An-Najah National University
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Techno-economic Analysis of Using Solar Energy, Diesel and Electrical Networks for Water Pumping in The West Bank

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Dedication

To

The candles that burnt to light the road for me…my parents

My brother and sisters……

Those who enlightened my way with their glitter words

Our beloved Al –aqsa mosque…….

My beloved city Nablus……..

Acknowledgments

Praise be to Allah who gave me the ability and patience to complete this thesis .. Peace and blessings be upon His Prophet and his truthful companions .

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A great thankful to my eye sight my loving father and loving mother , who implemented me in loving science and success, Allah gives them long and healthy life.

Also special thanks to my brother and sisters..in them I see big hope and help.I don't forget my teacher whom light my way with faith

Dyana S. Salah

الإقرار

إنا الموقعة أدناه مقدم الرسالة التي تحمل عنوان

Techno-economic Analysis of Using Solar Energy, Diesel and Electrical Networks for Water Pumping in The West Bank

التحليلات الفنية والاقتصادية لاستخدام الطاقة الشمسية, الديزل والشبكات الكهربائية لضخ المياه في الضفة الغربية

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Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's name: **اسم الطالبة:**

Signature: **التوقيع:**

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Abbreviations

AC	Alternative current
DC	Direct current
DG	Diesel generator
DOD	Depth of discharge
Kg	Kilo gram
KW	Kilo watt
KV	Kilo volt
KVA	Kilo volt ampere
kWh	Kilo watt hour
PSH	Peak sun hour
PV	Photovoltaic
PVS	Photovoltaic system
TLS	Transmission Line System
WB	West bank
LCC	Life cycle cost
MPPT	Maximum power point tracker

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Techno-economic Analysis of Using Solar Energy, Diesel and Electrical Networks for Water Pumping in The West Bank

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Abstract

This thesis describes the technical and economic analysis of using solar energy, diesel and electricity for water pumping in the West Bank.

The target area in this research, is the north of west bank; where groundwater is the main source of water for the population, especially farmers.

First the nature of groundwater in the region was examined in terms of depth, static and dynamic head , water pumping rate , and the used water pumping system ,the system studied are ones powered by diesel. Information was collected via questionnaire for farmers. Other information was gathered from international experiences in this field to know the optimum configuration for this region. Data collected from the field have been used as input for Excel program that built to deal with solar system .

The economic analysis were done using Excel program to investigate the feasibility analysis and cash flows from the use of various energy sources in order to pump water .

Three configurations for solar water pumping system were studied in this thesis; AC solar water pumping with storage battery , AC solar water pumping with storage tank , and DC direct solar water pumping.

The cost of kilo watt hour produced from each configuration were calculated and compared with that produced by using diesel generator.

The calculated cost per kilo-watt hour for all configurations of solar water pumping system were in the range 0.2 $ -0.5 $, while the average calculated cost per kilo-watt hour for diesel generator was 0.46 $, and 0.18 $ for expansion of electrical net work.

The cost of water pumped using PV system was between 0.01 $ - 0.19 $ per cubic meter ,compared to 1.07 $ per cubic meter water pumping by diesel generator, and 0.031 $ by expansion of electrical net work .

CHAPTER ONE

INTRODUCTION

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INTRODUCTION

1.1 General Background

Water resources are essential for satisfying human needs, protecting health, and ensuring food production, energy and the restoration of ecosystems, as well as for social and economic development and for sustainable development [1].

However, according to UN (2003), World Water Development Report, it has been estimated that two billion people were affected by water shortages in over forty countries, and 1.1 billion did not have sufficient drinking water [2]. There is a great and urgent need to supply environmentally sound technology for the provision of drinking water. Remote water pumping systems are a key component in meeting this need [3].

In Palestine, as in many other countries, water is the most precious natural resource and its relative scarcity (due to the limited accessibility and availability) is a major constraint on economic development. Water demand in the West Bank is expected to increase substantially in the future by more than 50% until year 2020 [4]. Groundwater is the major source of fresh water, and is thus of primary importance to the Palestinians [5]. 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 will be very expensive. Windmills have been installed traditionally in such areas; many of them are inoperative currently due to lack of proper maintenance.

For this reason, technology to pump groundwater in ways that are economic and environmentally friendly should be developed.

Solar pumps offer a clean and simple alternative to fuel-burning engines and generators for domestic water, livestock and irrigation. Solar pumps are most effective during dry and sunny seasons, and require no fuel deliveries, minor maintenance, easy to install, naturally matched with solar radiation as usually water demand increases during summer when solar radiation is a maximum , and less expensive than other alternative sources of energy such as windmills.

Powering of water pumping systems with (PV) generators has been an applied technology in many countries since 1977 [7].

PV cells are made of semiconducting materials that can convert sunlight directly to electricity. When sunlight strikes the cells, it dislodges and liberates electrons within the material which then move to produce a direct electrical current (DC). This is done without any moving parts [8].

Today, many stand-alone type water pumping systems use internal combustion engines. These systems are portable and easy to install. However, they have some major disadvantages, such as: the high initial cost , variable water production, and require frequent site visits for refueling and maintenance. If a reliable pump system is to be realized, the system designer must be familiar with the water source, the storage system, the terrain surrounding the source, in addition to manufacturers' data on available pumps [10]. Furthermore, diesel fuel is often expensive and not readily available in rural areas of many developing countries [3].

The consumption of fossil fuels also has a negative environmental impact, in particular the release of carbon dioxide (CO_2) into the atmosphere. CO_2 emissions can be greatly reduced through the application of renewable energy technologies, which are already cost competitive with fossil fuels in many situations.

Water pumping systems are classified based on the kind of the used pump (AC or DC) and configurations of the system. There are two configurations of the water pumping systems; standalone systems and hybrid systems. Hybrid systems in general used two energy source like wind turbine or diesel generator or PV. The AC standalone water pumping systems in general consist of PV array, inverter with centralized maximum power point tracker and pump. Such mentioned system can be with a block of batteries as a backup power supply, but since the system cost is very important factor, the systems sometimes designed in a way to meet the village demand during the solar day without any needs for batteries this can be achieved using a reservoir to store water [9].

The importance for this research is to determine feasibility of using PV system instead of diesel or expanding of electrical network.

There are many studies that have been carried out for using photovoltaic water pumps worldwide, but this technology is still in its infancy in Palestine.

As of 2010, solar photovoltaic generates electricity in more than 100 countries and, while yet comprising a tiny fraction of the 4.8 terawatt total global power-generating capacity from all sources, is the fastest growing power-generation technology in the world. Between 2004 and 2009,grid-connected PV capacity increased at an annual average rate of 60%, to some 21 gigawatt [11].

Internationally, previous results show that many countries in rural zones of Africa, Asia or Latin-American have available wells along with good sun exposure favoring solar PV water pumping. In Mexico between 1994 and 2000, 206 PV water pump systems were installed, a survey where done to determine the user's approval; "55% of users agreed that PV pump systems are very economical, 39% said it to be economical and the rest 6% considered these systems as not economically viable" [10].

About 13 million grids –connected pumps was the total number in 2002 in India , most of them were installed in wells [12].

A previous comparative study was performed in Namibia about the cost of solar water pumping and diesel over a group of heads of pump (10 to 200 m) and a group of daily flow rates (3 – 50 m^3/day), this analysis showed that solar pumps (with a higher upfront cost) can compete with diesel pumps (usually lower upfront but with ongoing diesel and intensive maintenance costs) [10].

A previous study proposed a methodology for load matching and optimizing of directly coupled PV pumping system, the main advantage of this method is that it accounts for the variance of solar radiation not from just a single day but from a longer period of time as it should be in a real application [14].Also Daoud, Midoun ,(2008) where develop maximum power point tracker (MPPT) technique for solar PV water pumping system using single flow rate sensor, Solar energy is captured by a PV array and delivered into a DC motor pump through a DC to DC boost converter which performs the function of tracking the MPP [14].

A model for photovoltaic water pumping system, had made by Ould-Amrouche et al. (2010), this model express the water flow out put (Q) directly as a function of the electrical power input (P) to the motor pump for different total head.

Ould-Amrouche et al. (2010) also in their research made financial study using the life cycle cost (LCC) method; and show that although the high cost of the primitive cells of PV, but compared with diesel, the annual cost is lower. The water price for PV systems depends on water pumping rate , head ,technology used, for the study of Ould-Amrouche and others the price varies between 0.17 $/m^3$ and 0.36 $/m^3$, it ranges from 0.26 $/m^3$ to 0.65 $/m^3$ for diesel systems [15].

Previous studies in Palestine about the use of photovoltaic cells was restricted to using it in lighting, for example Energy Research Center at the An-Najah National University implemented of the lighting project in Atouf Village using of PV cells [17]. Photovoltaic systems are not used as much as possible in Palestine due to financial and political situations.

In this thesis the technical analysis and the feasibility of using PV system for water pumping in Palestine was studied , in addition to that as a case study for pumping system six wells in north west bank have been investigated .

1.2Goal

The main goal of this study is to analyze the techno-economic analysis of water pumping by using solar powered energy compared to diesel powered ones or expanding the electrical network.

1.3 The Study Area

The area under consideration in this research is the North of West Bank, where we will study the wells existed in the region and that are already using diesel generator for water pumping.

1.4 Research Objectives

1. To assess the techno-economic aspects of solar energy use for water pumping in Palestine.

2. To create alternatives to diesel or oil fuel and thus reduce dependence on the Israeli supplies.
3. To assess the financial benefits of using the solar energy compared to diesel.
4. To evaluate the environmental effect of using solar energy on air pollution.

1.5 Research Motivations

1. Groundwater is the most important water sources for Palestinians ,so creating a reliable energy source to abstract it is very important.
2. No professional research was performed to evaluate the use of solar energy in water pumping in the West Bank.

1.6 Who Will Benefit From This Work?

The outcome of this research will be of great importance for:

1. Education and research sectors, since this work will to be the first to be carried out in the West Bank, it will stimulate the interest to carry out similar work at different locations and different fields.
2. Economists and decision makers in the water or energy sectors.
3. Farmers ; this work support the agricultural sector to protect water sources from pollution resulting from the combustion of diesel , also

reduce the cost of material resulting from the purchase and maintenance of diesel pumping motor.

1.7 What’s New in this Research?

The significance of this study is that it is the first study in this field in Palestine. The expected results will present the relationship between the amount of pumping from wells and the economic cost by using various energy sources. In addition to that it will show the feasibility of using solar energy instead of diesel or expanding the electrical network.

1.8 Expected Outputs

1. Feasibility analysis of using solar PV system, and cash-flow of using different energy sources for water pumping.

2. Selection the optimum configurations of PV system for water pumping.

3. Developing a mathematical model and drawing curves that show the relationship between the amount of pumping and the cost of various alternatives; PV system, diesel , or expanding the electrical network.

4. Developing a mathematical model drawing curves that show the relationship between the water head and the cost of various alternatives sources; PV system, diesel , or expanding the electrical network.

1.9 Methodology

The overall research methodology is divided into four components: data collection, design of different scenarios, techno-economical evaluation, and output analysis.

The first step includes collecting data on existing wells in the West Bank, which is currently operated by diesel to pump at different rates and at different altitudes, this information we will look them from the Palestinian Water Authority and other sources and via questionnaire for well's owners.

In addition, literature review was carried out in order to select the best configuration, and to understand the basis of the use of solar energy for water pumping.

The second step includes design of different configurations and scenarios and data processing by using computer programs that was designed and also making techno-economical evaluation.

The third step was verification of the program and selecting the optimum alternative.

The fourth step included decision analysis in addition to conclusions and recommendations.

CHAPTER TWO

WATER PUMPING SECTOR IN THE WEST BANK

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2.1 Water Pumping in the West Bank

The major water resources in the West Bank consist of groundwater and springs, while additional sources include rainwater harvesting.

There are 40 municipal wells in the West Bank that are used either wholly or partially by Palestinians. Their annual yield is around 30 million m^3 [18].

Historically pumping from boreholes in the west bank has been predominantly achieved with diesel pumps. Diesel engines became attractive choice for water pumping during the second half of the twentieth century with the development of the fuel supply infrastructure and the technology to allow diesel driven engines to pump from wells .

Diesel engines have a fairly low capital cost but require regular maintenance, linked to the hours of operation and have a fairly short life expectancy (highly dependent on the level of maintenance, operating conditions , quality of the engine and the installation). Most diesel pumps require manual starting making remote pumping installations more costly to operate.

Recently many of the agricultural wells in the West Bank were converted from running on diesel to electricity, but the problem appears in the remote areas that are difficult to deliver its power from the main network.

Pumping water using PV cells may be the best solution for such areas, as it is the case in Bettillo village (5west north Ramallah), this project was completed successfully with benefits as: around $70,000 per year as a saving cost for diesel fuel, CO_2 emission from diesel stopped, in addition to that the project area benefited from the solar units to provide electricity to the farmers houses especially in winter.

2.2 Water Pumping Problems and the Possible Solutions .

The continual shortage of water for all economic sectors in Palestine and the steady increase in water demand for drinking and irrigation have increased the risks of groundwater depletion and contamination caused by the over-pumping of old wells. The increased pumping has led to rising operating costs and the drying-up of existing wells. Industrial and agricultural production is impossible without water.

Palestine is considered as one of the poorest countries in terms of availability of conventional energy resources , most fossil energy and electricity are imported from Israel and thus are economically costly in addition to the resulting environmental problems .

Also the Palestinian electricity sector suffers from many problems, such as high distribution losses that was estimated to be (20%-30%). The economic consequence of such loss is estimated at 4.29 million US dollars per year, which in turn leads to a high price for KWh of energy (between 0.15-0.2 $/ KWh) [17].

Water pumping also affected by Israelis actions that could be summarized as follows [19]:

1. Israelis does not allow new wells to be drilled by Palestinians and has confiscated many wells for Israeli use. Israel sets quotas on how much water can be drawn by Palestinians from existing wells.

2. During the war of 1967, 140 Palestinian wells in the Jordan Valley were destroyed to divert water through Israelis National Water Carrier. Palestinians were allowed to dig only 13 wells between 1967 and 1996, this number is less than the number of wells dried up during the same period due to Israelis refusal to deepen or rehabilitate existing wells.

3. The Gaza strip relies predominately on wells that are being increasingly infiltrated by salty sea water because over-pumping the groundwater. UN scientists estimate that Gaza will have no drinkable water within fifteen years.

4. Israel has built the Wall that is not only an Apartheid Wall, but also a water wall. Some of the largest Israeli settlements (such as Ariel and Qedumin) are built over the Western mountain aquifer, directly in the middle of the northern West Bank agricultural districts, and this is exactly where the wall cuts deepest into Palestinian territory to surround and annex this vital water source.

5. In the West Bank, around 50 groundwater wells and over 200 cisterns have been destroyed or isolated from their owners by the Wall. This

water was used for domestic and agricultural needs by over 122,000 people. To build the Wall, 25 wells and cisterns and 35,000 meters of water pipes have also been destroyed.

From previous it is clear that the security and availability of energy sources are very important for water pumping sector ,water resources are scarce, this study suggest a replacement for diesel pumping, especially for remote areas to exploit water resources available; so we will study the techno-economical analysis of using solar energy for water pumping.

CHAPTER THREE

THE POTENTIAL OF SOLAR ENERGY FOR WATER PUMPING IN PALESTINE

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3.1 Solar Energy in Palestine

Palestine is located between latitudes 34.15° and 35.40° east and between the latitude circles 29.30° and 33.15° north, this geographical location encourage the use of PV energy. The daytime temperatures ranging from 14° to 26°C are benign to the operation of the standalone photovoltaic system (SPVS).Solar radiation data is very important for designing and sizing PV system.

Palestine has a high solar energy potential, where average solar energy is between 2.63 KWh/m^2 per day in December to 8.5 KWh/m^2 per day in June, and the daily average of solar radiation intensity on horizontal surface is 5.46 KWh/m^2 per day while the total annual sunshine hours amounts to about 3000 [20], Fig.(3.1) show the solar radiation in North West Bank, solar radiation reaches 8kWh/m^2 in June, July and August (Summer months) [17].

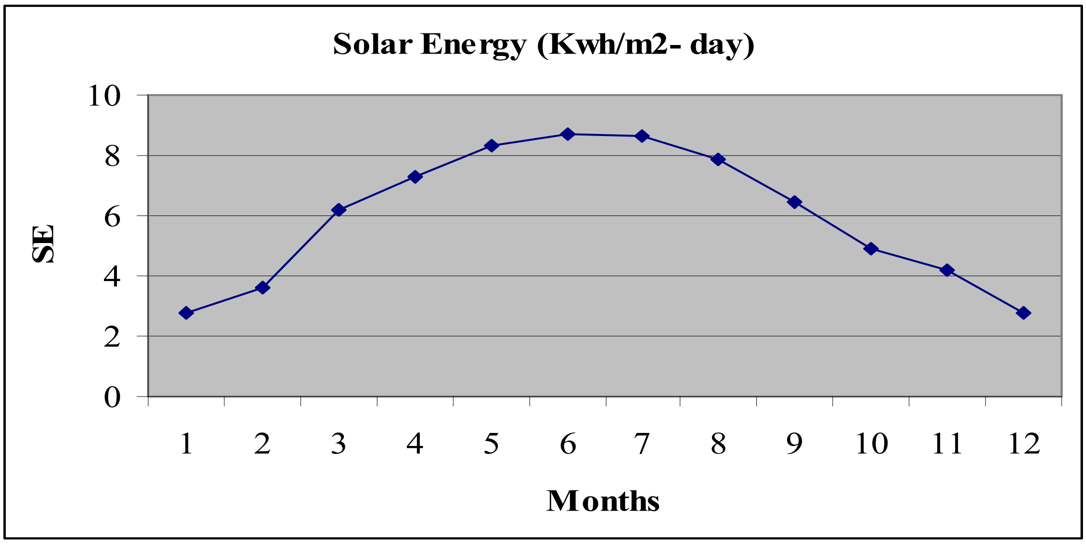

Figure (3.1): Monthly average solar radiation in North West Bank [21].

3.2 Solar Photovoltaic (PV) Cells

Solar PV cells are cells that made from semi-conductor materials which can convert sunlight into electricity; PV cell contains at least two layers one has positive charge and the other negative, when the sun strikes the cells, some photons from the light are absorbed by semiconductor freeing electrons from negative layer to positive one; this movement of electrons produces a direct electrical current.

A module is an assembly of PV cells encased in glass or clear plastic wired in series or series / parallel to produce a desired voltage and current, most cells produce approximately one _ half of a volt; therefore a 36 cell module will typically have an operating voltage of 18 volts under standard conditions and a nominal voltage of 12 volts.

Modules can be aggregated together to make an array that is sized to the specific application wired together to achieve a desired voltage and current. (Figure 3.2) [8].

