charge controller. The term nominal refers that it has a low fluctuation of voltage and current. So change in input voltage or current will not affect output voltage or current. As the output of MPPT is connected to motor or pump. And pumps and motors can’t work efficiently on fluctuating power, and it will harm motor or pumps longevity and nominal power is the product of nominal voltage and nominal current, as shows following figures I-V curve of PV Panel (a, b)

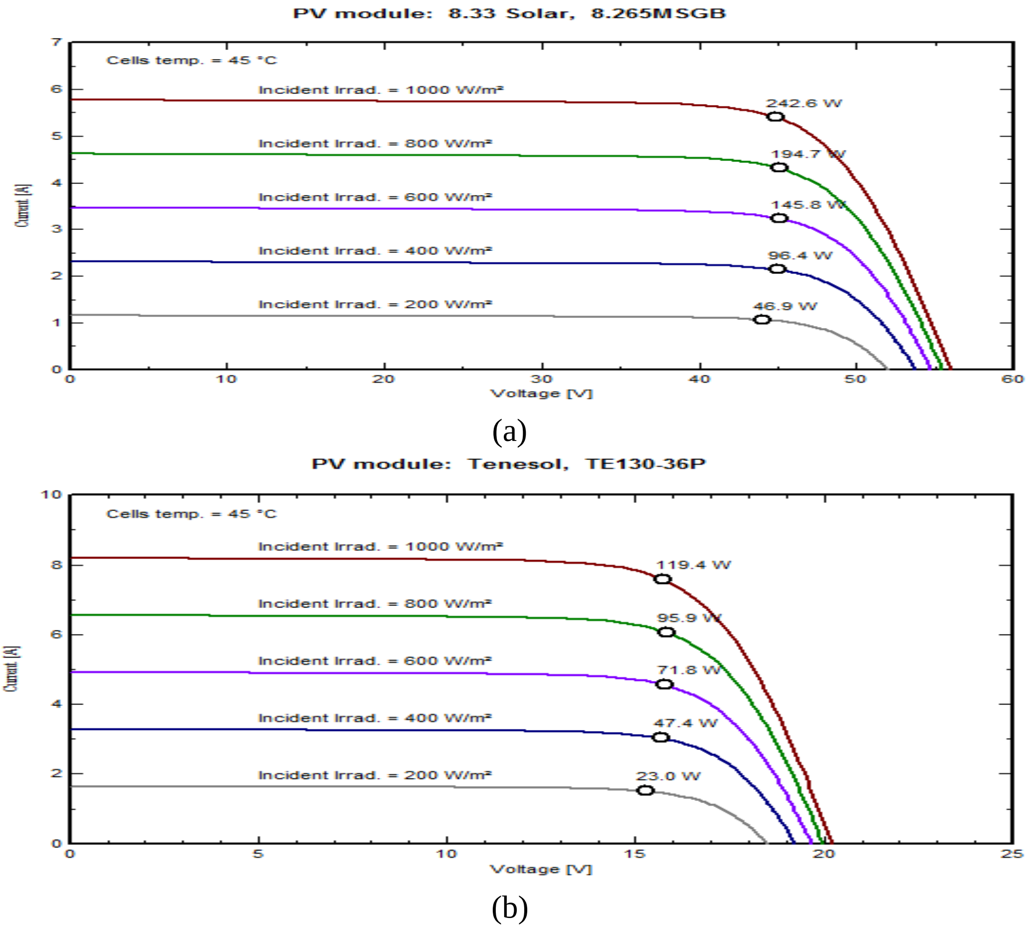
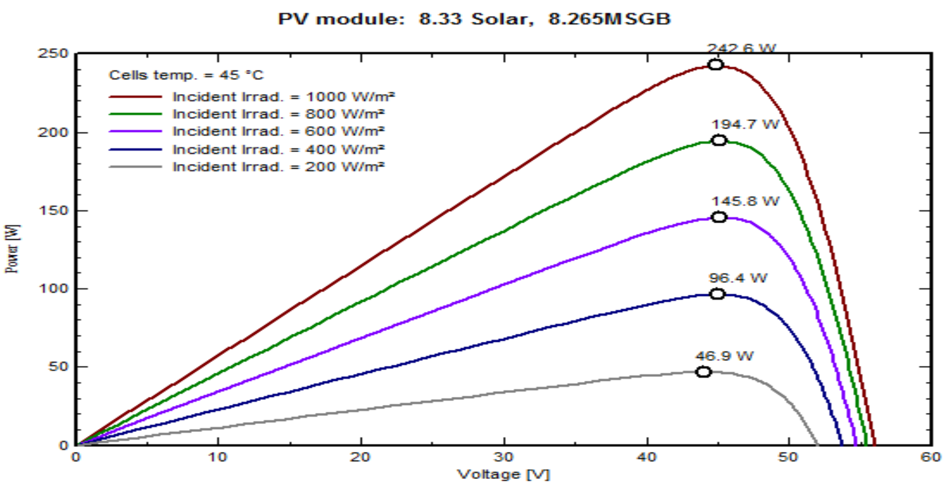
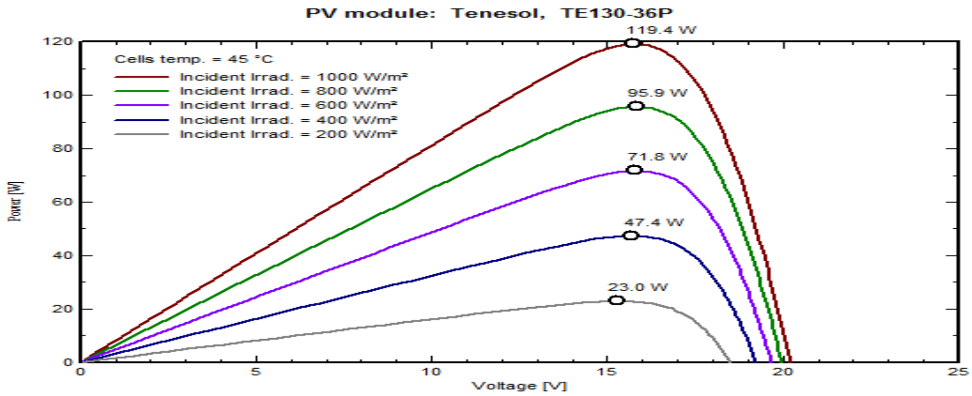


Figure 6.3: I-V Curve of PV Panel (a, b)

The I-V curve shows the voltage current relationship of solar PV module. As the output depends on solar radiation incident. So change in solar radiation bring changes in output voltage and power. The I-V curve shows current and voltage levels of different solar radiation level as show figure6.4 P-V Curve of PV Panel (a, b)



(b)



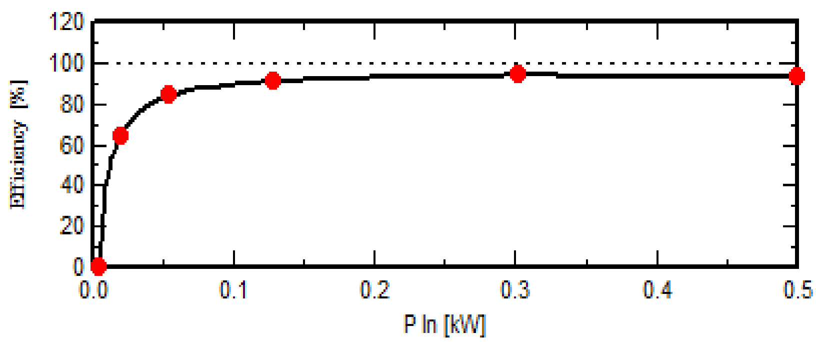
(b)

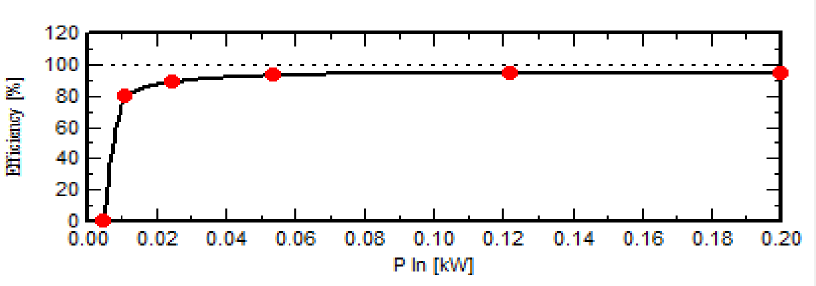
Figure 6.4: P-V Curve of PV Panel (a, b)

The P-V curve shows the power and voltage relationship of a PV module. In P-V graph voltage and corresponding power of different radiation are given. This helps to know the maximum power output in different radiation levels.

6.3 MPPT - DC converter

MPPT refers to maximum power point tracking. It tracks the maximum power point of PV panel and keeps the output almost same as solar irradiation changes. It is the most efficient technology so far. Solar radiation changes frequently. This changes the output of solar PV panels. This frequent change is not suitable for motors. That’s why to regulate it, a DC converter is needed. It keeps the output of PV panel regulated. As BLDC motor has a high starting current the controller is sized to handle the high current. Usually starting current is 2-3 times of nominal current. But this current stays for a short time. The figure below shows the efficiency of MPP-DC converter in terms of power. As we see the Solarjack PCB-90’s efficiency is reduced slightly if maximum power is drawn but Lotentz PS 200’s efficiency remains saturated as shows figure 6.5.





(b). Lotentz PS 200

Figure 6.5: MPPT-DC converter Efficiency-Power Curve (a,b)

Table 6.4: Comparison table of flow rate

Watermax AD(Afgoye)			Lorentz_PS200_HR_04_MPPT (Kismayo)		
Power (W)	Flow rate (l/sec)	Head (meterW)	Power (W)	Flow rate (l/sec)	Head (meterW)
130	0.2611	10	62	0.0292	60
161.6	0.2528	20	101	0.0678	60
192	0.2444	30	143	0.1069	60
223.2	0.2375	40	188	0.1489	60
			235	0.1800	60