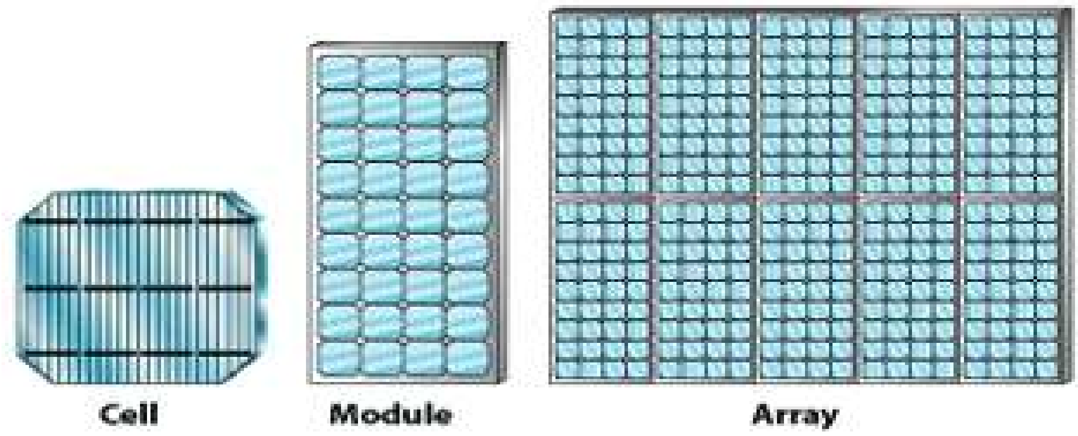

Figure (3.2) Diagram that shows how individual cells make up a module. An array consists of sets of modules [8].

3.3 Solar Energy Project in Palestine

Solar power in Palestine is already exploiting for several years through the solar water heaters. With the development of technology solar energy has been exploited in wider projects in different fields .

Some of the available projects in West Bank included the following:

1. Electrification of isolated villages through photovoltaic Systems (Atouf Village, WB, Palestine), With total peak power of 11.7 KW, and an energy storage system of 120 KWh,(Figure 3.3).

Figure (3.3): Photovoltaic solar energy panels in Atouf Village

2. Electrification of isolated villages through photovoltaic Systems (Amnazel village, WB, Palestine), (Figure 3.4).

Figure (3.4): Photovoltaic solar energy panels in Amnazel Village

3. Using solar energy for public lighting in Palestine (Wadi-Gaza Bridge), (Figure 3.5).

Figure (3.5): Utilizing solar energy for lighting of the Wadi Gaza Bridge.

The solar energy potential in Palestine can be considered as very high comparing with other countries, this potential is very encouraging to perform techno – economical analysis for solar energy use in water pumping.

CHAPTER FOUR

CONFIGURATION OF USING SOLAR ENERGY FOR WATER PUMPING

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CONFIGURATION OF USING SOLAR ENERGY FOR WATER PUMPING

4.1 Systems of Water Pumping

Photovoltaic pump system consists of a number of components, including photovoltaic array which converts solar energy directly into electricity as DC, and pump that drive by electric motor . The characteristics of these components need to be matched to get the best performance. The pump motor unit will have its own optimum speed and load depending on the type and size of the pump.

There are two categories of pump used in stand-alone PV systems; rotating and positive displacement pumps, in addition to many specification under each category. Pumps are also classified as surface or submersible, a submersible pump remains underwater , such as in a well as in figure (4.2), while a surface pump is mounted at the top of the water as a floating pump or adjacent to the water source as in figure (4.4).

Surface pumps are more accessible for maintenance and less expensive than submersible pumps, but they are not well suited for suction and can only draw water from about 20 vertical feet. Surface pumps are excellent for pushing water long distances [8].

Most submersible pumps have high lift capability, but they are sensitive to dirt/sand in the water and should not be run if the water level drops below the pump.

Examples of the rotating pumps are centrifugal, rotating vane, or screw drive. This type of pump moves water continuously when powered . The output of this pump is dependent on head, solar radiation (current produced) and operating voltage. Rotating pump is suited for conditions of pumping of moderate to high flow in tube wells, shallow reservoirs or cisterns, shallow well pumps are typically be surface pumps. It uses suction pipe to pull water up from the aquifer, located no more than 7.62 meter below the ground. Most shallow well pumps have suction limits around 10 meters. Volumetric or Positive displacement pump move packets of water, it could be diaphragm or piston pump (jack pumps). It is typically used for pumping water from deep wells and suitable for conditions of low flow rates and /or high lifts. Jack pumps output is nearly independent of head and proportional to volume and solar radiation. Jack pumps should not be connected directly to a PV array output because of the large load current changes during each pump cycle [16].

Generally, positive displacement pumps are best for low flows (under 15 m^3/day) and high heads (30-500 m). Submersible centrifugal pumps are best for high flow rates (25-100 m3/day) and medium heads (10-30m) [21].Table (4.1)shows typical wire to water efficiency ranges for different types of pumps.

Also Water pumps can be split into two categories [25]:

1. Dynamic - the water velocity is increased then reduced at the output and thus increasing pressure.

2. Displacement (volumetric) - these include rotary and reciprocal pumps.

Taking into consideration the pump categories, four water pumping type will be as follow :

a) Submerged pump and motor - used with centrifugal pumps for medium depth bores. The pumps are automatically primed and easy to maintain.

b) Pump with surface motor - this type of configuration allows easy access to the motor, but requires a mechanical drive down the bore to the pump.

c) Floating pump and motor - this type of pump is ideal for open wells and canals, but is unsuited to borehole pumping.

d) Surface suction pump - ideal for small surface systems, but priming can be an issue of the water level varies.

Table (4.1) Typical Wire to Water Efficiency Ranges [22].

Typical Wire to Water Efficiency Ranges		
Head (m)	**Type of Pump**	**W-W Efficiency (%)**
0-5	**Rotary**	**15 – 25**
6-20	**Centrifugal with jet**	**10 – 20**
6-20	**Displacement**	**20 – 30**
21-100	**Displacement**	**30 – 40**
21-100	**Jack Pump**	**30 – 45**
Greater than 100	**Jack Pump**	**35 – 50**

Solar pumping technology continues to improve. In the early 1980s the typical solar energy to hydraulic (pumped water) energy efficiency was around 2% with the photovoltaic array being 6-8% efficient and the motor pump set typically 25% efficient. Today, an efficient solar pump might have an average daily solar energy to hydraulic efficiency of more than 9% but lower efficiencies of 2 -3% are still common.

It is important to get the most efficient pump available as the difference in cost between the poor pump and a very efficient pump is much less that the additional cost required for a larger PV panel, accurate sizing of the array is important in keeping costs down [23].

The criteria for choosing a motor for a PV system includes: price, efficiency, reliability, availability, and the wattage. Motor could be: permanent magnet dc motors under 2,250 watts (3 horsepower), wound field dc motors for 2,250-7,500 watts (3-10 horsepower), and ac motors above 7,500 watts (10 horsepower) [21].

Solar water pumping system could be either direct current (DC) or alternative current (AC) type.

4.2 Solar DC Water Pumping

Solar water pumping systems in its simplest way, have the solar panels connected directly to the small DC motor that drives the water pump. These systems use centrifugal pumps, because of their ability to be matched to the output of the solar panels; the choice of a DC motor is attractive because PV arrays supply DC power.

Solar water pumps are designed to use the direct current (DC) provided by a PV array, although some newer versions use a variable frequency AC motor and a three-phase AC pump controller that enables them to be powered directly by the solar modules [8].

Solar DC water pumping system consists of the following components [23]:

1. A DC pump that operate on a range of DC voltage from 12V - 200V.

2. A solar PV array that consists of solar panels connected in series and parallel combination to achieve the desired voltage and current necessary to drive the DC Pump. The power rating of the solar array will be suitable to the design of the pump.

3. A controller unit, it takes care of the monitoring and controlling of the Pump like dry running protection, automatic reset, reverse polarity and overload protection. Controller Unit also has the features to adjust pump speed in order to reduce flow rate. It also has an integrated MPPT for extracting the maximum energy from the solar array.

4. Battery bank or storage tank; to provide backup power to the pump during low sunshine days and also during the night, figure (4.1)shows the block diagram of DC solar water pumping system.

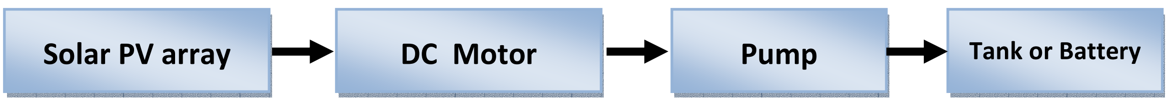

Figure (4.1), Block Diagram of DC Solar Water Pumping System

4.2.1 Types of DC Pumps

There are two types of DC pumps namely surface pumps and submersible pumps. All Surface pumps are centrifugal, while submersible pumps can be both centrifugal and helical rotor pumps. Table (4.2) shows comparison between the two types of DC pumps.

Table (4.2) Comparison between centrifugal and helical rotor pumps.

Features	Centrifugal	Helical rotor
Suitable DC voltages	**12 V - 375 V**	**12 V - 375 V**
Maximum total dynamic head	**170 m**	**350 m**
Maximum flow rate	**70 m3/hr**	**4 m3/hr.**
Maximum submersion	**250 m**	**Unlimited**

Figure (4.2): Submersible pump that uses a helical rotor and brushless motor, (Guide to SPW PS in New York State, 2001).

4.2.2 AC Water Pumping

Solar AC water pumping systems consists of an AC Pump, Solar PV array, controller unit ,battery bank or storage tank, and an inverter that converts DC power generated from solar array to AC to drive the pump, Figure (4.3) shows the block diagram of AC solar water pumping system.

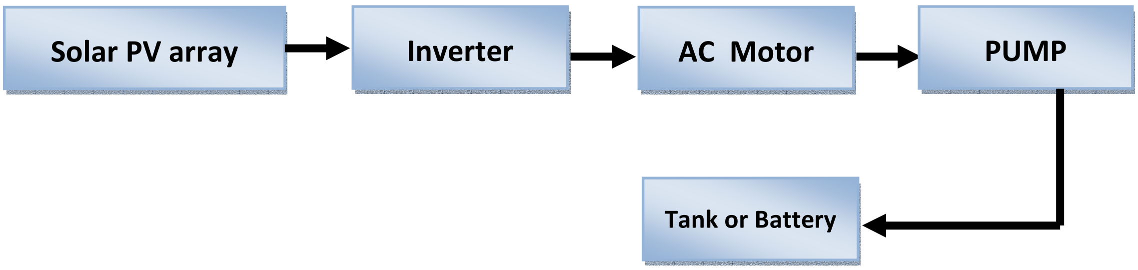

Figure (4.3): Block Diagram of AC Solar Water Pumping System

4.2.3 Types of AC Pumps

Most conventional AC pumps use a centrifugal impeller that "throws" the water into motion. A multi-stage centrifugal pump has a series of stacked impellers and chambers.

When operating at low power, the amount of water pumped by centrifugal pumps drops dramatically. This makes centrifugal pumps somewhat limited in solar applications, though efficient centrifugal pumps are currently used. Many designers of solar water pumps took the approach of using positive displacement pumps, which bring water into a chamber and then force it out using a piston or helical screw. These types generally pump more slowly than other types of pumps, but have good performance under low power conditions, and can achieve high lift [8]. AC pumping system can be designed for Pumps from 0.5 hp to 300 hp, and also be designed to run DC pumps directly.

Figure (4.4): Surface pump [8].

4.2.4 Comparison Between DC and AC water pumping systems

The type of application and the circumstances s determine the type of pump that will be used, whether DC or AC.DC motors are compatible with the power source and have higher efficiency than that of AC motors but their initial cost is higher.

DC water pumps in general use one-third to one-half the energy of conventional AC pumps [24].When a better output performance is required during low levels of radiation, the AC motor exceeds its performance capabilities compared to the DC motor.

In general, the AC powered system is an economic source and takes minimum maintenance when AC power is available from the nearby power grid. In PV-powered pumping systems AC motors are limited to high power applications because they require inverters, and this will introduce additional costs and some energy loss which lowers the overall system efficiency rate.

The DC motor stops completely during cloud cover or environmental pollution. Since the efficiency of these pumps will vary widely during a typical day. Using an electronic matching device such as linear current booster (LCB) or (MPPT) will increase pump system efficiency and flow by better matching the array to the pump or choosing a motor that is highly efficient in providing the maximum amount of water during solar water pumping, specifically during times when solar irradiance is low, table (4.3) summarize the comparison between DC and AC solar water pumping system.

Table (4.3) Comparison between DC and Ac water pumping systems

	DC solar pump	AC solar pump
Power output	Up to 2kW	From 150W to 55kW
Applications	Garden fountain, landscaping	Landscaping to irrigation, especially large scale such as farmland irrigation, desert control, etc.
Price	Relatively low-priced (require slightly less solar panel)	Expensive, as it requires an inverter
Compatibility	low compatibility (only selected controller work selected motor)	high compatibility (inverter works with different kinds of AC motor and pump

4.3 Advantages And Disadvantages of the Different Energy Sources (Diesel, Solar, and Electric Transmission Line) :

Water pumping has a long history, several methods were used to pump water also use different energy sources, such as manpower, animal power, wind power and solar energy and fuel.

The PV system has many advantages as an energy source its main feature include :

1. It considered a clean source of energy that uses sunshine only. Do not release any pollutants into air ,water or environment, and do not deplete natural resources, or endanger animal or human health.

2. It is the most cost-effective source of electricity when the cost is high for extending the utility power line or using another electricity-generating system in a remote location.

3. It is a reliable source of energy ; since PV modules have no moving parts and require little maintenance compared to other electricity-generating systems.

4. Modularity ;PV systems can be expanded to meet increased power requirements by adding more modules to an existing system. Table (4.3) shows comparison between the three different energy sources.

Table (4.4) comparison between diesel, PV and electricity

System Type	Advantages	Disadvantages
PV Powered System	• Low maintenance • Unattended operation • Reliable long life expectancy (20+ years) • No fuel and no fumes • Easy to install • Low recurrent costs • System is modular and closely matched to need	• Relatively high initial cost • Low output in cloudy weather
Diesel Powered System	• Moderate capital costs • Easy to install • Can be portable • Extensive experience available	• Needs maintenance and replacement • Site visits required • Noise, fume, dirt problems • Fuel is expensive and supply intermittent
Electricity transmission lines	• Transmit large amounts of electric power over long distances.	• High technical • Voltage drop • Expensive • Maintenance required

4.4 Water Pumping Configurations

To design an optimum water pumping system configuration it is required to know the demand for water; requirements and conditions under which water needs to be pumped, the capacity of the source, the depth of water. In addition to that, more information needs to be gathered about specification of available pumps, the season and time of the pumping, and most importantly, the amount of solar radiation in the designated area .

Based on using either AC or DC energy sources , and either using a battery bank or storage tank , three main configuration are investigated for solar water pumping system in this study:

1. AC configuration with storage batteries.

2. AC configuration with storage Tank.

3. DC direct configuration with storage Tank.

4.4.1 AC Configuration with Storage Batteries.

In this configuration, PV arrays are connected with controller ,then to inverter that is connected to the AC pump , batteries are used for energy storage, as shown in figure (4. 5).

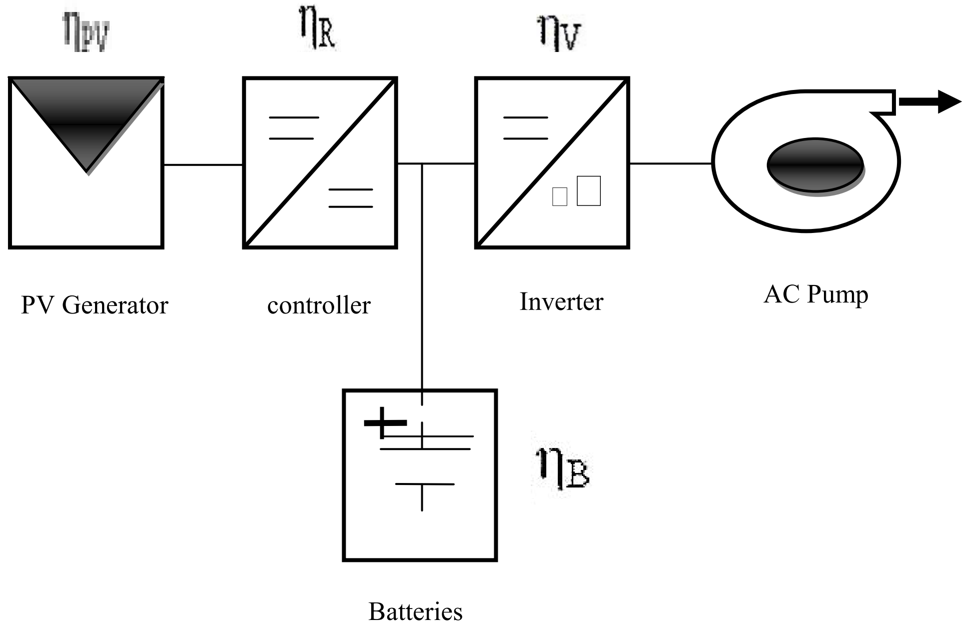

Figure (4.5) AC Water pumping system Configuration with Batteries

4.4.2 AC Configuration with Storage Tank.

In this configuration, PV arrays are connected with inverter that is connected to the AC pump , tank are used for energy storage, as shown in figure (4. 6).

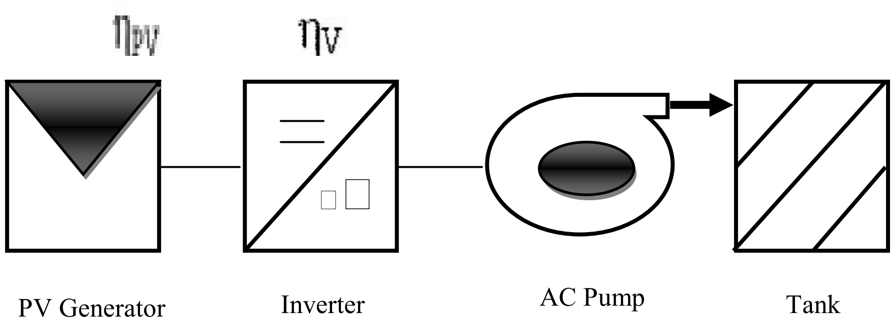

Figure (4.6) AC Water pumping system Configuration Using Storage Tank

4.4.3 DC Direct Configuration with Storage Tank .

In this configuration, PV arrays are connected directly to the DC Pump , a tank is used for energy storage as shown in figure (4. 7).

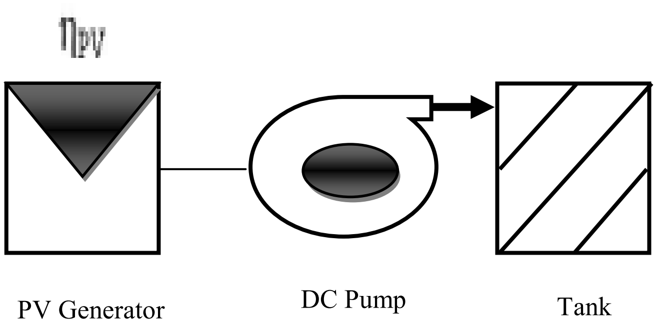

Figure (4.7) DC Direct Configuration With Tank

With any of the previous configurations, the water pump used has to be a surface pump due to its advantages over types.

CHAPTER FIVE

DESIGN ELEMENTS OF WATER PUMPING SYSTEM BY USING THE SOLAR ENERGY

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DESIGN ELEMENTS OF WATER PUMPING SYSTEM BY USING THE SOLAR ENERGY

5.1 Determination of Hydraulic Energy Requirements

Diesel generators used in most areas of the West Bank for the purpose of water pumping, especially in remote areas and villages.

Usually, these engines require regular maintenance and high running cost in addition to that contribute to polluting the environment either through the gases resulting from the burning process or as a result of the oil leakage to water sources.

Samples of wells has taken from different areas in the West Bank, which operate on diesel, with different capacity and power factor 0.85.

Main characteristics of the studied wells and their diesel generators were summarized in table (5.1).These data were collected by distributing a questionnaire on a group of wells owners in north west bank areas (appendix 1).

Table (5.1): Data for some wells that operating by diesel generators in the WB:

Well number 1	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6
Use	Agricultural	Agricultural + domestic	Agricultural	Agricultural	Agricultural	Agricultural
Depth (m)	180	70	200	60	180	50
Static water level (SWL) (m)	90	20	50	20	30	18
Dynamic water level (DWL) (m)	150	60	80	56	80	32
Water pumping (m^3/hr)	7	3	12	3	15	12
Average number of pumping hours per day (hour)	24	12	24	12	24	24
Type of generator	Perkins	Perkins	Perkins	Lester	Perkins	Lester
Generator capacity (KVA)	16	7.5	16	10	16	15
Average daily consumption of diesel (L / hr)	4	3	4	3	4.5	2.5
Generator cost $	2638.5	1847	3430	1583	3166.23	1055.4
Maintenance cost $/year	924	528	1055	528	660	1055.4

5.1.1 AC Configuration With Storage Batteries

A schematic diagram of the AC configuration with storage battery is shown below in figure (5.1).

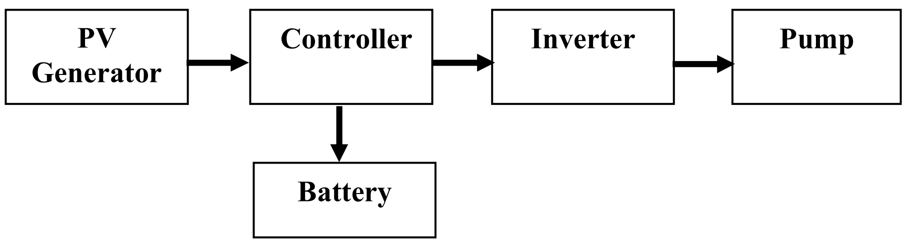


Figure (5.1):AC Configuration with Storage Battery

The hydraulic energy(HE) can be calculated using the equation :

$$HE\ (KWh / day) = 0.002725 \times Q \times TDH \qquad (5.1)$$

Where :Q is water pumping rate (m^3/day) and TDH is total dynamic head (m).

For well No.2 in WB where water pumping rate was about 3 m^3 /hr,12 operating hours and head of 60 m, (HE) is 5.886 KWh / day , the annual HE is 2148.4 KWh / year, and the annual water pumping rate is 13140 m^3 / year.

5.2 PV Generator Selection

PV generator selection is based on the plans of PV sizing systems submitted by the performance of manufacturers, and different from an area to other.

The peak power of the PV generator (Ppv) is obtained as follows:

$$Ppv = HE / (\eta s \times PSH) \qquad (5.2)$$

Where PSH is the peak sun hours, ηs is the efficiency of the system components. For well No.2 in the WB HE is 5.886 KWh / day calculated by equation (5.1),PSH is 5.4 in Palestine [20], ηs is 0.6 ,the calculated Ppv using Eq.(5.2) is 1.822 KW

To install this power a PV module type Kyocera KD135SX – 135Watt, with the specifications in table (5.2) and Appendix 3, rated at 48 Vdc and a peak power of Pmpp = 135 W is selected.

Table (5.2): Specification of Kyocera KD135SX module at standard conditions.

Maximum Power	135 W
Maximum Power Voltage	17.7 V
Maximum Power Current	7.63 A
Open Circuit Voltage (Voc)	22.1 V
Short Circuit Current(Isc)	8.02 A
Area	1.003 m²

The number of PV module required (Npv) is obtained as :

$$Npv = Ppv/Ppv\ module \qquad (5.3)$$

For well No.2 in WB, for Ppv is 1.822 KW and Ppv module is 0.135 KW then number of modules required can be calculated by Eq.(5.3) is 15modules to get the required energy. The modules can be connected to give the desired Vdc which is 48V, so the number of series modules required is :

$$\text{Number of modules in series} = Vdc / Vmax \qquad (5.4)$$

Vdc = 48 V , Vmax = 17.6 V

Then the number of modules in series calculated by Eq.(5.4) is 3 modules. The modules connected in parallel group of three in series to produce operating system voltage 48VDC. one array will be used, built 5 parallel strings. The arrays connected in parallel to produce 48VDC as figure (5.2).

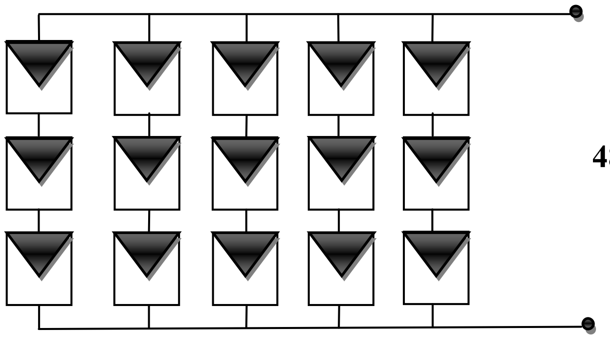


Figure (5.2) Block diagram For the arrangement of module in the array

5.3 Pump Selection

Pump selection depends on the daily water pumping rate and the hydraulic head,(Q , H).For well No.2 in the WB where (Q = 3 m^3/hr , H = 60 m), vertical multistage pump will be used , depending on (Appendix 2) , then the resulting power of the pump (Pp) is: 2.2 KW**.** The motor power (Pm) can be calculated as:

$$P\,m = P\,p / ή \qquad (5.5)$$

ή is the pump efficiency and equal 0.85 , then P m is 2.6 KW **.**The pump current (Ip) can be calculated as:

$$Ip = (Pp \times 1000) / (sqrt(3) \times V \qquad (5.6)$$

For a 3Ø system, V= 400 volt, then the pump current (Ip) will be 3.17 A**.**The motor current (Im) can be calculated by eq.(5.7)

$$Im = (Pm \times 1000) / ή \times (sqrt(3) \times V \qquad (5.7)$$

Im is 3.74 A

5.4 DC/AC Inverter Selection

The inverter is used if the system power load is AC ,it converts the battery's low-voltage DC electricity into standard AC voltage output .The input of inverter have to be matched with the battery block voltage while its output should fulfill the specifications of the maximum power of the pump, for well No.2, the battery block voltage is 48 V, while its output voltage is 400 V. The Inverter power(Pi) can be calculated as:

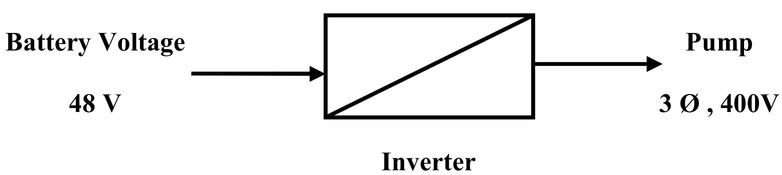
$$Pi \geq (fs \times Pmax)/PF \qquad (5.8)$$

Where fs is factor of safety that it is 1.1 value added to the maximum power demand of the inverter to make sure that the inverter can allow maximum power flow from the battery to the load and also reduce the chances of the inverter getting damaged due to high power**,** PF is power factor and it is 0.9, then the Pi is 3.5 KVA

The specifications of the inverter will be as in table(5-3) and figure(5-3) .

Table(5-3) :The specifications of inverter selected

Inverter type: XG-SF3700NEW (3.5KVA)	
Input	**Output**
48V	**400**
73 A	**9A**
Rated power (KVA) = 3.5	



Figure(5.3): Inverter specifications

5.5 Controller Selection

Charge controller regulates the power from the panel to the battery, it stops the charging when the battery is fully charged, and cuts off the power from the battery to the loads when the battery is depleted below a safe level. Two conditions must be take into account when controller chosen to enlarge the lifetime for the battery ,these include the voltage and current. The controller voltage have to be matched with the PV array voltage which is 48V while its current can be calculated depending on the number of parallel PV strings and maximum current of module from the specifications. The controller current (Ic) can be calculated using eq.(5.9)

$$Ic = \text{No. parallel PV strings} \times \text{maximum module current} \qquad (5.9)$$

For well No.2 in the WB that has 5 PV parallel strings with its selected module of Kyocera KD135SX – 135 ,and maximum current of 7.63 A. The resulted Ic is 38.15 A ,knowing that standard value is 40 A. Number of controller required is 1 , so the total current that enter the junction box will be 40 A.

5.6 The Storage Capacity and Battery Sizing

The battery size is obtained as follows .

$$CAH = (1.5 \times HE) / (VB \times DOD \times ή B \times ή V) \qquad 5.10$$

Where CAh is the ampere hour capacity, VB and ηB are voltage and efficiency of battery block, while DOD is the permissible depth of discharge rate of a cell.

For well No.2 in the WB assuming realistic values of ηB=0.95, DOD=0.85 , ηv = 0.95 and VB=48V, for 1.5 autonomy days .The CAh calculated is 239.7 Ah, ,knowing that standard value is 300AH.so ,number of batteries is 4, with 12V for each one connected in series to achieve the desired 48V.

Results for the selection elements of water pumping system using solar cells for the rest of the studied wells is summarized in the table (5.3).

Table (5.4): Data for the selection elements of AC configuration with batteries.

	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6
Module No	162	15	144	15	30	60
Module in Parallel	9	5	8	5	5	10
Pump Selected (KW)	15	2.2	11	0.55	5.5	7.5
Inverter Selected (KVA)	22	3.5	16	1.5	8	11
Controller Selected(A)	80	40	65	40	40	80
Controller No.	6	1	6	1	2	2
Battery Selected (AH)	3000	300	3000	300	500	1500

5.6.1 AC Configuration With Storage Tank

A schematic diagram of the AC configuration with storage tank is shown below in figure (5.4).

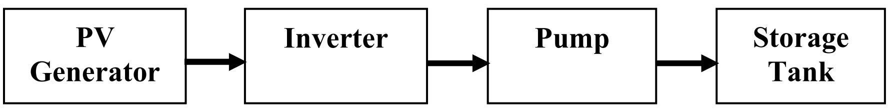


Figure (5.4):AC Configuration with Storage Tank

For this configuration all elements are selected based on same calculations as the previous configuration of AC with storage battery, except that a storage tank will be used instead of batteries .For well No.2 in the WB data for the selection elements for this configuration can be summarized in the table (5.4) .

Table (5.5): Data for the selection elements of AC configuration with storage tank.

	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6
Module No	162	15	144	15	30	60
Module in Parallel	9	5	8	5	5	10
Pump Selected (KW)	15	2.2	11	0.55	5.5	7.5
Inverter Selected (KVA)	22	3.5	16	1.5	8	11
Tank Selected m3	5	5	5	5	5	5
Tank No	3	3	1	3	1	1

5.6.2 DC Direct Configuration With Tank .

A schematic diagram of the DC direct configuration with storage tank is shown below in figure (5.5).

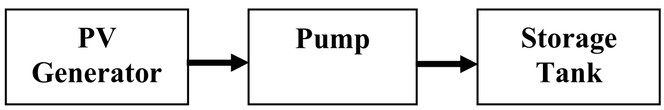


Figure (5.5): DC Direct Configuration with Storage Tank

For well No.2 in the WB for the selection elements for this configuration is summarized in the table (5.5). Elements that will be used are only PV arrays and tank.

Table (5.6): Data for the selection elements of DC direct configuration with storage tank.

	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6
Module No	162	15	144	15	30	60
Module in Parallel	9	5	8	5	5	10
Pump Selected (KW)	15	2.2	11	0.55	5.5	7.5
Tank Selected m3	5	5	5	5	5	5
Tank No	3	3	1	3	1	1

Later we will analyze the design and conduct the necessary economic calculations through the program that designed using Excel software.

CHAPTER SIX

DESIGN OF SOFTWAR PROGRAM FOR WATER PUMPING SYSTEM BY USING SOLAR ENERGY

CHAPTER SIX

DESIGN OF SOFTWAR PROGRAM FOR WATER PUMPING SYSTEM BY USING SOLAR ENERGY

6.1 Program Presentation Through Flow Chart

Program has been designed using Excel software that is very simple for anyone to deal with, it is divided into blocks and outputs are display in different ways, figures or tables. The data was obtained through the questionnaire that was presented to farmers in the study area. This program could be comparable to the global programs such as PV SYST and HOMER software, which are very costly .The program is divided into Sub blocks showing the path followed in the selection and design of the PV system.

6.2 Data Input for The Program

Input data for the program includes: water pumping rate Q (m^3/hr), dynamic and static head H (m), diesel generator type, diesel consumption (L/d), working hours for the pumps ,maintenance and generator cost .

6.3 Mathematical Modeling for Hydraulic Energy calculation and Water Pump Selection

Using values of Q and H, hydraulic energy can be calculated by building an equation in the Excel program, also pumps can be selected by using catalogue as in figure (6.1).

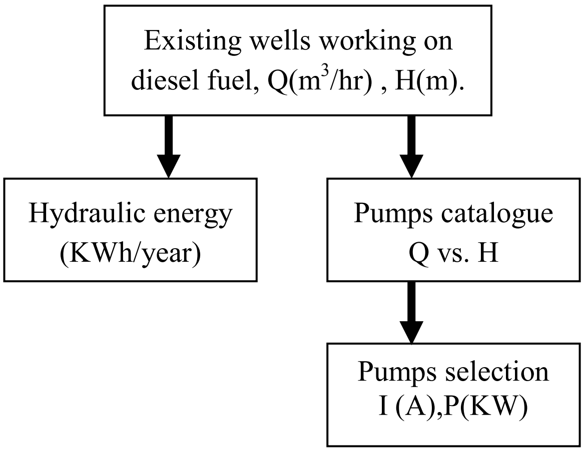


Figure (6.1): Hydraulic Energy Calculation and Pump Selection

6.4 Mathematical Modeling of PV Array Selection.

Depending on hydraulic energy value that is calculated and the efficiency of system, the energy of the PV module is calculated , and then PV array is designed, as in figure (6.2).

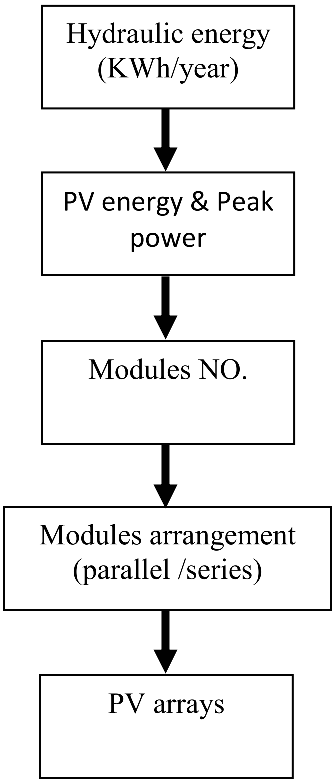


Figure (6.2): PV Arrays Construction

6.5 Mathematical Modeling for AC Configuration with Batteries

After calculation of hydraulic energy the programming steps for this configuration is presented in figure (6.3).

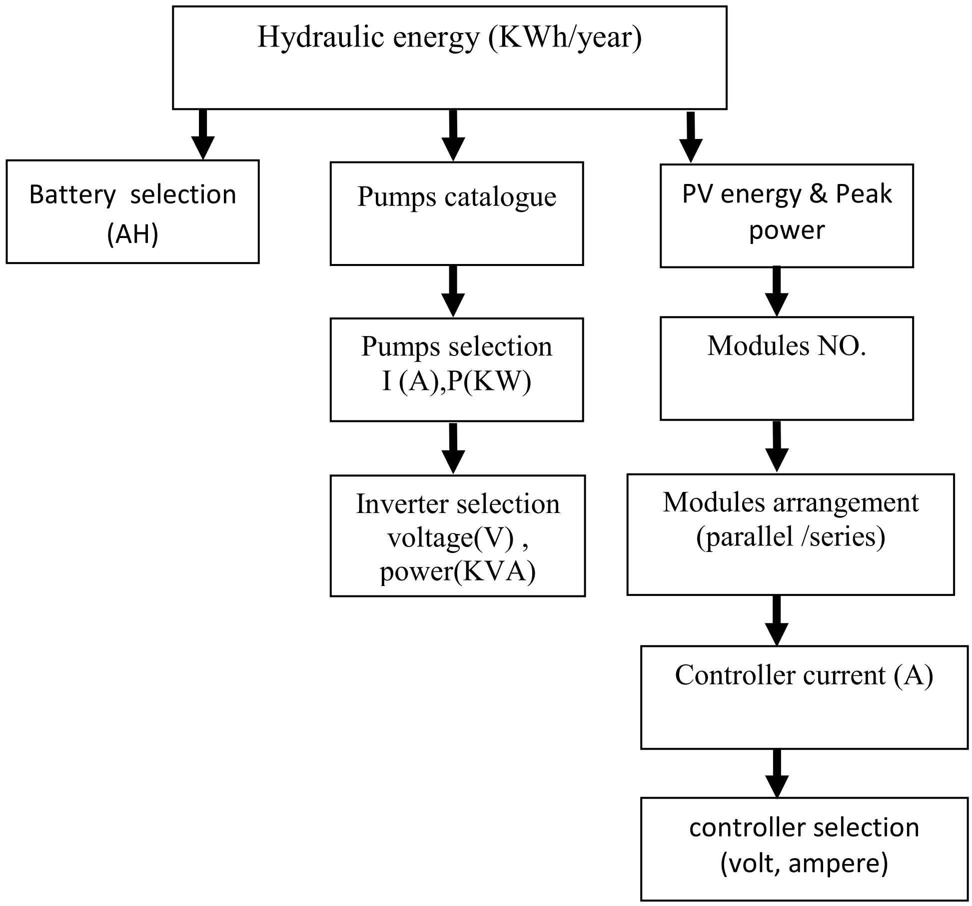


Figure (6.3):Program Steps for AC Configuration with Batteries

6.6 Mathematical Modeling for AC Configuration with Storage Tank

After calculation of hydraulic energy the programming steps for this configuration is presented in figure (6.4).

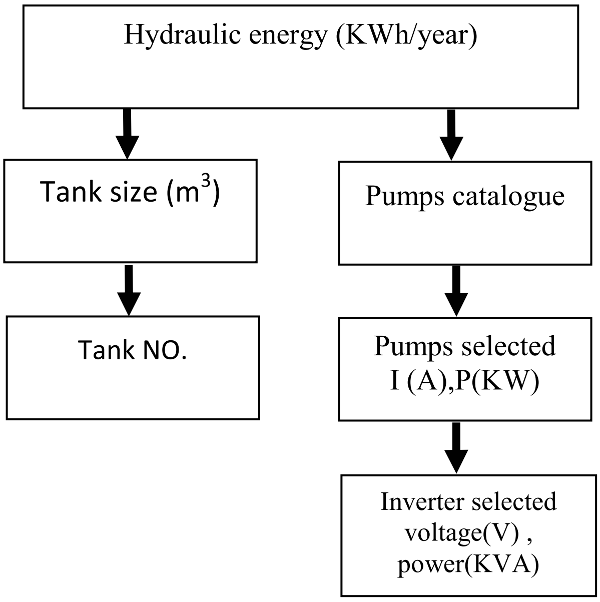


Figure (6.4): Program Steps for AC configuration with Tanks .