Table 6.5: Simulated Main results of Afgoye

	GlobEff kWh/ m²	EArrMPP kWh	EPmpOp kWh	ETkFull kWh	HPump meterW	WPumped m³	WUsed m³	W Miss m³
January	182.9	40.89	29.33	7.71	33.71	130.9	124.0	0
February	180.4	39.91	25.11	11.22	33.78	112.0	112.0	0
March	197.4	43.61	27.81	11.79	33.74	124.0	124.0	0
April	167.2	37.56	26.88	7.00	33.61	120.0	120.0	0
May	163.3	37.15	27.72	5.71	33.57	123.8	124.0	0
June	147.2	33.95	26.87	3.53	33.52	120.2	120.0	0
July	149.9	34.61	27.77	3.22	33.54	124.1	124.0	0
August	162.2	37.31	27.76	5.80	33.56	124.0	124.0	0
September	168.7	38.11	26.91	7.48	33.61	120.0	120.0	0
October	161.9	36.84	27.77	5.41	33.59	124.0	124.0	0
November	154.0	35.13	26.89	4.76	33.59	120.0	120.0	0
December	165.3	37.42	27.78	5.97	33.62	124.0	124.0	0
Year	2000.4	452.50	328.60	79.59	33.62	1466.8	1460.0	0

Table 6.6: Simulated Main results of Kismayo

	GlobEff kWh/m²	EArrMP kWh	EPmpOp kWh	ETkFull kWh	H Pump meterW	WPumped m³	W Used m³	W Miss m³
January	180.7	39.17	30.80	6.802	33.72	130.9	124.0	0
February	173.3	37.30	26.35	9.358	33.72	112.0	112.0	0
March	185.8	40.03	28.84	9.493	33.70	122.5	124.0	0
April	157.2	34.23	27.91	4.718	33.61	118.7	120.0	0
May	157.2	34.63	29.63	3.491	33.61	126.4	124.0	0
June	140.8	31.37	27.48	2.608	33.55	117.0	120.0	0
July	152.9	34.06	29.88	2.892	33.61	127.4	124.0	0
August	161.9	35.89	28.83	5.626	33.63	123.1	124.0	0
September	165.0	36.15	28.17	6.219	33.67	119.7	120.0	0
October	171.3	37.48	29.39	6.304	33.65	125.1	124.0	0
November	158.4	34..92	27.86	5.508	33.62	118.8	120.0	0
December	170.6	37.21	29.43	6.082	33.68	125.3	124.0	0
Yearly	1975.0	432.43	344.57	69.102	33.64	1466.9	1460.0	0

GlobEff: Effective global

H Pump: Average total head at pump

EArrmpp: Array virtual energy at MPP

WPump: Water pumped

E PmpOP: Pump operating energy

W Used: Water drawn by the user

ETkfull: Unused energy (tank full)

W Miss: Missing water

Table 6.5 depicts the balance and main results of PV based water pumping system. Yearly Global Effective irradiation is 2000.4 kWh/m^2. The Yearly Array virtual energy at MPP is 452.50 kWh. Total Energy used by pump throughout the year is 328.60 kWh. Yearly Average total head at pump is 33.62 meter. Yearly water used by the user is 1460.0m^3.

Table 6.6 depicts the balance and main results of PV based water pumping system. Yearly Global Effective irradiation is 1975.0 kWh/m^2. The Yearly Array virtual energy at MPP is 432.43kWh. Total Energy used by pump throughout the year is 344.57kWh. Yearly Average total head at pump is 33.64meter. Yearly water used by the user is 1460.0 m^3

Results: From the simulation result it is seen that both of the systems are sized in a way that no water shortage in any month will occur. The less solar radiation available is in the month of June. But in June no water shortage will occur due to shortage of power. For this reason the amount of unused energy in June is lesser than other months. In Afgoye region the total system loss is more than Kismayo region. The lesser system losses the better the performance of the total system. As the performance ratio is the factor of effective energy at pump (Y_f) by total irradiant energy (Y_r). So the performance ratio is increased in the month of June. Total system losses can be given by the following equation.

$$T_{Loss} = L_u + L_c + L_s$$

Total system loss in Kismayo:

$$T_{Loss} = 0.94 + 0.84 + 0.17 = 1.95\ kWh$$

Total system loss in Afgoye:

$$T_{Loss} = 1.1 + 0.77 + 0.38 = 2.16\ kWh$$

Here, L_u is depicted unused energy (meand the losses caused by unused energ), L_c is the collection losses, and L_s is the system losses.

The graphs below shows the detailed results as shows figures 6.6 and 6.7.