6.7 Mathematical Modeling for DC Direct Configuration with Storage Tank

After calculation of hydraulic energy the programming steps for this configuration is presented in figure (6.5).

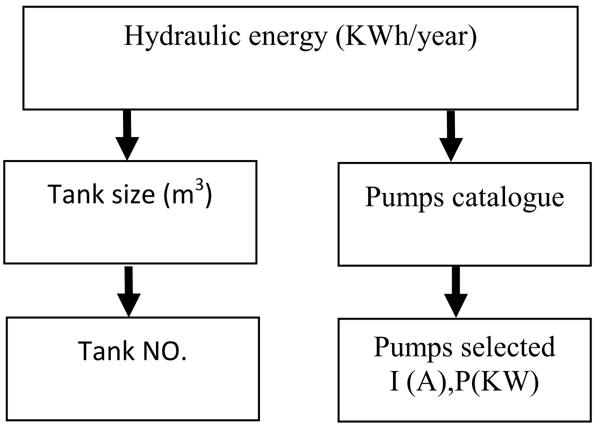


Figure (6.5): Program Steps for DC Direct Configuration with Tanks .

The detailed technical Excel programming steps could be represent as in figure (6.6)

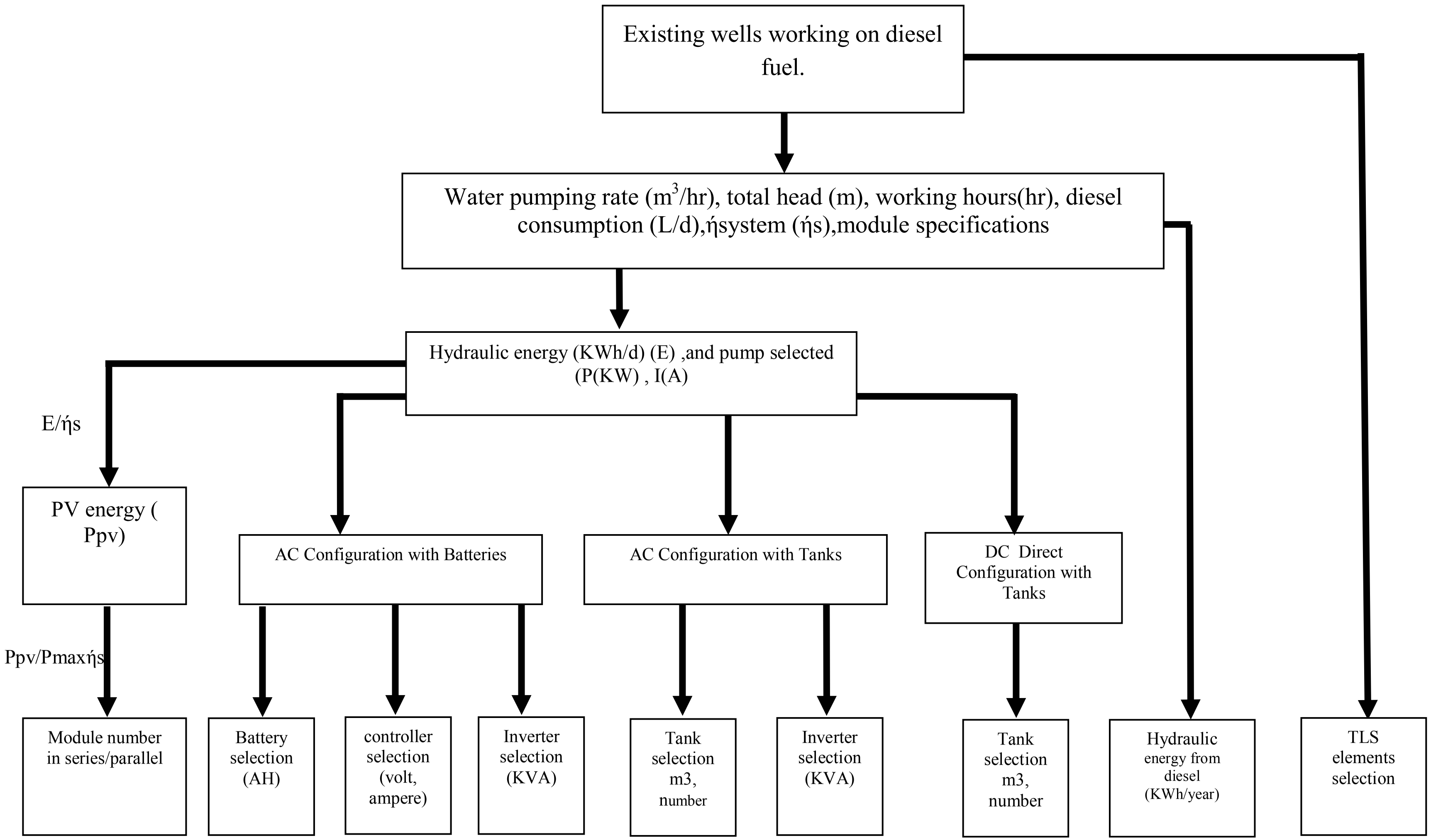


Figure (6.6):Detailed Technical Program flowchart

CHAPTER SEVEN

MATHEMATICAL MODELING OF WATER PUMPING FOR REAL WELLS (SIX CASES) IN THE WEST BANK

CHAPTER SEVEN

MATHEMATICAL MODELING OF WATER PUMPING FOR REAL WELLS (SIX CASES) IN THE WEST BANK

For the six studied wells that are studied in this thesis, the excel program designed in previous chapter can be implemented depending on available data from the questionnaire . After data was entered for the studied six wells into the program , the designed elements resulted from the program were presented in figures (7.1) to (7.6).

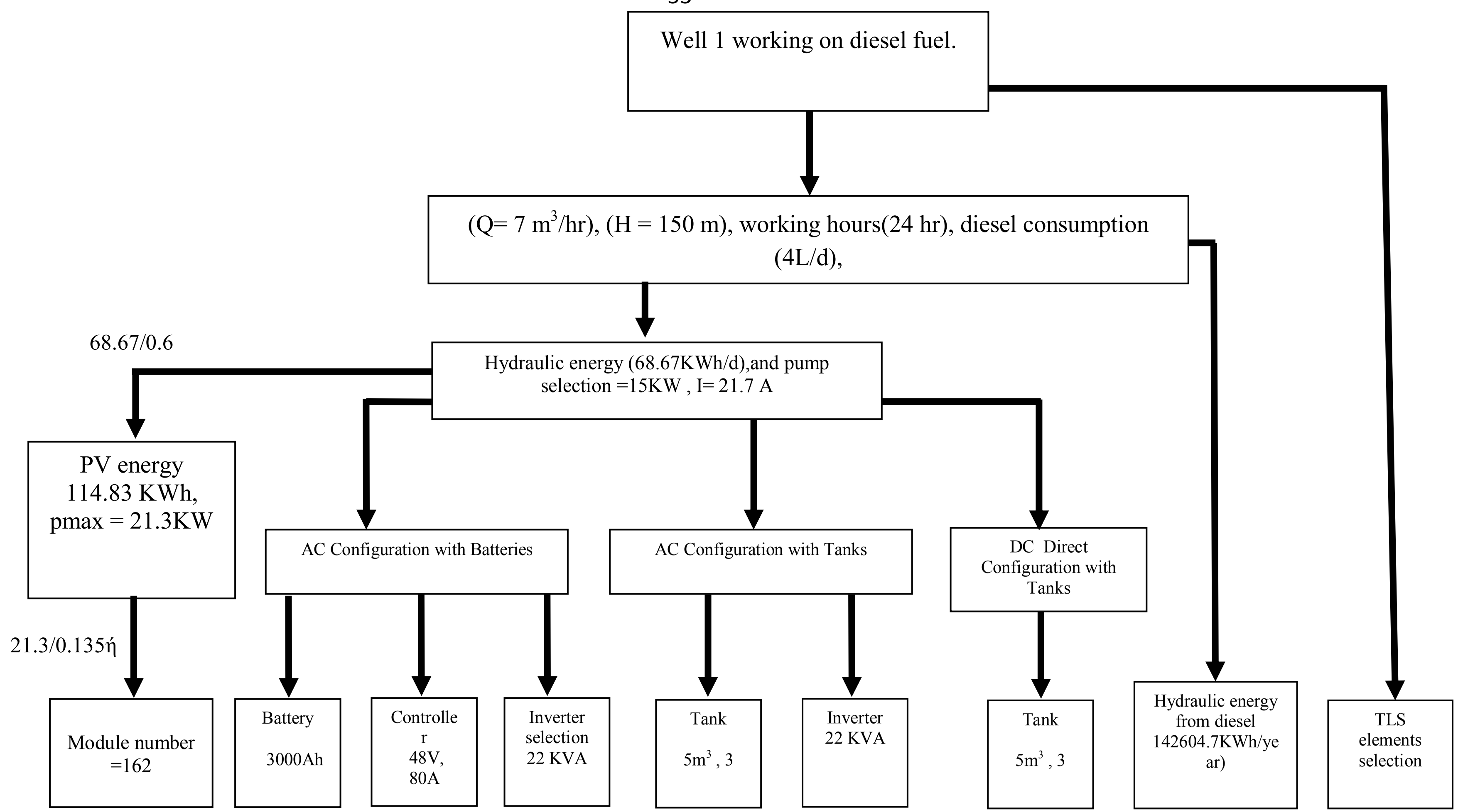


Figure (7.1): Program flowchart for well No. 1

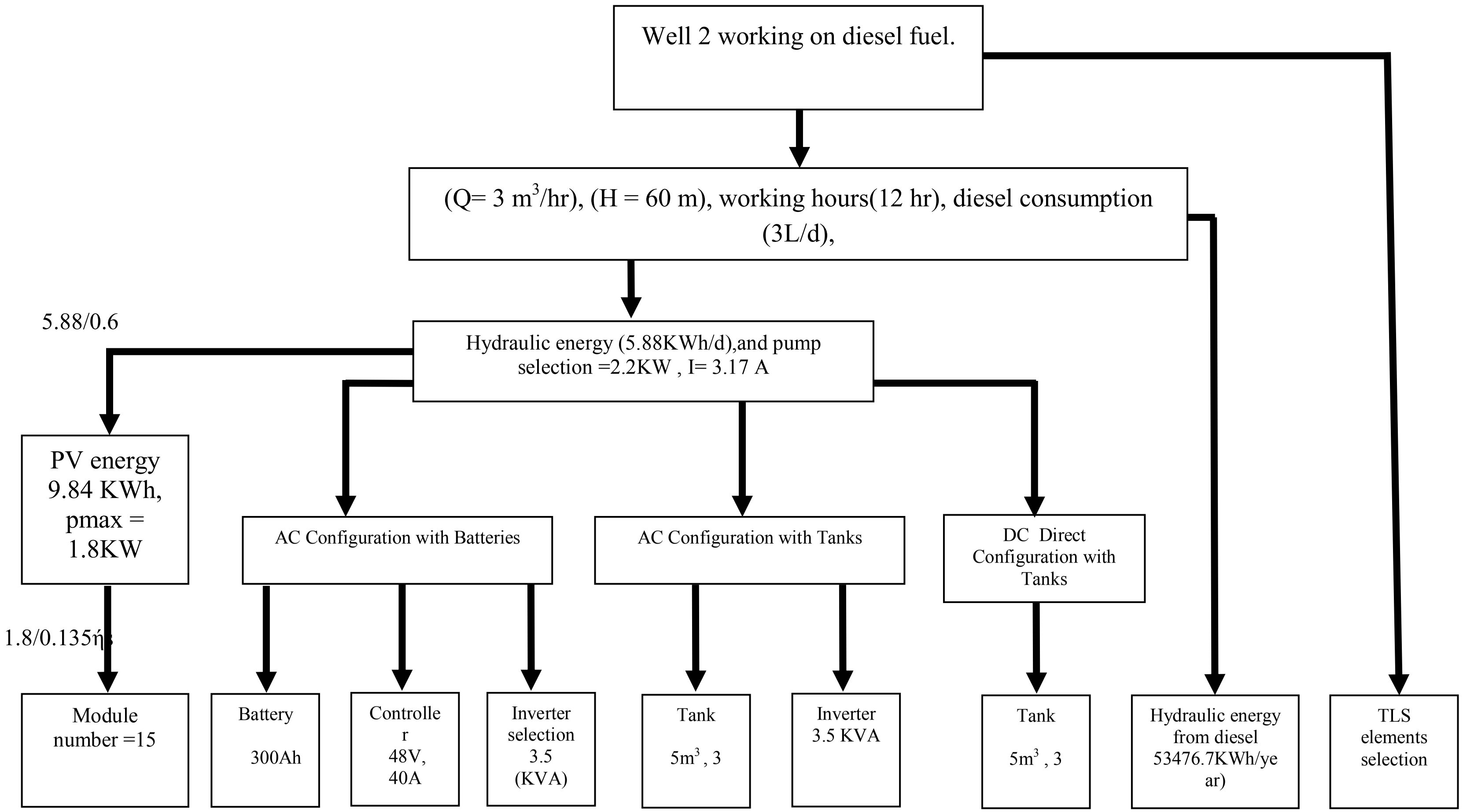


Figure (7.2): Program flowchart for well No. 2

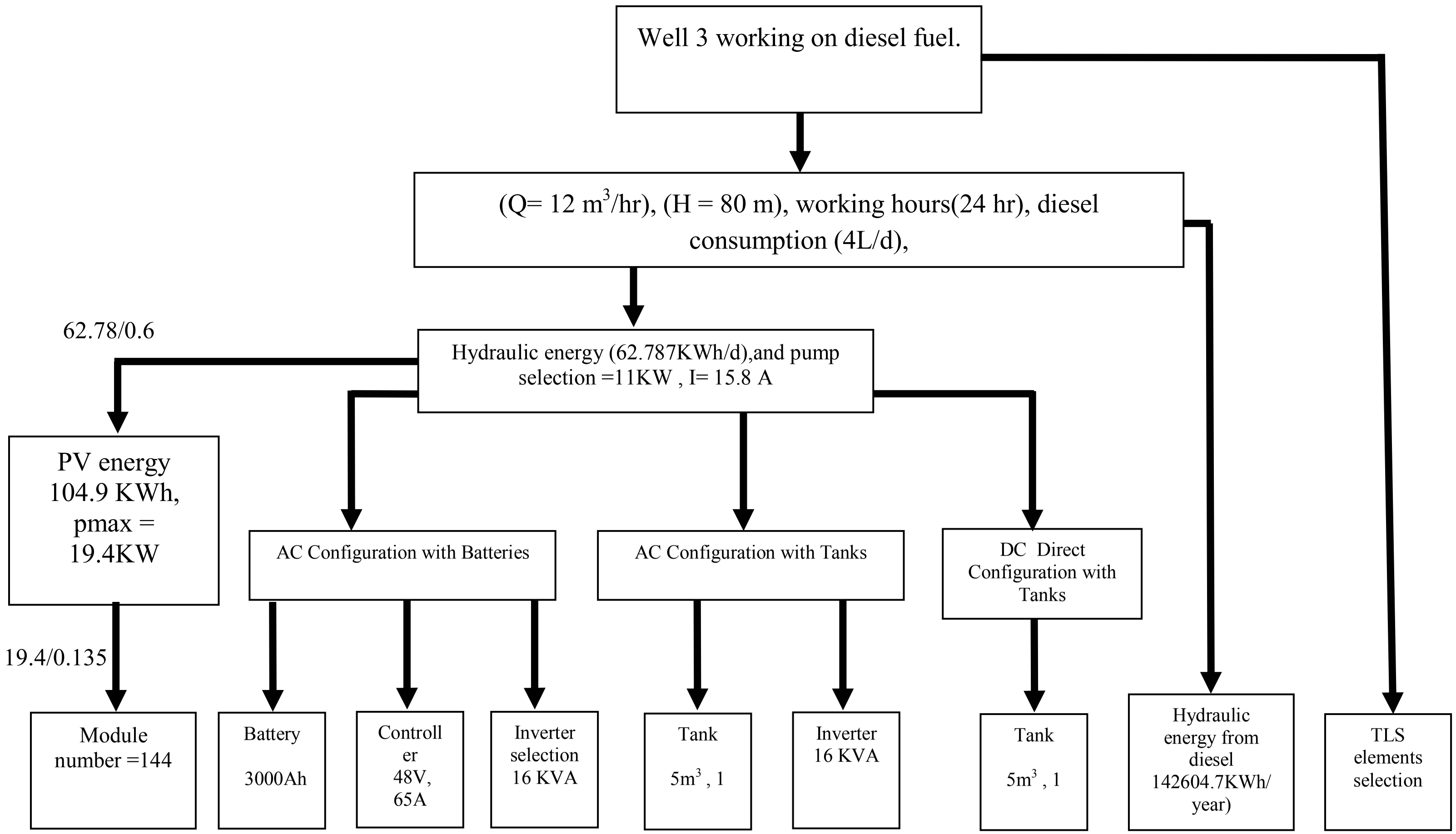


Figure (7.3): Program flowchart for well No. 3

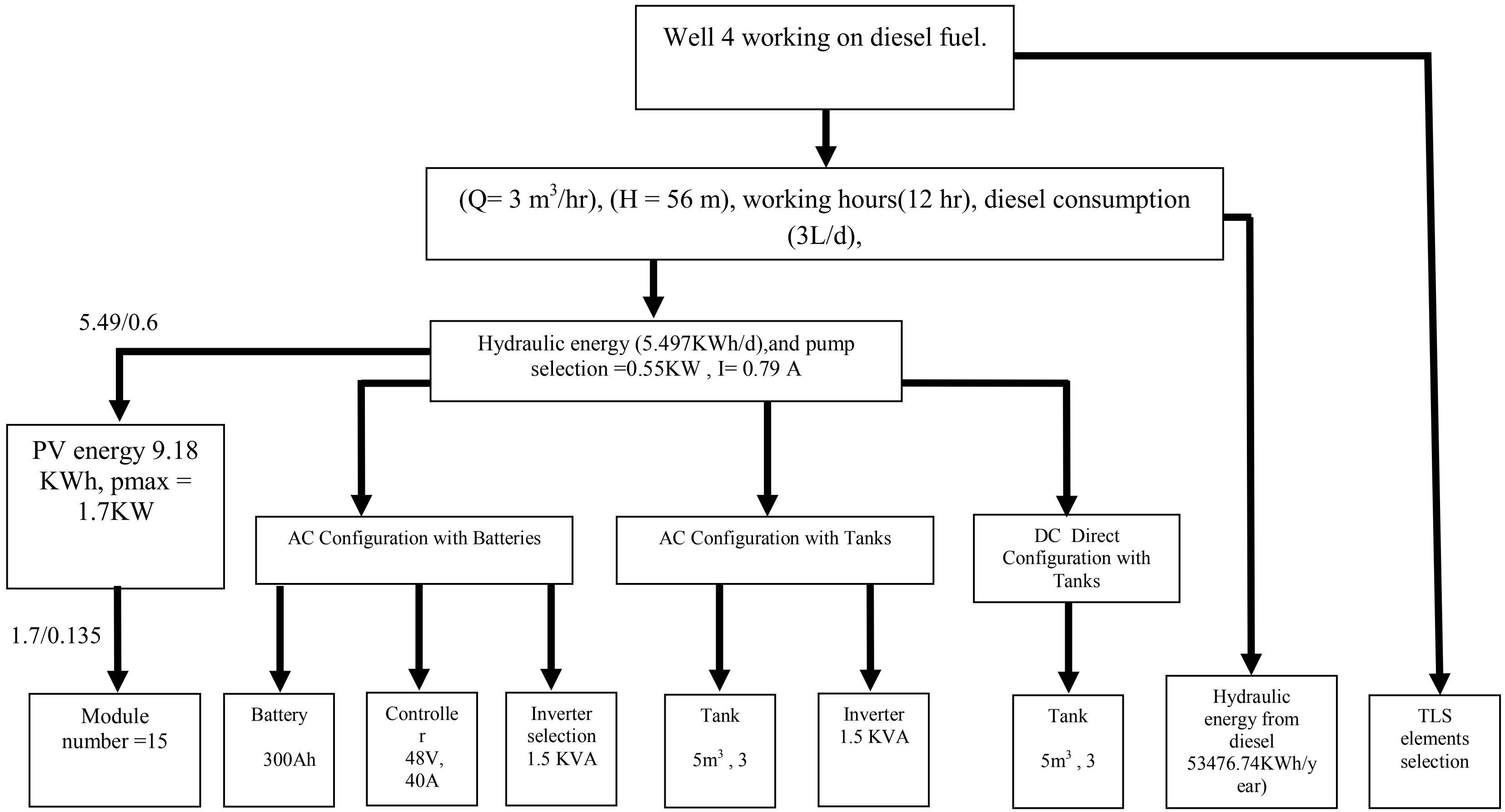


Figure (7.4): Program flowchart for well No. 4

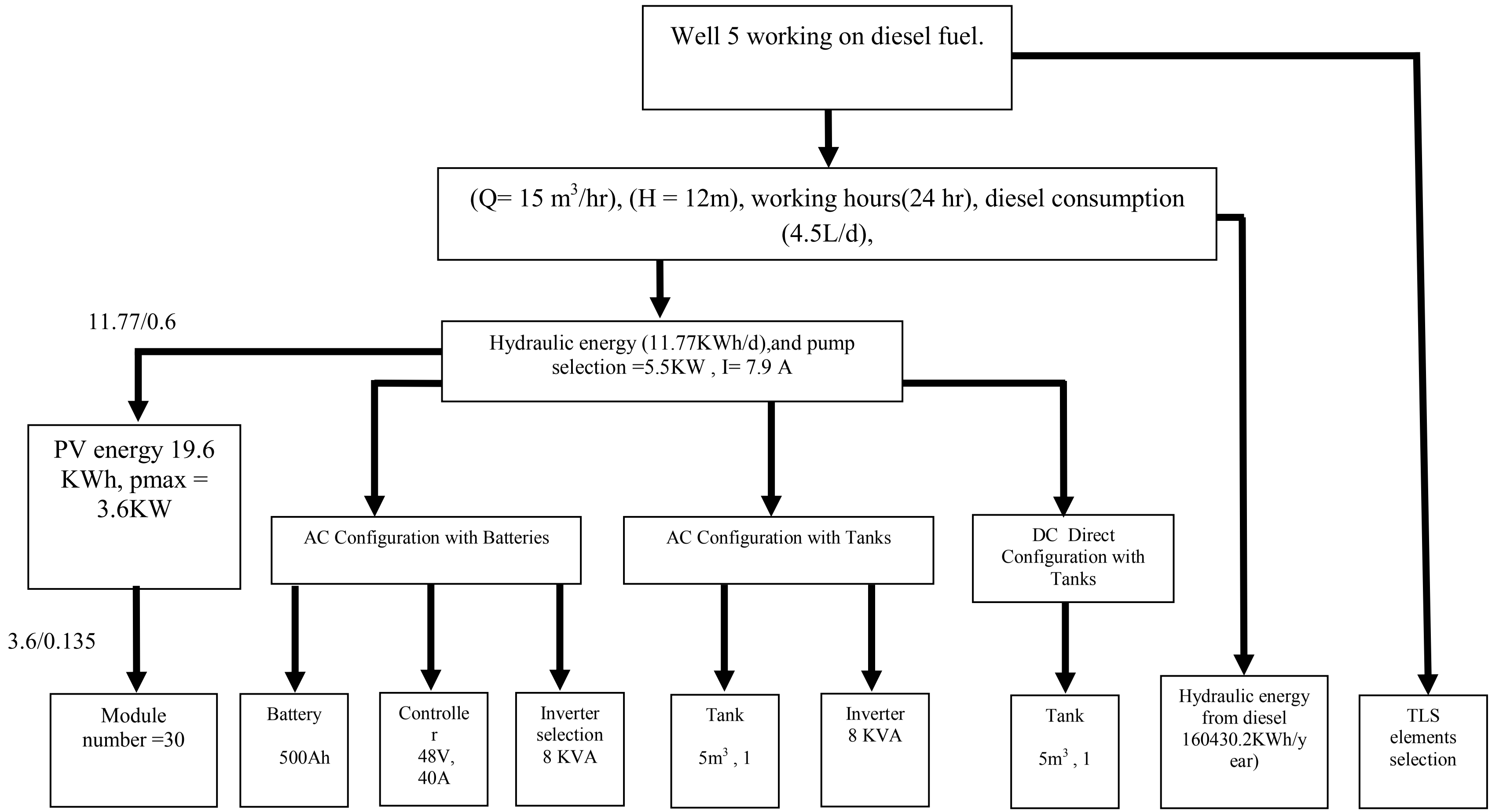


Figure (7.5): Program flowchart for well No. 5

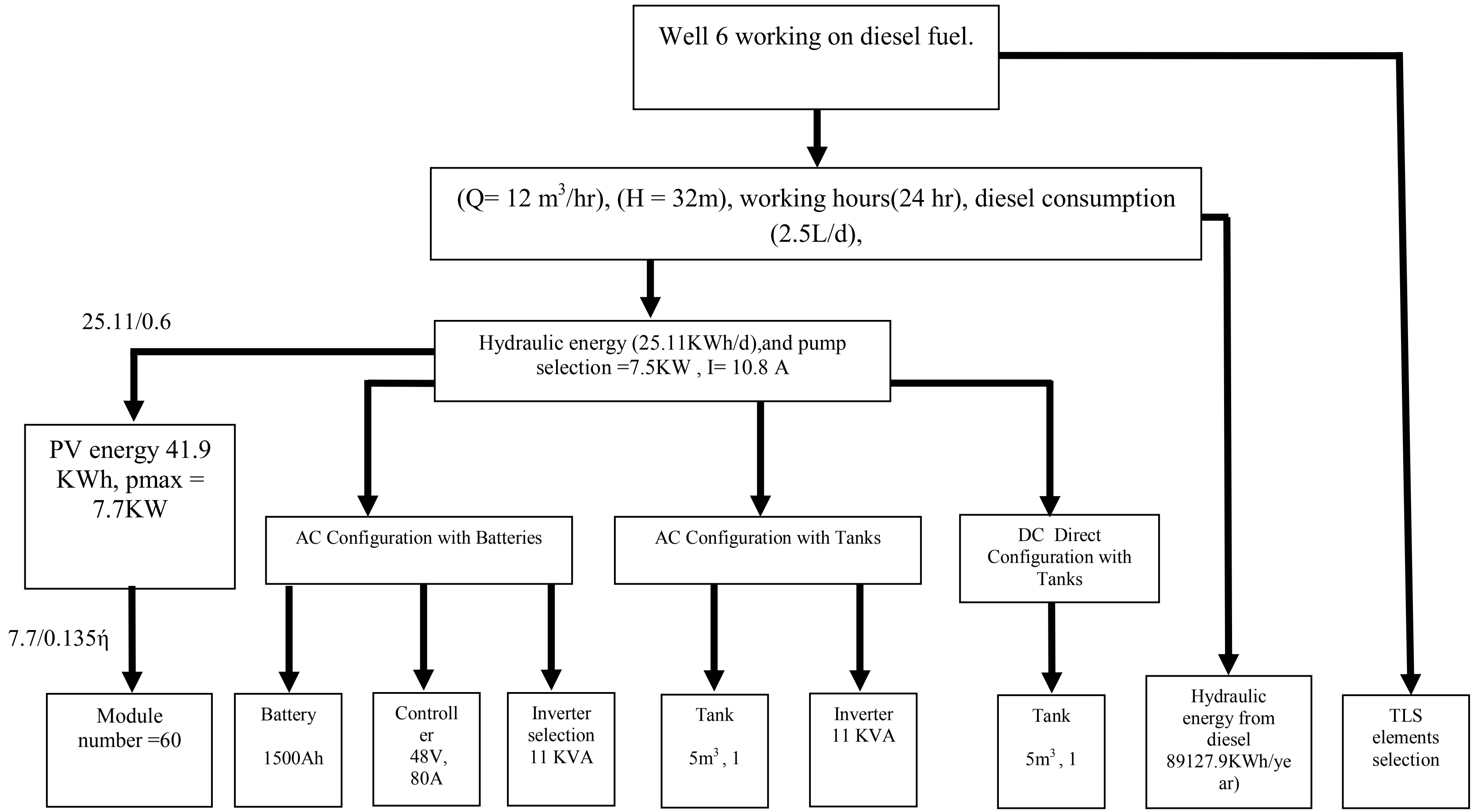


Figure (7.6): Program flowchart for well No. 6

The Excel designed program for DG cost calculation and CO_2 that emitted from the six studied wells is presented in figure (7.7), while the Excel designed program for PV elements selection and cost calculation with different configurations for the six studied wells in the west bank is presented in figure (7.8).

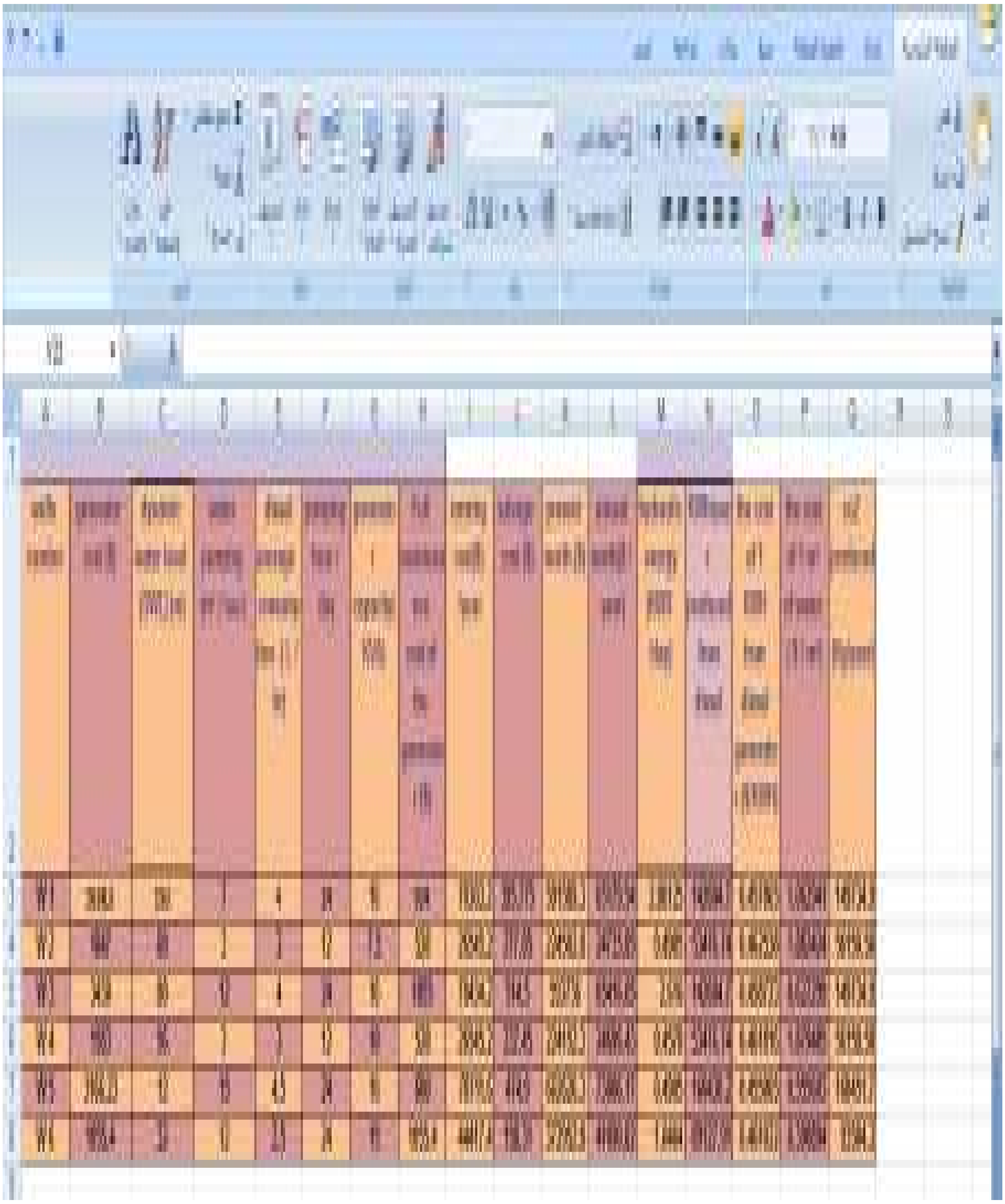


Figure (7.7): Excel designed program for diesel generator elements selection

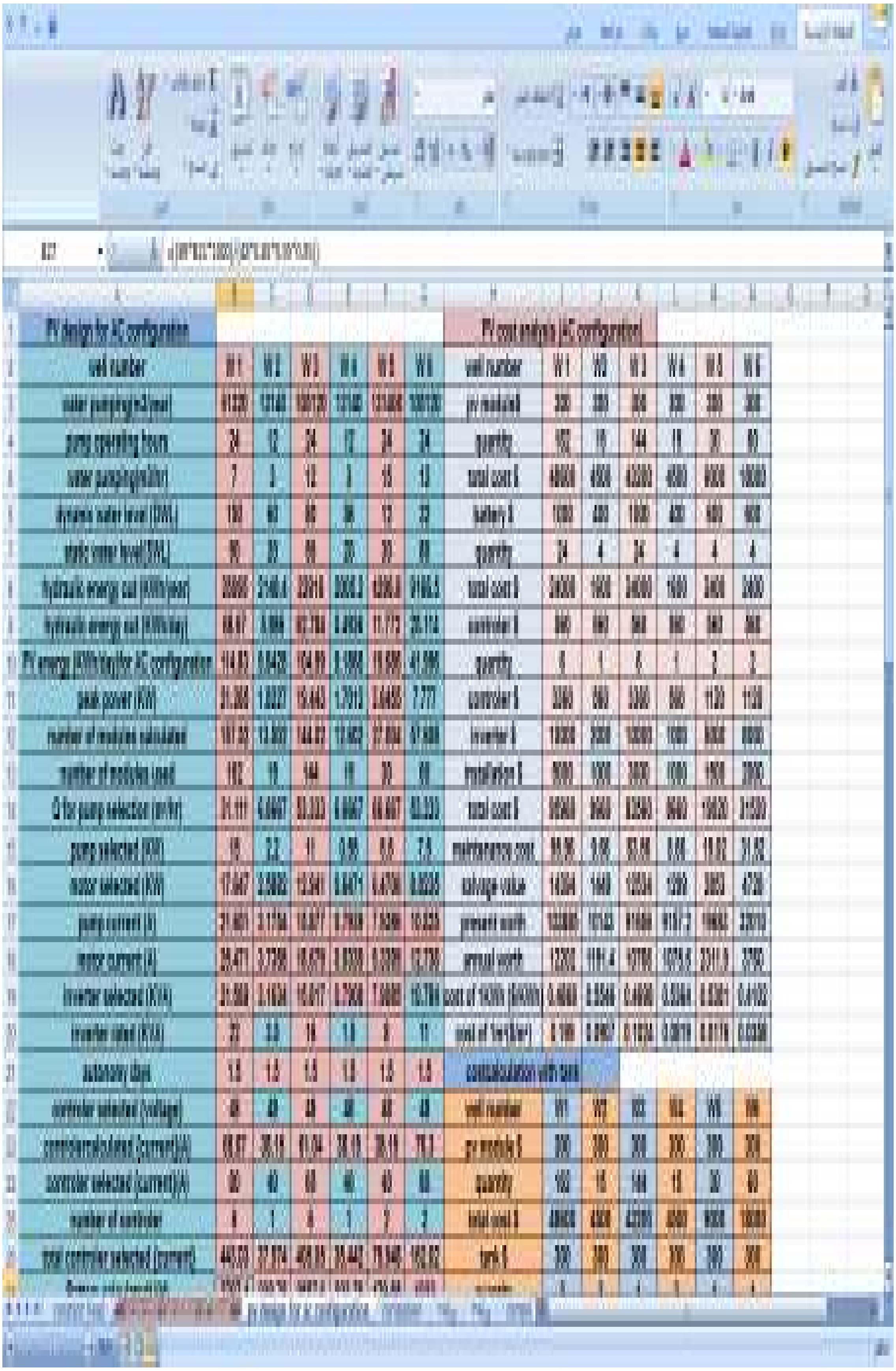


Figure (7.8): Excel designed program for PV elements selection

CHAPTER EIGHT

ECONOMICAL AND ENVIRONMENTAL IMPACT OF USING SOLAR ENERGY PUMPS VERSUS DIESEL AND ELECTRICAL NETWORKS

CHAPTER EIGHT

ECONOMICAL AND ENVIRONMENTAL IMPACT OF USING SOLAR ENERGY PUMPS VERSUS DIESEL AND ELECTRICAL NETWORKS

8.1The Cost for Energy Produced from PV System AC Configuration with Batteries.

The life cycle cost method is the most largely used method to evaluate the financial viability of the PV system, it is the sum of the capital cost and the present worth of all components in the system. The costs of a stand-alone PV system include acquisition costs, operating costs, maintenance costs, and replacement costs. All these costs have many specifications include [26]:The initial cost of the system (the capital cost) is high, no fuel costs, low maintenance costs, and low replacement costs (mainly for batteries).

For PV system, the life cycle cost will be estimated by making the assumptions as follow:

1. The lifetime of all the items is considered to be 20 years, except that of the battery which is considered to be 10years.
2. The interest rate is about 10%.

Table (8.1) show the fixed cost PV system components for well No.2

Table (8.1) The fixed cost for PV system with batteries

Components	Quantity	Unit price($)	Total price($)	Life time(years)
PV module Kyocera	15	300	4500	20
Battery cells	4	400	1600	10
Controller	1	560	560	20
Inverter	1	2000	2000	20
Installations		1000	1000	20
Total			9660	

The initial cost of the PV system AC configuration with batteries could be calculated by adding all PV system components.