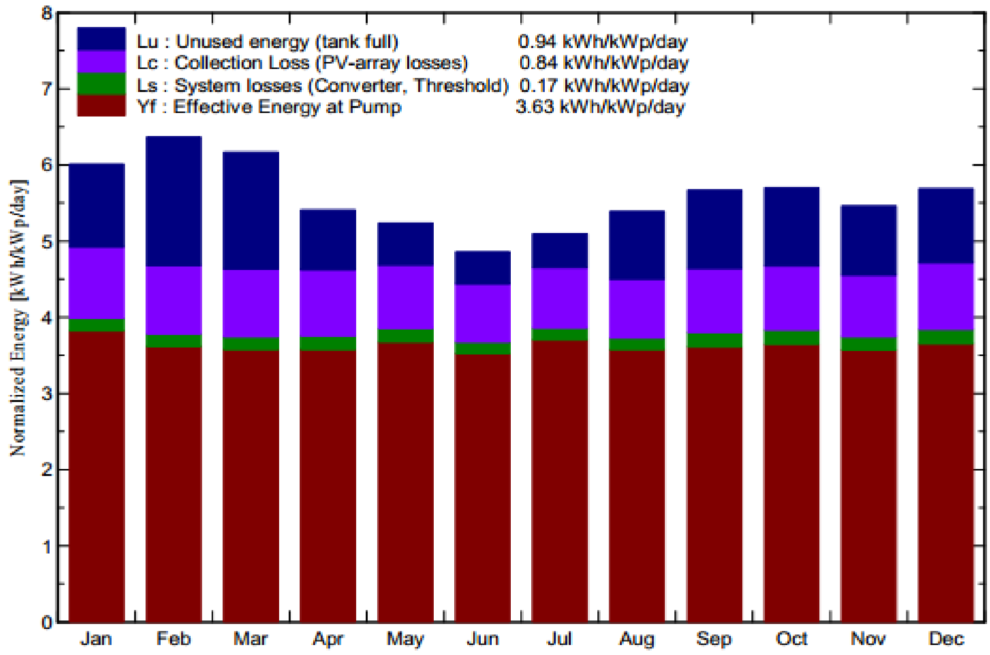


Figure 6.6: Energy balance of the SPV system Kismayo

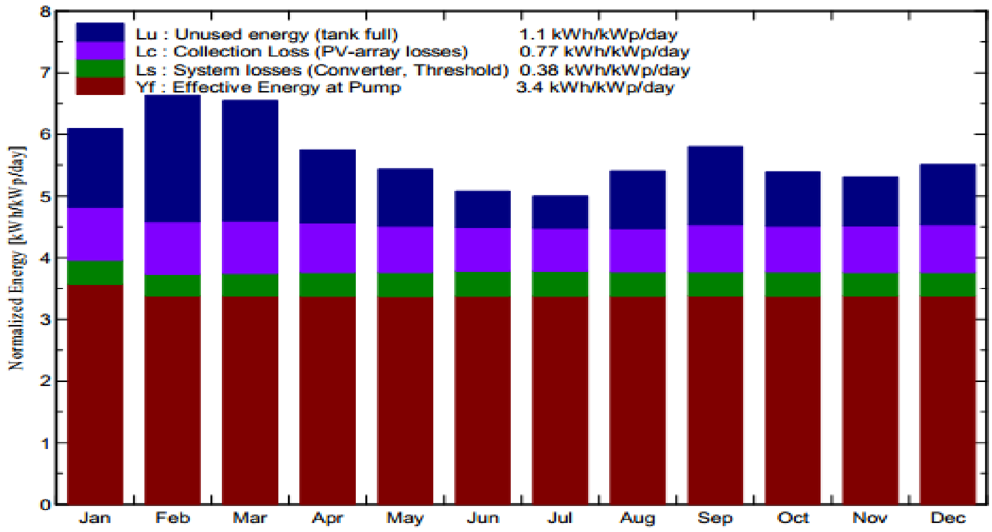


Figure 6.7: Energy balance of the SPV system Afgoye

The above two figures shows the normalized values of, effective energy at pump, collection loss, system loss and unused energy (tank full) in the system. As we have seen from the figures the unused energy in the system for all sites are minimum and the system and collection losses are seems a little bit higher. This is because the system is designed to pump maximum possible amount of water per day using all available energy on the system. When the production maximized the system subjected to high losses, but if we reduce the amount of water pumped by the system per day, we can minimize the losses but the unused energy in the system will be maximize. Performance Ratio (PR) is the ratio of final PV system yield (Y_f) and the Reference yield (Y_r). Figures (a), (b).

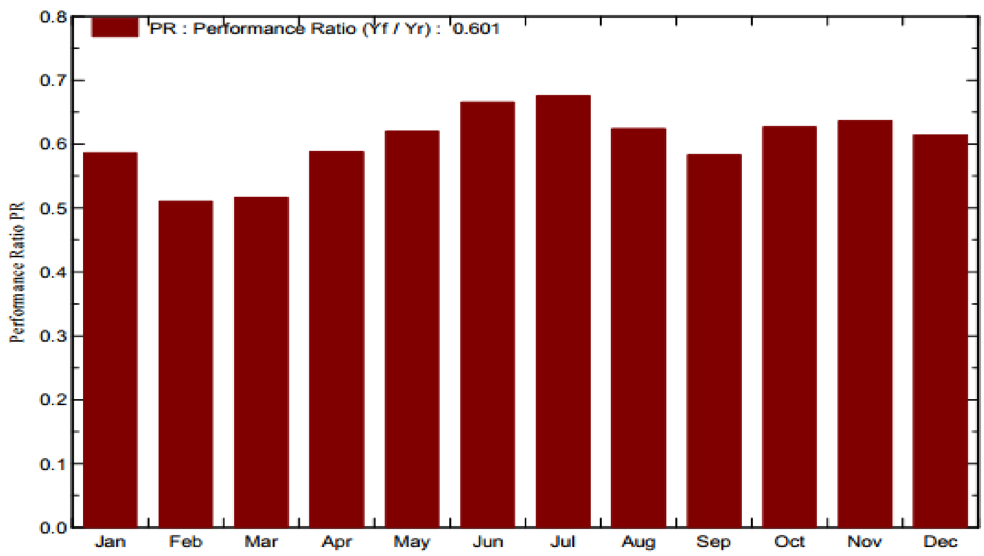


Figure 6.8: Performance ratio of system in Afgoye

Figure 6.8 represent the Performance Ratio of the Incident energy for the entire month of the year graphically. The average Performance Ratio is 0.601