For selected well in WB (well No.2) the resulted initial cost by taking information in table (8.1) is 9660 $.

The needed maintenance cost for PV system during the life time of the system, which assume to be 20 years, is about 2% of the total PV system cost [17]:this means that the yearly maintenance cost (Cm) is

$$Cm = (0.02 \text{ x initial PV cost}) / n \text{ years} \tag{8.1}$$

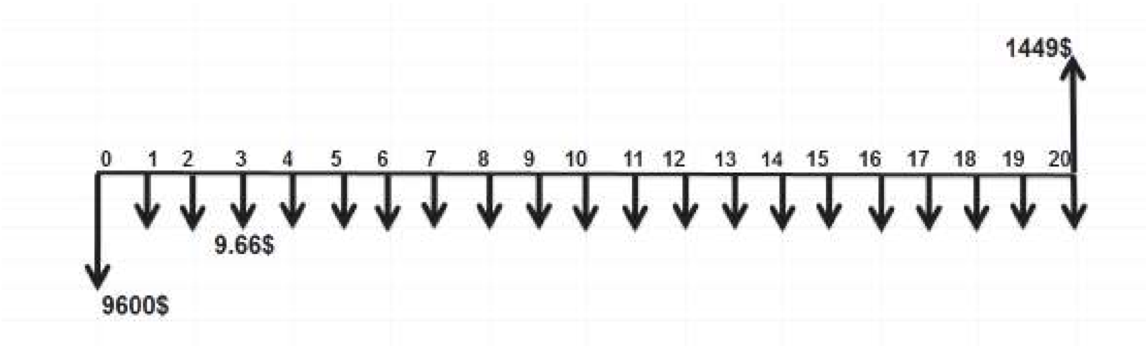
Based on eq.(8.1) Cm for well No.2 is 9.66 $/year.

Salvage value is taken about 15% from PV system cost and it is obtained as follow:

$$\text{Salvage} = 15\% \text{ x initial PV cost} \tag{8.2}$$

For well No.2 in WB using eq. (8.2) Salvage value resulted is 1449 $,and cost of second group of batteries after 10 years is equal to 1600 $.

Based on previous calculations life cycle cost for PV system is obtained by drawing cash flow for well No.2 as in figure (8.1):



Figure(8-1): Cash flow of PV System AC Configuration with Batteries for well No.2

As shown in the cash flow, figure (8.1), the values are randomly distributed so the equivalent uniform annual series is calculated by adding the values of initial cost of PV system, present worth of maintenance and operation, present worth of second group of batteries, and subtracting present worth of salvage.

For well No.2 in WB the life cycle cost of PV system can be calculated as:

The life cycle cost of PV system = 9660 + 9.66(P / A i ,n) –1449 (P / F i ,n) + 1600(P / F i ,n).

The term A(P / A i ,n) is represent the uniform-series present worth factor which begins at the end of year 1and extends for n years at an interest rate i, (P/A) can be calculated using eq.(8.3) [17]:

$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \qquad i \neq 0 \qquad (8.3)$$

The term $F(P \ / F \ \ i, n)$: represent the P/F factor that can determines the present worth P of a given future amount F after n years at interest rate i , and (P/F) can be calculated by eq.(8.4) [17]:

$$P = F\left[\frac{1}{(1 + i)^n}\right] \tag{8.4}$$

Appendix (4) presents a table prepared for engineering economy calculations with interest value 0.1.Based on all previous the present worth can be calculated as :

PW = 9660 + 9.66(P / A 10% , 20) – 1449(P / F 10% , 20) + 1600 (P / F10% , 10).

Using appendix (4) to take factors value then PW is 10143.4 $

Then to find the equivalent annual worth as eq.(8.5):

$$AW = PW\,(A / P\ i\ , n) \tag{8.5}$$

Using appendix (4),AW is 1191.44 $

The output energy is 2148.39 kWh/year, as in section (5.1) ,then cost of 1 kWh from the PV generator is 0.55 $ / kWh.

The annual water pumping rate as 13140 m^3/year , as in section (5.1), the cost of 1 m^3 from the PV generator is 0.09 $/$m^3$

8.2 Mathematical Modeling of Life Cycle Cost Calculation(LCC) for PV System AC Configuration with Batteries.

After program construction for PV system AC configuration with batteries, LCC program calculation was designed in Excel program, prices of all elements used were introduced to the program ,the unit price was calculated through the program, the designed programming steps are presented as in figure (8.2).

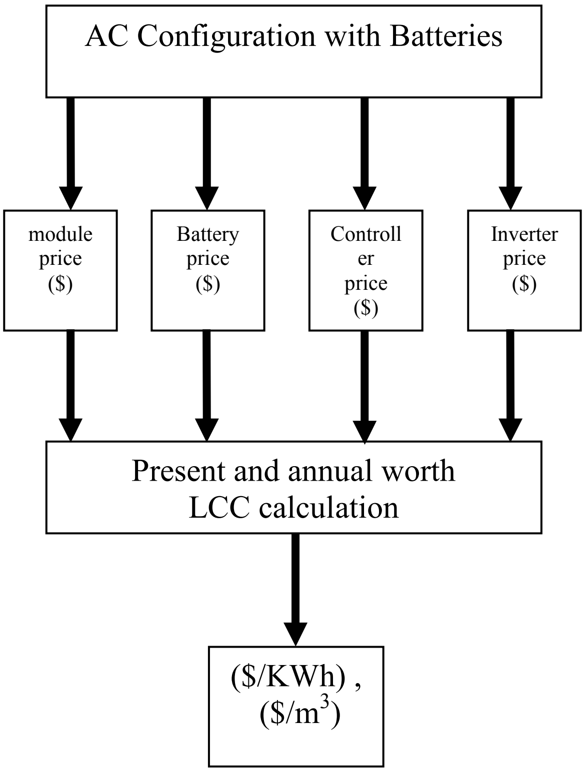


Figure (8.2): LCC calculations for AC Configuration with batteries

For well No.2 the entered values for programming steps would be as in figure (8.3).

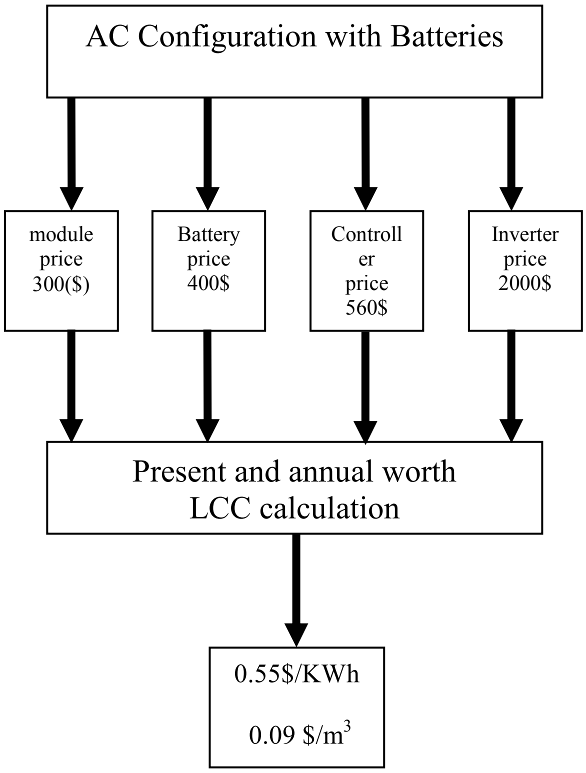


Figure (8.3): LCC calculations for AC Configuration with batteries for well No.2

8.3The Cost for Energy Produced from PV System AC Configuration with Storage Tank .

For this PV water pumping configuration the components and their fixed cost for well No.2 in WB are summarized in the table (8.2)

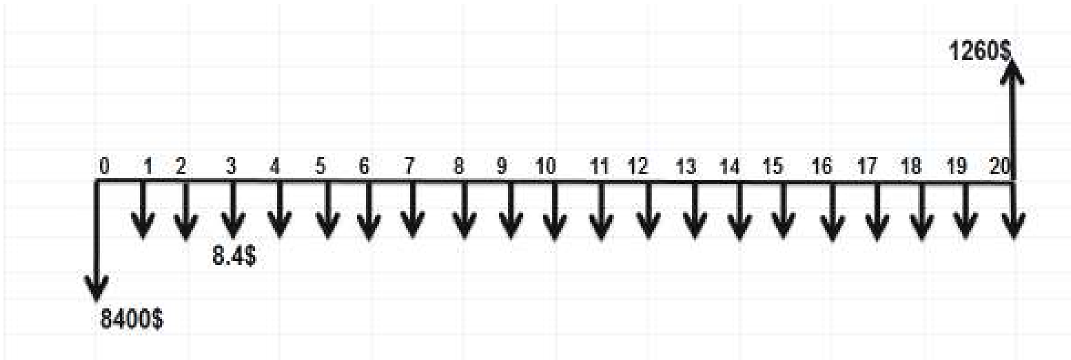
Table (8.2): The fixed cost for PV system with storage tank

Components	Quantity	Unit price($)	Total price($)	Life time(years)
PV module Kyocera	15	300	4500	20
Tank	3	300	900	10
Inverter	1	2000	2000	20
Installations		1000	1000	20
Total			8400	

The initial cost of the PV system AC configuration with storage tank could be calculated by adding all PV system components.

For well No.2 in WB the resulted initial cost by taking information in table (8.2) is 8400 \$.The annual maintenance cost (Cm) calculated using eq. (8.1) is 8.4 \$/year. Salvage value calculated using eq.(8.2) is 1260 \$

Based on previous calculations life cycle cost for PV system is obtained by drawing cash flow for well No.2 as in figure (8.4).



Figure(8.4): Cash flow of PV system AC configuration with storage tank for well No.2.

Same calculations as in the previous section and using factors in appendix (4) the present worth is 8284.278 \$, and the equivalent annual worth is 973.0713 \$ **.**

The output energy is 2148.39 kWh/year, and the annual water pumping rate = 13140 m^3/year as in section (5.1):

The cost of 1 kWh from the PV generator is 0.45 \$ / kWh, while the cost of 1 m^3 of water is 0.07 \$/m^3

8.4 Mathematical Modeling of Life Cycle Cost Calculation for PV System AC Configuration with Tanks.

After program construction for PV system AC configuration with tanks, LCC program calculation was designed in Excel program, prices of all elements used were introduced to the program ,the unit price was calculated through the program, the designed programming steps are presented as in figure (8.5).

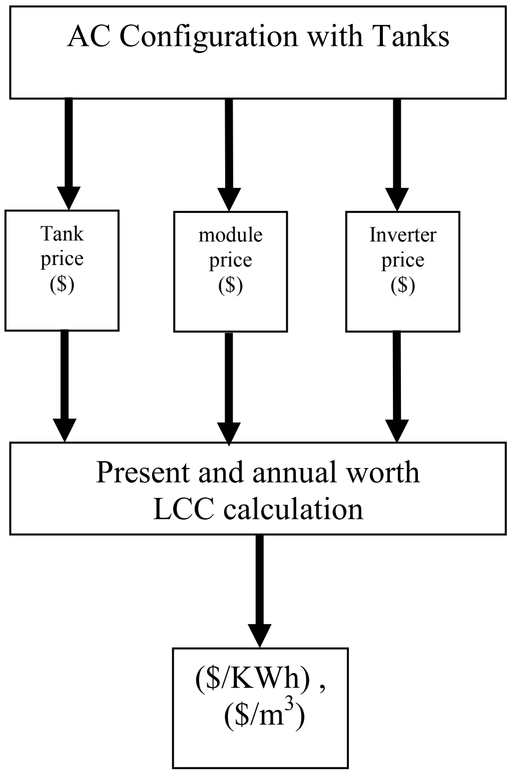


Figure (8.5): LCC calculations for AC configuration with tanks.

For well No.2 the entered value for programming steps would be as in figure (8.6).

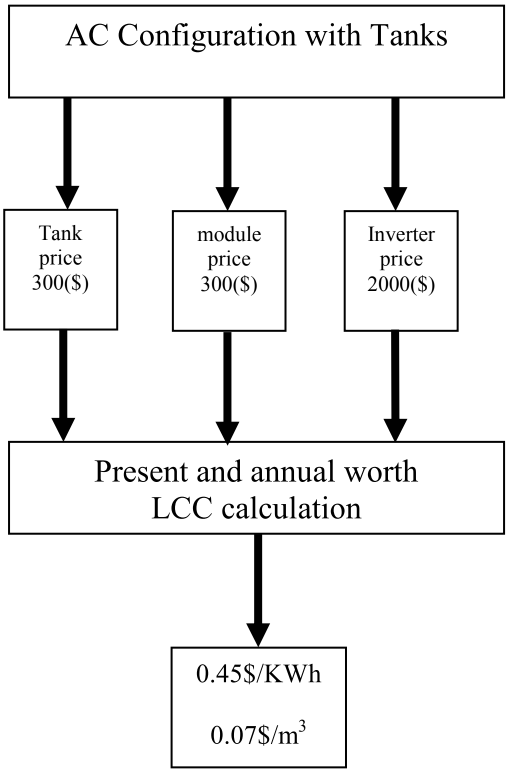


Figure (8.6): LCC calculations for AC configuration with tanks for well No.2.

8.5 The Cost for Energy Produced from PV System DC Direct Configuration with Storage Tank .

For this PV water pumping configuration the components and their fixed cost for well No.2 in WB are summarized in the table (8.3)

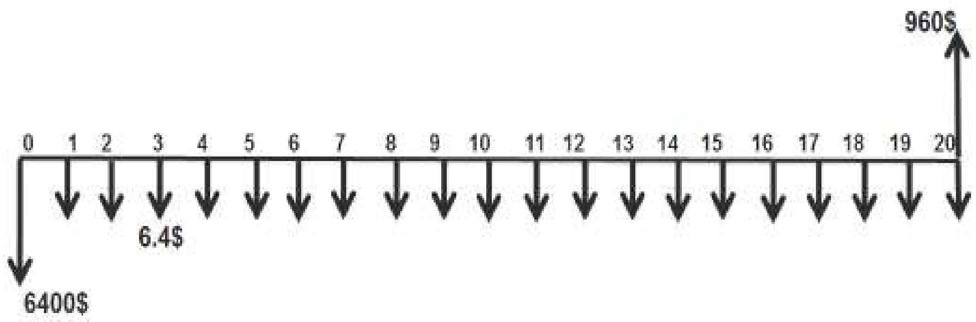
Table (8.3): The fixed cost for PV system DC direct configuration with storage tank.

Components	Quantity	Unit price($)	Total price($)	Life time(years)
PV module Kyocera	15	300	4500	20
Tank	3	300	900	10
Installations		1000	1000	20
Total			6400	

The initial cost of the PV system DC direct configuration with storage tank could be calculated by adding all PV system components

For well No.2 in WB the resulted initial cost by taking information in table (8.3) is 6400 $.The annual maintenance cost (Cm) calculated using eq. (8.1) is 6.4 $/year. Salvage value calculated using eq.(8.2) is 960 $

Based on previous calculations life cycle cost for PV system is obtained by drawing cash flow for well No.2 as in figure (8.7).



Figure(8-7): Cash flow of PV system DC direct configuration with storage tank for well No.2.

Same calculations as in the previous section and using factors in appendix (4) the present worth is 6811.831 $,and the equivalent annual worth is 741.3877 $.

The cost of 1 kWh from the PV generator is 0.35 $ / kWh, while the cost of 1 m^3 of water is 0.06 $\$/m^3$.

8.6 Mathematical Modeling of Life Cycle Cost Calculation for PV System DC Direct Configuration with Tanks.

After program construction for PV system DC direct configuration with tanks, LCC program calculation was designed in Excel program, prices of all elements used were introduced to the program ,the unit price was calculated through the program, the designed programming steps are presented as in figure (8.8).

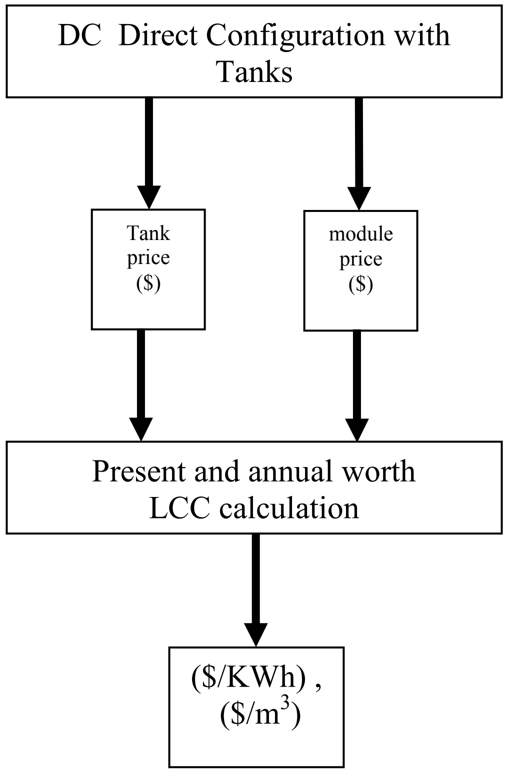


Figure (8.8): LCC calculations for DC direct configuration with tanks.

The entered value for programming steps for well No.2 would be as in figure (8.9).

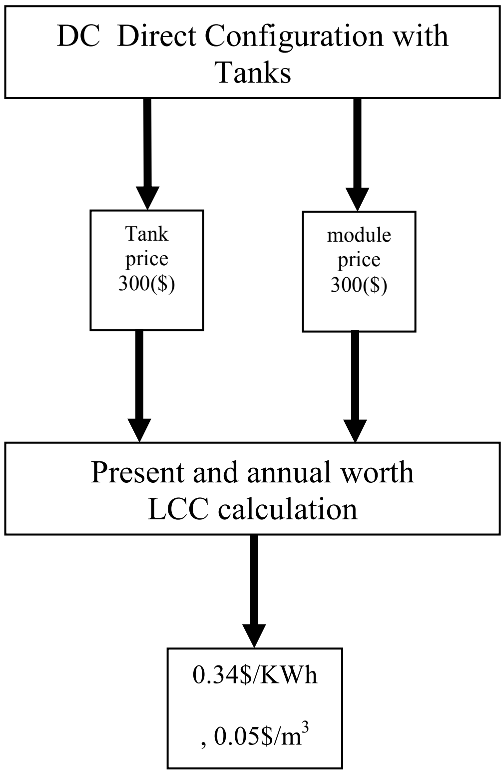


Figure (8.9): LCC calculations for DC direct configuration with tanks for well No.2.

8.7The Cost for Energy Produced from Diesel Generator (DG)

To demonstrate the viability of PV pumping system, we must compare it with other energy conventional energy sources so the cost of 1 KWh and 1 m^3 pumped by diesel will be analyzed.

The energy produced by diesel generator (Ed) can be calculated as:

$$Ed = (Dc \times Fc \times \acute{\eta}g) / (Fwh) \quad (8.6)$$

Where Dc is diesel consumption, Fc is factor conversion liter to calorie, ήg is generator efficiency, and Fwh is factor conversion calorie to kilo watt hour.