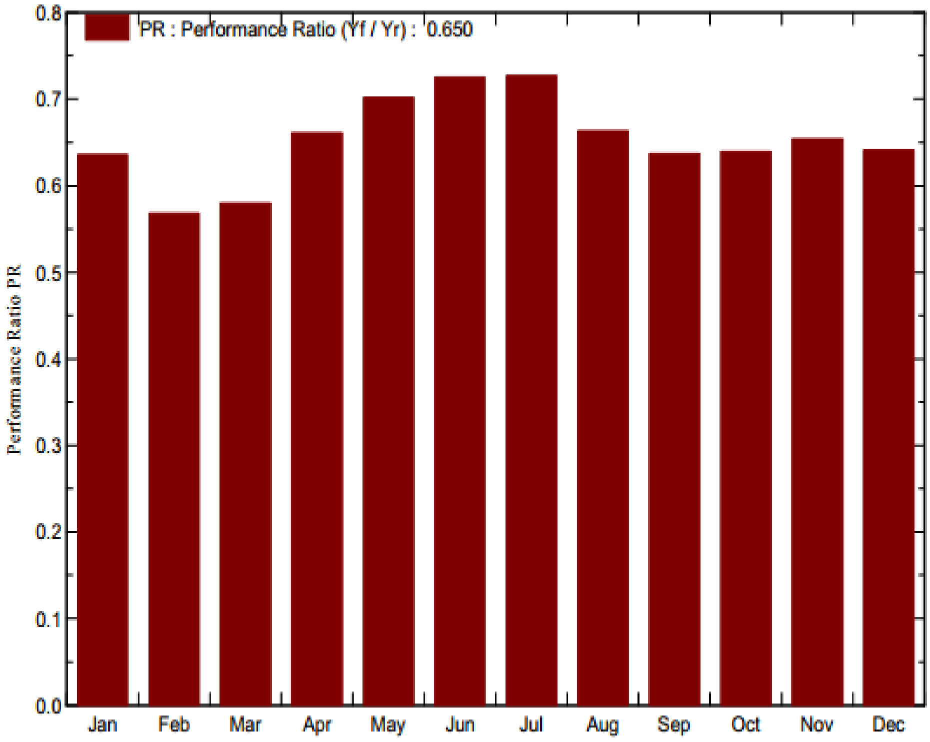


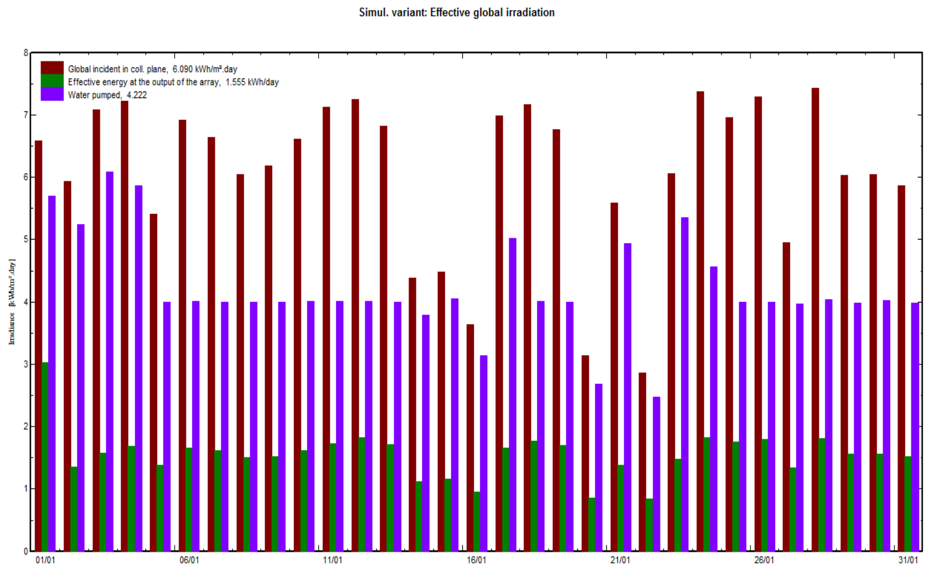
Figure 6.9: Performance ratio of system in Kismayo

Figure 6.9 represent the Performance Ratio of the Incident energy for the entire month of the year graphically. The average Performance Ratio is 0.650.

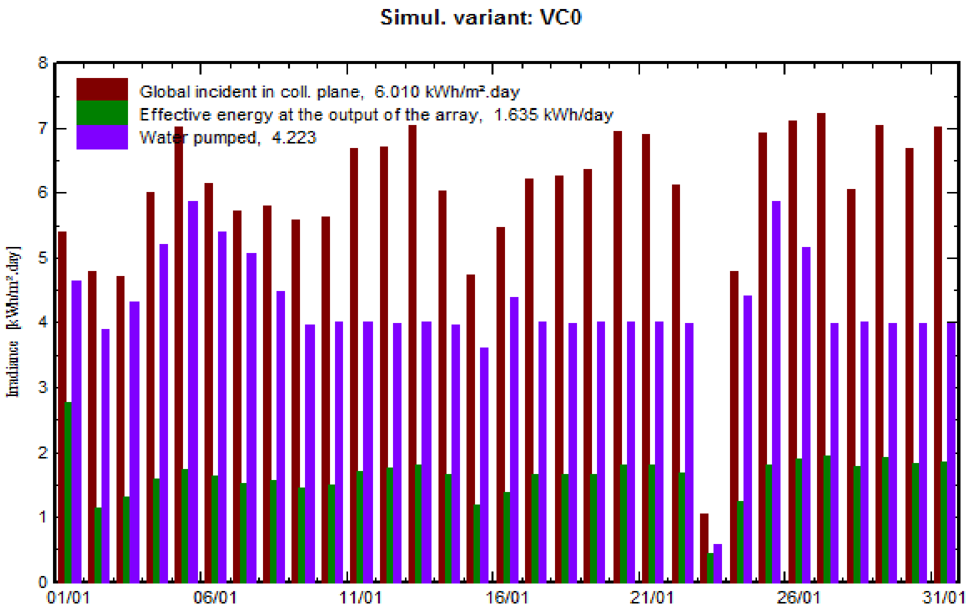
The above two figures shows the normalized values of, effective energy at pump, collection loss, system loss and unused energy (tank full) in the system.

As we have seen from the figures the unused energy in the system for all sites are minimum and the system and collection losses are seems a little bit higher. This is because the system is designed to pump maximum possible amount of water per day using all available energy on the system. When the production maximized the system subjected to high losses, but if we reduce the amount of water pumped by the system per day, we can minimize the losses but the unused energy in the system will be maximize.

Finally the total system efficiency of Afgoye and Kismayo ans shows graphs below figures 6.10.



(a) Afgayo region



(b) Kismayo region

Figure 6.10: Daily global irradiation, Effective energy at the output of array and water pumped (a,b)

Finally the total system efficiency of Afgoye is 72.6% and for Kismayo region the efficiency is 79.7%. And the both system's efficiency is good.

7. CONCLUSION

7.1 Conclusion and Evaluation of PV Water Pumping

Utilization of solar energy for drinking water supply pumping is a feasible solution especially for remote villages and homes far from power grid. Using photovoltaic (PV) pumps has predominant advantages where grid connection is not available, good solar conditions exist, and distances from transport facilities are long. In solar powered pumps, pumping and transporting water from the source to end user requires a lot of energy. The energy required for pumping and transporting water can be obtained from solar powered pumps. The overall objective of this thesis is to study the feasibility of solar powered pump/solar photovoltaic pump for drinking water supply in rural areas of Somalia and to compare the economics of photovoltaic pump with diesel generator powered pump.

The use of solar energy in Somalia, particularly photovoltaic energy, for water pumping is well suited in this arid and semi-arid area due to the existence in this region of an underground water potential, and a large solar energy potential more than 6.5kWh/m^2. Photovoltaic generators are coupled directly to the pump with a DC/AC converter. Storing water in the tanks avoids additional costs accumulator used to store electrical energy. The case study clearly shows the advantage of photovoltaic pumping system compared to conventional energy one which has many constraints of distance to the power grid, of transportation of fuel, and of periodic maintenance of the engines. The cost of one cubic meter (1 m^3) of water pumped by the PV system is more advantageous than others systems. This pumping system constitutes a solution for the water supply of these sparsely populated, remote and isolated areas, with the falling prices of solar panels, this source of energy must be popularized and integrated in the development strategy of these countries.

Using the data provides options to test various key design scenarios and demonstrate the design method and terminology for a direct-coupled solar water pumping system. It is important to consider the limits of this first version as it is only able to calculate for flow rates up to 7 gpm and TDH values no greater than 70 feet due to the very limited PV and pump selection options within this version.

In the case of the design values greater than these and for other pumps or PV module choices not available within the spreadsheet, the user should reference alternative pump performance data provided by solar pump or PV manufacturers. Photovoltaic powered water pumping systems are attractive for livestock and agriculture producers with remote water sources and limited access to AC power. Even though windmills have been in use for decades and will continue to provide effective solutions for water pumping, solar power has made significant steps towards becoming the system of choice for these situations.

The low maintenance and simple operation, no fuel (transportation or storage) costs, environmentally benign, as well as competitive life-cycle economics of solar systems place them at the forefront of choices in supplying water to livestock or agriculture. The technology for solar water pumping is exceeding all expectations, and will continue to be a viable choice for more and more users as its capabilities, reliability, and versatility increases while costs decrease.

7.2 Difficulties and Future Research

This study presents a design and simulation of a simple but efficient photovoltaic water pumping system for Afgoye, Somalia. PVsyst v6.0 software is used to design and perform simulation of water pumping system. The solar data, well characteristics, water demand and storage tank size are input to PVsyst. In addition, the cost and lifetime of PV module, solar pump and controller are input to the software. The output of the software includes the amount of water delivered for daily use to users in Afgoye region, amount of missing water, the excess (unused) PV energy and the system efficiency (performance ratio) during the year. The simulation results have shown the percentage of pump efficiency of the water pumping system and System efficiency of the water pumping system The life cycle cost analysis of pumping water shows that the SPV water pumping system is more economical and feasible compared to Diesel system. The results also indicate that more SPV systems can be installed in the country, replacing the existing more expensive Diesel systems, which would play significant role in achieving the country’s Millinium Development Goal (MDG) targets.