Each one liter of diesel produces 10000 kilo calorie , and each one kilo watt hour equal to 860 kilo calorie and if the efficiency of generator ήg is 0.35, for typical well No.2 in west the KWh produce from 3 L/hr can calculated by substituting these values in eq.(8.6) is 53476.74 KWh/year

The annual total cost =annual fixed cost + annual running cost (8.7)

Using values in table (5.1) for well number 2 to estimate the LCC for DG, and assuming the generator life time 10 years.

Salvage value is taken about 15% from diesel generator cost this value is every 10 years and it is obtained as follow:

Salvage value for diesel generator = 15% x Generator cost (8.8)

Using eq.(8.8) for well No.2 , salvage value is 277.05 $.

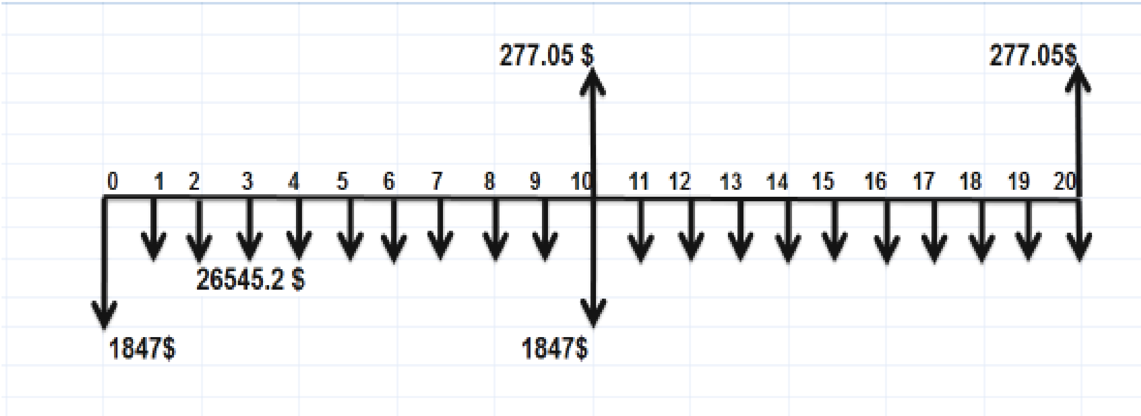
The annual fixed cost from table (5.1) is 1847 $

The annual running cost = annual diesel cost + annual maintenance cost + oil cost (8.9)

Oil cost = 0.1 × diesel cost (8.10)

For typical well No.2 using eq.(8.9),(8.10) and if diesel cost is 1.8 $ /L, then annual diesel cost is 23652 $/year ,the annual oil cost is 2365.2 $/year and the annual running cost is 26545.2 $ /year

Based on previous calculations life cycle cost for DG is obtained by drawing cash flow for well No.2 as in figure (8.10).



Figure(8.10): Cash flow of diesel generator for well No.2

The present worth can be calculated as :

PW = 1847 + 26545.2(P / A 10% , 20) + 1847(P / F 10% , 10) – 277.05 (P / F 10% , 10) - 277.05 (P / F 10% , 20)

Using appendix (4) then PW is 224502.8 $.

The equivalent annual worth as:

AW = 224502.8 (A / P 10% , 20).

Using appendix (4) AW is 24735.05 $

The cost of 1 kWh from the DG generator is 0.46 $ / kWh, while the cost of 1 m^3 of water is 1.88 $\$/m^3$.

8.8 Mathematical Modeling of Life Cycle Cost Calculation for DG .

From data of existing wells that had been worked on DG, hydraulic energy was calculated through an excel program that designed as in figure (8.11).

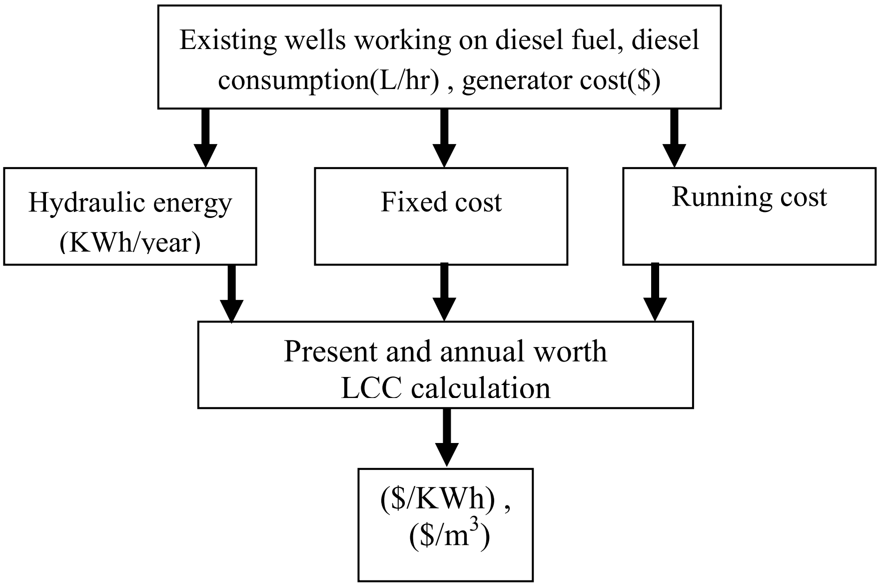


Figure (8.11): LCC Calculation for DG

For well No.2 the entered value for programming steps would be as in figure (8.12).

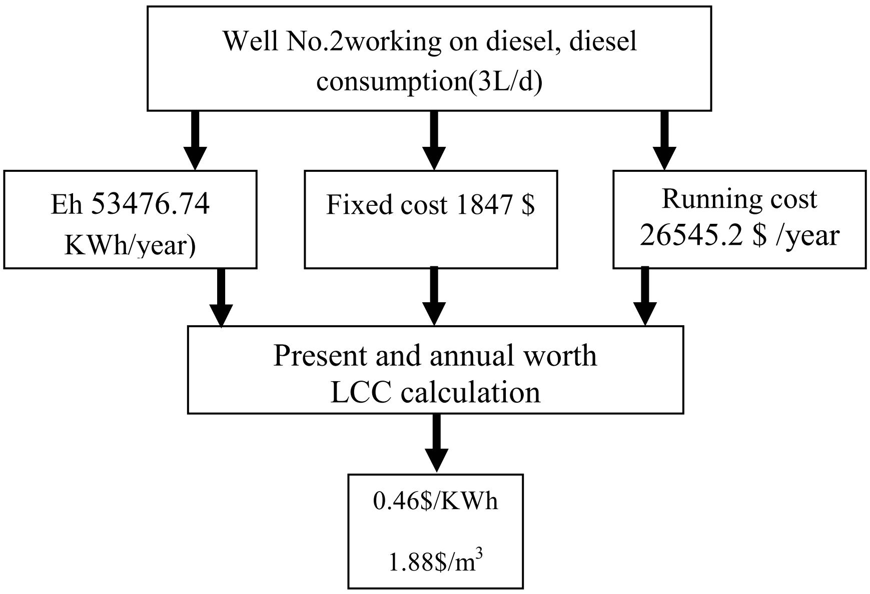


Figure (8.12): LCC Calculation for DG for well No.2

8.9The Cost for Energy Produced from Expansion of Electrical Net work

The six studied wells in this thesis are in different remote villages, thus there are difficulties to make one cost calculation or selection using one program for the extension of the electric grid for all of them. However the methodology to be used is explained below.

The annual total cost could be calculated using eq.(8.7) . The annual fixed cost include: the cost of all elements used in the expanding of the electricity grid , such as: Tower, Conductors ,Insulators, Earthing electrodes, Isolator switch, Transformer, Distribution board, and mechanical parts, all of these could be assumed as initial cost.

Annual running cost = Energy cost + cost of electric losses + maintenance cost (8.11)

Cost of energy from grid = HE × energy cost (8.12)

Having these values available, and considering salvage value as 15% of initial cost, cash flow can drawn and LCC can be done to calculate present worth ($),and annual worth ($).

For six wells in WB, energy cost is 0.18 $/KWh, so the cost of 1 KWh, and the cost of 1 m^3 could be calculated as in eq.(8.13), (8.14).

$/KWh = Cost of energy from grid / HE(KWh/year) (8.13)

$/$m^3$ = Cost of energy from grid / Q (m^3/year) (8.14)

For well No.2 in WB the cost of 1 kWh is 0.18 $ / kWh, while the cost of 1 m3 of water is 0.074 $/m3,for other wells results would be in table (8.4).

It is known that the annual running cost of electricity may be less than PV, but must take into account that the fixed cost is much larger than the PV.

8.10 Mathematical Modeling of Life Cycle Cost Calculation for Distribution Line System

The LCC calculation for TLS could be summarized in programming steps as in figure (8.13)

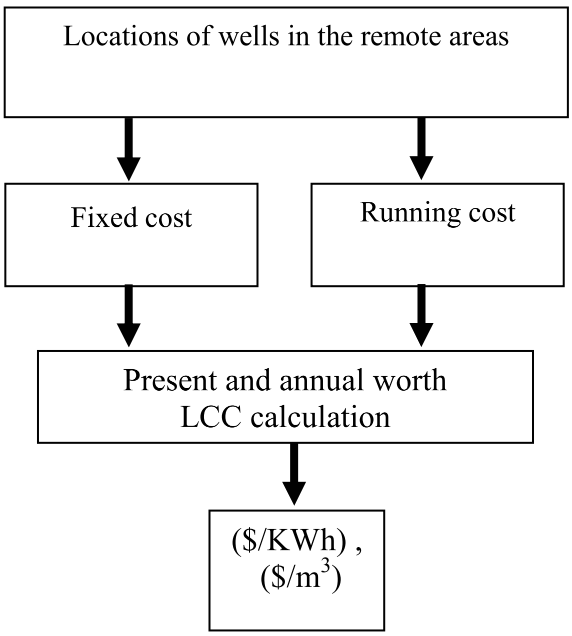


Figure (8.13): LCC Calculation for TLS

For well No.2 the entered value for programming steps would be as in figure (8.14).

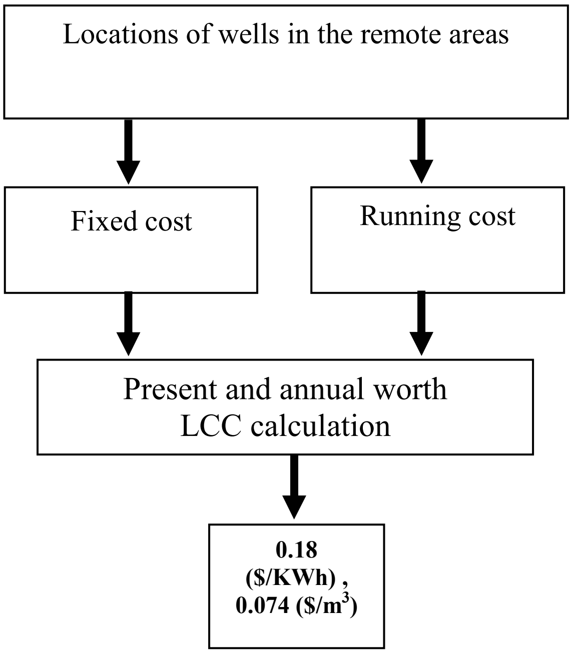


Figure (8.14): LCC Calculation for TLS for well No.2

8.11 The Energy Cost Comparison Between all Configurations for Diesel and PV

After applying the designed program to input data for all configurations, economic results could be summarized as in the table (8.4).

Table (8.4) Comparison of Producing (1KWh,1m³) Between Different Energy Sources

Configuration type	Life cycle cost	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6
PV system with AC pump and battery	$/KWh	0.410186	0.469796	0.486837	0.531061	0.536416	0.554575
	$/m³	0.020537	0.051955	0.067145	0.075961	0.102416	0.198995
PV system with AC pump and storage tank	$/KWh	0.287147	0.325429	0.336212	0.434171	0.480232	0.502137
	$/m³	0.014197	0.029318	0.062598	0.073283	0.082099	0.133019
PV system with DC pump and storage tank	$/KWh	0.234567	0.247055	0.251908	0.296857	0.418044	0.447905
	$/m³	0.009707	0.021966	0.051136	0.06835	0.06835	0.100984
Pumping by diesel	$/KWh	0.455056	0.457065	0.458723	0.461032	0.461816	0.462538
	$/m³	0.390894	0.555603	0.622299	1.062941	1.879485	1.882424
Pumping by electricity	$/KWh	0.18	0.18	0.18	0.18	0.18	0.18
	$/m³	0.074	0.029	0.039	0.027	0.005	0.015

For more clearly view figure (8.15) shows the comparison between the cost ($/KWh) of water pumping by diesel verses solar cells and electricity.

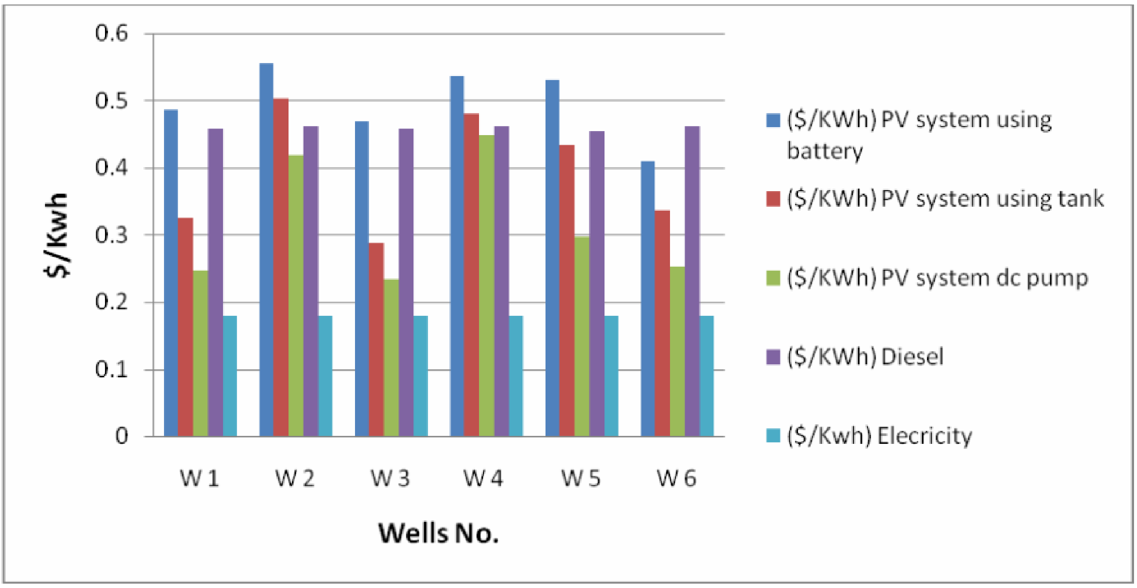


Figure (8.15):The Cost of Producing One kilowatt hour Energy from Different Sources with Different Head and Water Pumping Rate

From figures (8.15) we note that the cost of pumping water by diesel is more than water pumping using electricity or PV system knowing that the running cost for diesel is without fixed cost value ,so if we take fixed cost then the life cycle cost will rise more and more.

If electricity is available then it will be the best option to pump water with minimum cost taking into account only the value of running cost, while fixed cost vary from one case to another.

For some of water pumping rate and head the life cycle cost for pumping water using PV system with AC pump and storage battery will be larger than pumping water using diesel.

Also figure (8.16) shows the comparison between the cost ($\$/m^3$) of water pumping by diesel verses solar cells and electricity.

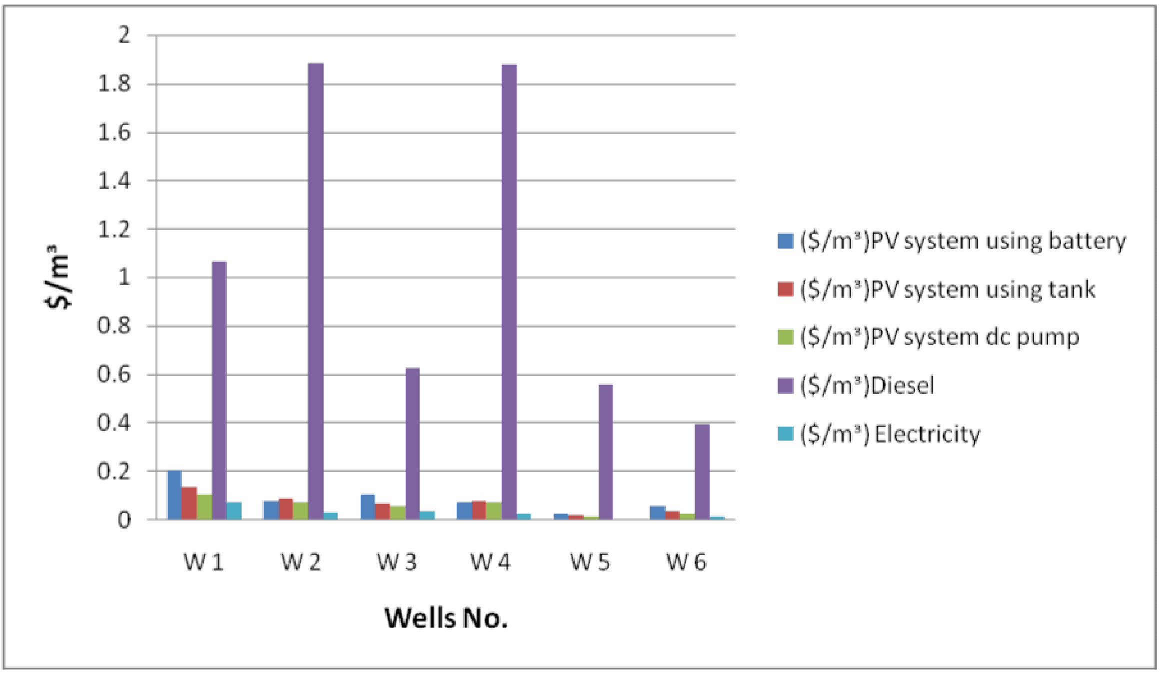


Figure (8.16):The Cost of Pumping One Meter Cube from Different Sources with Different Head and Water Pumping Rate

The cost of meter cube for water pumping by PV system is smaller than that pumping by diesel generator.