The Government's plan is to provide access to water supply for the entire population by the end of the century. This will be difficult to achieve unless renewable energy technologies such as solar photovoltaic water pumping systems are used where other cheaper alternatives are not feasible. Although PV water pumping systems have high initial costs, they require virtually no maintenance, require no fuel and thus save foreign exchange. They are easy to install and operate, have no moving parts and hence are highly reliable and durable and are modular in nature for future expansion. PV systems are found to be competitive with conventional diesel generator systems. Despite these facts, policy makers are still not convinced that solar PV water pumping systems can support rural development. Correct modeling of the BLDC converter and DC water pump is an important area of study, and various difficulties remain in the current study.

A more realistic model of the BLDC converter would involve a diode loss, and resistive losses in inductors and capacitors. The model used for simulations of BLDC water pump gives results within a reasonable range. The accuracy of model is, however, uncertain because the parameters are only estimates. If tests could be run on the real water pump motor or an equivalent sized motor to determine reasonable entries to SIMULINK block parameters, this could lead to more accurate simulation runs. Also, increasing the size of system and using a larger motor could allow for better results in SUMILINK, though many PV water pumps rarely use such large motors. Physical implementation of the system remains for future research. Analysis of the monthly average radiation at the 0° tilt angle shows that the average monthly radiation in Afgoa Somalia is sufficient for the development of solar PV power project. Further, solar PV water pumping systems require energy mainly during the months. Since the periods of low solar radiation in Somalia coincide with the availability of rainfall (May to August), the availability of sufficient solar radiation to energies the solar PV pumping system is ensured.

Solar-powered pumping systems are making headway in becoming leading and appropriate technology for small-scale water systems in developing countries. This is partly due to the many NGOs funding and supporting the effort. However, other important reasons for the global use of the technology are cost reductions in the equipment, greater output efficiencies, low maintenance requirements, and durability of the systems. Not including the recommended three days of demand water storage, the PV modules are usually the most expensive element of the system, but the average 25 year life span of well-constructed PV modules may be the most attractive aspect of a SPPS. The technology has also been around for over 20 years, so many of the once common and costly installation mistakes can be avoided through a thorough feasibility study, research, and appropriate training.

Solar panels should be located in a sunny spot where no shading occurs. Altitude is not a factor, but height off the ground will affect whether or not you are able to keep them clear of snow. Panels should be angled optimally for solar gain, particularly during the shorter winter days. If your site is in the northern hemisphere you should point your panels to true south. The reverse is true for places in the southern hemisphere. For many locations there is quite a difference between magnetic south and true south, so you should consult a declination map before setting your mounting structure. The reliability and economy of solar electric power make it an excellent choice for powering remote water pumping. Cattle ranchers all over the world are enthusiastic solar pump users. Their water sources are often spread over many miles of rangeland where utility power is not accessible and where refueling and maintenance costs are high for generator use.

The monthly solar insolation is averaged for a day to obtain solar insolation kWH/m^2 day. Graph isavailable which shows the monthly variation of total radiation in kWH/m^2 day or it may be for values of solar insolation in kWH/m^2 year.

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APPENDICES

Sample from preliminary PVsyst simulations

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Pumping PV System: Basic simulation parameters

Project :	**Pumping PV Project at Afgoye**			
Geographical Site	**Afgoye**		Country	**Somalia**
Situation	Latitude	2.1°N	Longitude	45.1°E
Time defined as	Legal Time	Time zone UT+3	Altitude	88 m
	Albedo	0.20		
Meteo data:	**Afgoye**	Synthetic - NASA-SSE satellite data,	1983-2005	

Simulation variant :	**Effective global irradiation**	
	Simulation date	20/11/15 10h26

Simulation parameters

Pumping System parameter	System type	**Deep Well to Storage**		
Well characteristics	Static level depth	20.0 m	Specific drawdown	0.00 m / m³/h
(Diameter 18 cm)	Pump depth	60.0 m	Max. pumping depth	59.0 m
Storage tank	Volume	16.0 m³	Diameter	3.9 m
Feeding by top	Feeding altitude	13.0 m	Height (full level)	0.3 m
Hydraulic circuit	Piping length	70 m	Pipes PE20 (3/4")	Dint = 22 mm
	Number of elbows	3		
Water needs	Yearly constant:	4.00 m³/day		
Pump	Model	**Watermax WD**		
	Manufacturer	All Power		
Pump Technology	Membrane/Diaphragm	Deep well pump	Motor	DC motor, brushless

Operating conditions	**Head Min**	**Head Nom**	**Head Max**	
	10.0	30.0	40.0	mWater
Corresponding maximum Flow Rate	0.94	0.88	0.85	m³/h
Required power	130	192	223	W

Collector Plane Orientation	Tilt	0°	Azimuth	0°
PV Array Characteristics				
PV module Si-mono	Model	**8.265MSGB**		
Original PVsyst database	Manufacturer	8.33 Solar		
Total area	Module area	**1.7 m²**		
Control device	Model	PCB-90		
	Manufacturer	Solarjack		
	System Configuration	**MPPT-DC converter**		

Pumping PV System: Detailed Simulation parameters

Project : **Pumping PV Project at Afgoye**

Simulation variant : **Effective global irradiation**

Main system parameters	System type	**Deep Well to Storage**		
System Requirements	Basic Head	33.0 meterW	Water needs	4.0 m³/day
Pump	Model / Manufacturer	Watermax WD / All Power		
PV Array	Model / Manufacturer	8.265MSGB / 8.33 Solar		
	Nb. of modules	1 in series	Array Power	265 Wp
System Configuration	Control Strategy	**MPPT-DC converter**		

System Operating Control

Power conditioning unit MPPT - DC converter

Operating conditions	Minimum MPP Voltage	36 V	nominal power	500 W
	Maximum MPP Voltage	90 V	Power Threshold	5 W
	Maximum Array Voltage	200 V	Max. efficiency	94.0 %
	Maximum Input Current	14.0 A	EURO efficiency	92.0 %

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	136 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

PVSYST V6.39		20/11/15	Page 4/4

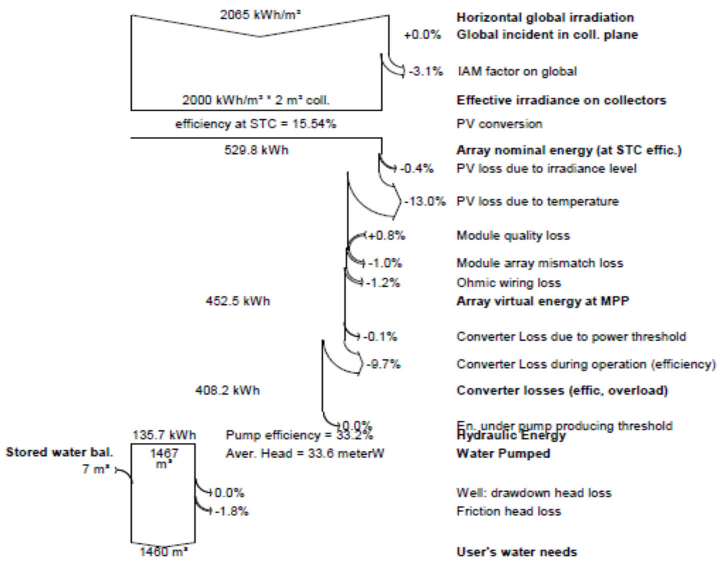
Pumping PV System: Loss diagram

Project : **Pumping PV Project at Afgoye**

Simulation variant : **Effective global irradiation**

Main system parameters	System type	**Deep Well to Storage**		
System Requirements	Basic Head	33.0 meterW	Water needs	4.0 m³/day
Pump	Model / Manufacturer	Watermax WD / All Power		
PV Array	Model / Manufacturer	8.265MSGB / 8.33 Solar		
	Nb. of modules	1 in series	Array Power	265 Wp
System Configuration	Control Strategy	**MPPT-DC converter**		

Loss diagram over the whole year



PVsyst Evaluation mode

CURRICULUM VITAE

Name Surname: Hashim Abdi

Place and Date of Birth: Mogadishu, Somalia, 21 March 1983

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EDUCATION:

- Higher Diploma in Electrical & Electronic Eng (**HDEE**) with Power System specialization, Islamic University of Technology, IUT, Gazipur, Dhaka, Bangladesh in Oct 2007.
- **B.Sc.:** Bachelor of Science in Technical Education, with a major of Instrumentation & control, Islamic University of Technology, IUT, Gazipur, Dhaka, Bangladesh in Nov 2008.
- **M.Sc.:** Master of Science in Electrical Engineering, Istanbul Technical University (ITU), Istanbul, Turkey in 2015

PROFESSIONAL EXPERIENCE AND REWARDS:

Motivated self-starter willing to work all atmosphere with extremely face-paced environment with good a multi-tasking skills, detail-oriented mind, creative and positive.

Practical Training: Various jobs to provide of educational experiences and as part of the completion of HDEE Programme:

- Ghorashal Thermal Power Station (GTPS)
- Bangladesh Telephone & Telegraph Board (BTTB) - Dhaka
- SCADA (Supervisory Control and Data Acquisition) – Dhaka
- Central Equipment Repairing Shop (CERS), Tongi,

List of Projects Projected:

- Towards a Model of a Multi-Mobile Robot System, final Project in B. Sc.
- Development of a Microcontroller Based Moving System Display. Final Project HDEE.
- Renewable Energy Photovoltaic Water Pumbing And Applications MSc

Journal & Conference Publications: “Towards A Model of Multi Mobile Robot System” published at the 12th IEEE, International Multitopic Conference (IEEE INMIC) held on 23-24 December 2008, at Bahria University, Karachi, Pakistan.

Computer & Technical Skills:

Basic Knowledge in Microsoft Windows Network CCNA, Cisco internetworking devices, router configurations.

- Programming Language: C and Assembly Language
- Electrical & Electronics Software: Matlab, PVsyst and Pspice,
- Microsoft Office Application: Word, Excel and PowerPoint.