The techno-economical program steps for well No.2 will be as in figure(8.17)

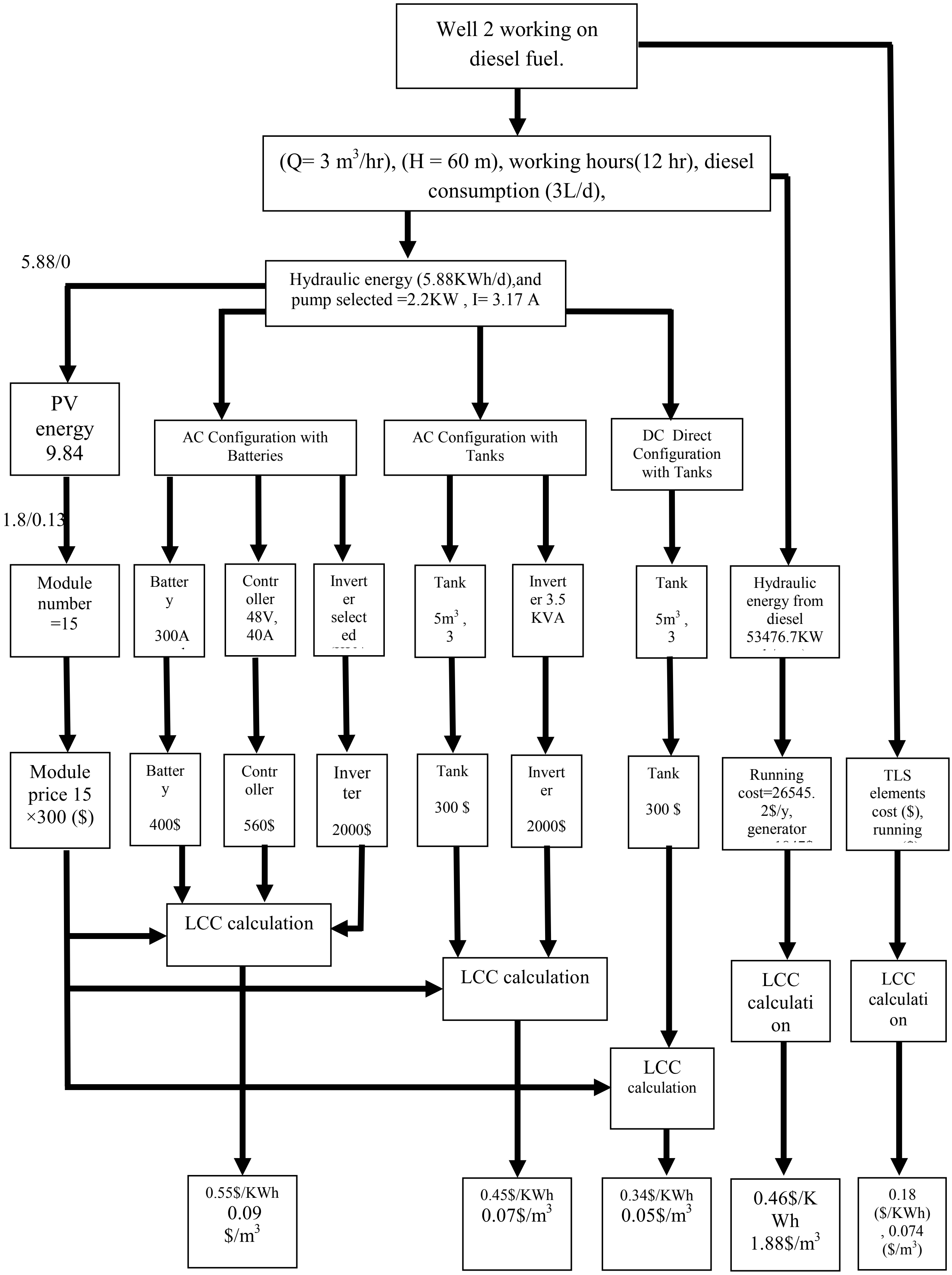


Figure (8.17): Full program with technical and economic steps.

8.12 Environmental Impact of Using PV

Replacement of diesel generator with PV have a significant environmental impact especially on air quality due to combustion process. For electricity the amount of CO_2 emitted per kilowatt-hour (KWh) depends on the method of generation; nuclear energy has no CO_2 emission or insignificant amount, while energy generated from coal produce a lot of CO_2 compared to gas.

Table (8.5) presents a life cycle analysis of CO_2 emissions for various methods of powering the electrical generator.

Table (8.5) : CO_2 emission from the different methods of generating electricity

Fuel	CO_2 emitted (g/KWh)
Diesel or coal	1050
Natural (combined cycle)	430 on average
Nuclear	6
Hydroelectric	4
Wood	1500

For diesel the environmental impact will be expressed numerically as: 1KWh energy produced from conventional energy sources (diesel) cause the production of 1.05 Kg of carbon dioxide. Table (8.6) presents amounts of CO_2 that can be emitted from generating 1 KWh for the studied wells in WB using conventional energy.

Table (8.6) : CO_2 produced by diesel combustion

Well {Q(m^3/hr),H(m)}	KWh/year from diesel	CO_2 produced (Kg/year)
(32,150)	142604.65	149734.9
(7,60)	53476.74	56150.58
(54,80)	142604.7	149734.9
(7,12)	53467.74	56150.58
(67,12)	160430.2	168451.7
(54,32)	89127.91	93584.3

From table (8.8) the total saving of CO_2 emission from all wells is about 674 tons CO_2 per year when using PV system instead of diesel generator.

8.13 Security of Solar Energy Source

While the price of energy produced by some PV water pumping configurations is higher than that produced by diesel it should be taken into account that solar energy is renewable and a future methodology should be designed for wider use in Palestine.

Every dollar which we invest in photovoltaic now will help to reduce our dependence on foreign energy sources and increase our political and economic independence.

Conclusion

1. This thesis discussed photovoltaic technology and the cost of photovoltaic power for water pumping. The information presented includes:

- an overview of how electricity is generated from solar radiation using photovoltaic cells,
- a description of a demonstrational photovoltaic powered water pumping systems for six selected wells and
- a discussion of the present day price of such a system and the potential future effects of current trends which continue to decrease the cost of photovoltaic power.

2. The results show the more feasible configuration is to use the solar water pumps run directly on solar panels (PV direct) and do not require batteries. Using batteries may complicate an otherwise straight forward application. Instead of storing electricity in batteries to run the solar pump at cloudy times, the results show that it is more feasible configuration is to store the water in a storage tank, since it will be of less cost and complexity.

3. The results shows that its more feasible and cleaner in Palestine to use solar water pumps instead of diesel pumps. If the wells are in a remote area and the cost of running traditional water piping is economically

infeasible , a solar water pump may be the right solution for water supply needs.

In conclusion, photovoltaic power for water pumping in West Bank is cost competitive with traditional diesel energy sources for small and big remote applications , if the total system design and time of utilization is carefully considered and organized to use the solar energy as efficiently as possible. In the future, when the prices of fossil fuels rise more and the economic advantages of mass production reduce the peak watt cost of the photovoltaic cell, the PV pump will be more competitive with conventional supply.

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APPENDIX

Appendix (1)

Questionnaire Used for Data Collection

اسم صاحب البئر			
الهاتف			
العنوان			
طبيعة الاستخدام	زراعي	صناعي	منزلي
معلومات البئر	الرقم	البيان	الوحدة
	1	عمق البئر	متر
	2	مستوى الماء الثابتSWL	متر
	3	مستوى الماء المتحرك DWL	متر
	4	قطر مواسير التعليق	انش
	5	كمية المياه المنتجة خلال ساعة	م^3/ساعة
	6	معدل ساعات الضخ اليومي	ساعة
معلومات المضخة	الرقم	البيان	التوضيح
	1	نوع المضخة	
	2	قدرة المضخة	
	3	عدد فازات المضخة	1فاز او 3 فاز
	4	سنة انتاج او شراء المضخة	
مصدر التيار الكهربائي من مولد الديزل	الرقم	البيان	التوضيح
	1	نوع المولد	
	2	قدرة المولد	
	3	سنة الانتاج او الشراء	
	4	ثمن المولد	
	5	معدل الاستهلاك اليومي للديزل	
	6	معدل تغيير فلاتر الزيت	
	7	معدل تغيير فلاتر الهواء	

	8	معدل تغيير الزيت	
	9	الصيانة الدورية للمولد	
	10	الصيانة الكاملة للمولد (افرهول)	

	الرقم	البيان	التوضيح
	1	معدل الاستهلاك الشهري KWh	
	2	سعر KWh	
	3	رسوم اشتراك الكهرباء	
	4	تكاليف انشاء الشبكة	

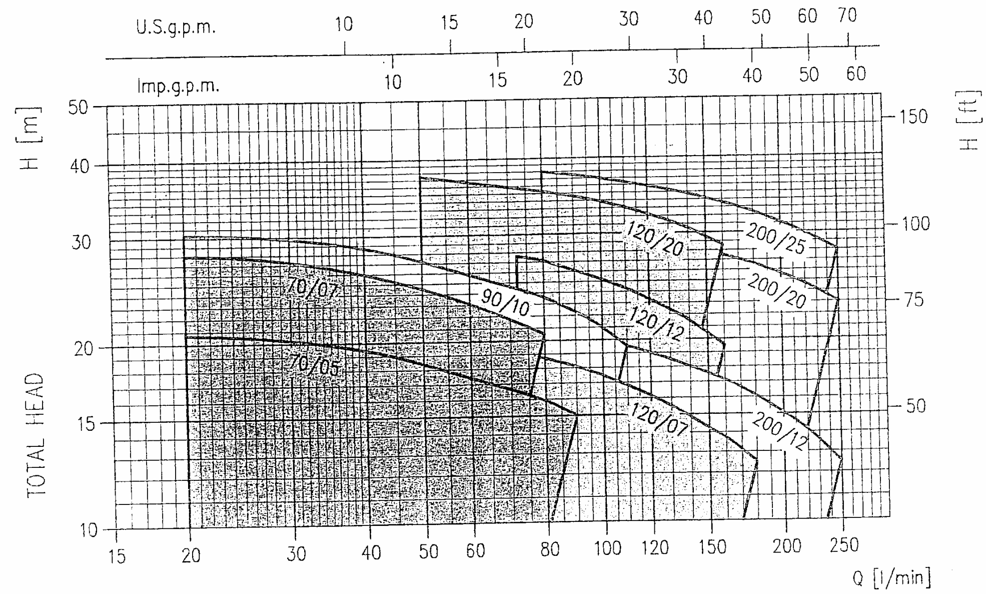
Appendix (2)

Pumps Catalogue

CDX

CENTRIFUGAL PUMPS - SINGLE IMPELLER in AISI 304

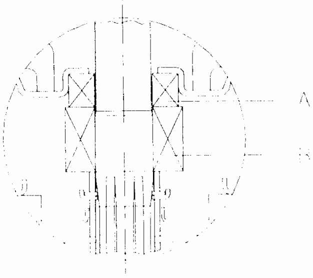
PERFORMANCE CHART (according to ISO 9906 Annex A)



PERFORMANCE TABLE

Pump type Single-phase 230V 50Hz	Pump type Three-phase 230/400V 50Hz	kW	Capacitor µF	Capacitor Vc	Absorbed Current (A) Single-phase	Absorbed Current (A) Three-phase 230V	Absorbed Current (A) Three-phase 400V	Q=Capacity l/min: 20 / m³/h: 1,2	50 / 3	80 / 4.8	90 / 5,4	110 / 6,6	130 / 7,8	160 / 9,6	180 / 10,8	210 / 12,6	250 / 15
								H=Total head									
CDXM 70/05	CDX 70/05	0,37	12,5	450	3,1	2,4	1,4	20,7	18,4	15,9	15	-	-	-	-	-	-
CDXM 70/07	CDX 70/07	0.55	16	450	4.6	3.5	2,0	28	24.5	20,5	-	-	-	-	-	-	-
CDXM 90/10	CDX 90/10	0,75	20	450	5,6	4,0	2,3	30,3	27,2	23,6	22,3	19,5	-	-	-	-	-
CDXM 120/07	CDX 120/07	0,55	16	450	4,6	3,2	1,9	-	20,5	18,7	18,1	16,8	15,5	13,7	12,5	-	-
CDXM 120/12	CDX 120/12	0,9	31,5	450	6,9	5.2	3,0	-	29,5	27,1	26,1	24,3	22,4	19,5	-	-	-
CDXM 120/20	CDX 120/20	1,5	40	450	9,3	7,0	4,0	-	37,5	35,3	34,6	33,1	31,4	28,6	-	-	-
CDXM 200/12	CDX 200/12	0.9	31,5	450	6,3	4,7	2,7	-	-	20,6	20,2	19,5	18,5	17,1	16,1	14,6	12,5
CDXM 200/20	CDX 200/20	1,5	40	450	10,7	7,0	4,0	-	-	31	30,6	29,7	28,9	27,5	26,6	25,1	23
	CDX 200/25	1,8	-	-	-	8,2	4,8	-	-	38	37,5	36,4	35,3	33,6	32.4	30,5	29

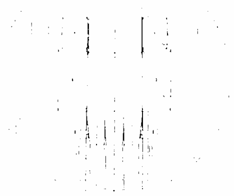
:ECHANICAL SEAL EVM 2-16



Pump Type EVM	Size [mm]	Max. working pressure [MPa]	Material A Stationary seal ring	Material B Rotary seal ring	Rubber
2-4	12.7	1.6	Silicon carbide	Carbon graphite	FPM
		2.5			
8	16	1.6			
		2.5			
16	20	1.6			
		2.5			
2-4*	12.7	1.6	Ceramic	Carbon graphite	EPDM
		2.5	Silicon Carbide	Carbon graphite	EPDM
8*	16	1.6	Ceramic	Carbon graphite	EPDM
		2.5	Silicon Carbide	Carbon graphite	EPDM
16*	20	1.6	Ceramic	Carbon graphite	EPDM
		2.5	Silicon Carbide	Carbon graphite	EPDM

* WRAS approved version

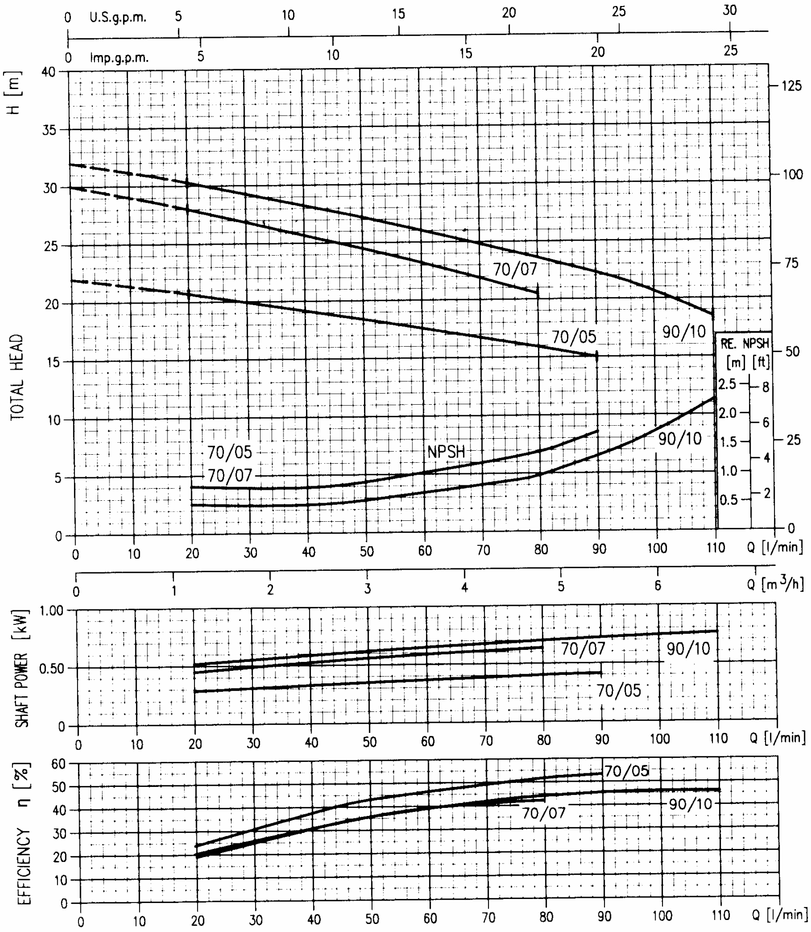
:CHANICAL SEAL EVM 30-60



[illegible] M	[illegible] [mm]	Max. working [illegible] [MPa]	Material [illegible]	[illegible]	[illegible]
30-60	25	1.6	Silicon carbide	Carbon graphite	FPM
		2.5			
30-60*	25	1.6	Silicon carbide	Carbon graphite	EPDM
		2.5			

* WRAS approved version

PERFORMANCE CURVES CDX 70-90 *series (according to ISO 9906 Annex A)*



EVM

VERTICAL MULTISTAGE PUMPS in AISI 304

Pump type EVM Single-phase	Three-phase	kW	Pmax [Mpa]	Motor Size	Capacitor µF	Vc	Absorbed Current (A) 1~	3~ 230V	3~ 400V	3~ 690V	l/min m³/h	Q=Capacity 20 1,2	40 2,4	60 3,6	75 4,5	80 4,8	120 7,2	150 9,0	225 13,5	300 18	400 24
												H=Total head									
EVM2 2N/0,37 M	EVM2 2N/0,37	0,37	1,6	71	10	400	3,0	1,65	0,95	-		16,8	12,8	7,5	-	-	-	-	-	-	-
EVM2 3N/0.37 M	EVM2 3N/0.37	0.37	1,6	71	10	400	3,0	1.65	0.95	-		25.2	19.2	11.1	-	-	-	-	-	-	-
EVM2 4N/0,55 M	EVM2 4N/0,55	0,55	1,6	71	12	400	3,8	2,34	1,35	-		33,9	26	15,2	-	-	-	-	-	-	-
EVM2 5N/0.55 M	EVM2 5N/0.55	0.55	1,6	71	12	400	3.8	2.34	1.35	-		42	32,5	18,8	-	-	-	-	-	-	-
EVM2 6N/0,75 M	EVM2 6N/0,75	0,75	1,6	80	20	400	5,3	2,8	1,6	-		50,5	38	22,5	-	-	-	-	-	-	-
EVM2 7N/0.75 M	EVM2 7N/0.75	0.75	1,6	80	20	400	5,3	2,8	1,6	-		58.8	44,3	26,1	-	-	-	-	-	-	-
EVM2 9N/1.1 M	EVM2 9N/1.1	1,1	1,6	80	30	400	6.5	4.0	2,3	-		75,7	58,1	33,8	-	-	-	-	-	-	-
EVM2 11N/1.1 M	EVM2 11N/1.1	1,1	1,6	80	30	400	6.5	4.0	2,3	-		91,1	68,7	39,5	-	-	-	-	-	-	-
EVM2 13N/1,5 M	EVM2 13N/1,5	1,5	1,6	90	40	400	9,5	5,7	3,3	-		109	84	48,8	-	-	-	-	-	-	-
EVM2 15N/1.5 M	EVM2 15N/1.5	1,5	1,6	90	40	400	9.5	5.7	3,3	-		126	95,5	55,9	-	-	-	-	-	-	-
EVM2 18F/2,2 M	EVM2 18F/2,2	2,2	2,5	90	60	400	13	7,6	4,4	-		156	120	74	-	-	-	-	-	-	-
EVM2 22F/2.2 M	EVM2 22F/2,2	2,2	2,5	90	60	400	13	7,6	4,4	-		186	141,2	81,7	-	-	-	-	-	-	-
-	EVM2 26F/3,0	3,0	2,5	100	-	-	-	10,9	6,3	-		220	165,1	105	-	-	-	-	-	-	-
EVM4 2N/0.37 M	EVM4 2N/0,37	0.37	1,6	71	10	400	3,0	1,6	0,95	-		-	17,2	15,8	13,9	13,4	6,9	-	-	-	-
EVM4 3N/0,55 M	EVM4 3N/0,55	0,55	1,6	71	12	400	3,8	2,3	1,35	-		-	25,7	23,4	21	20,2	10,5	-	-	-	-
EVM4 4N/0,75 M	EVM4 4N/0,75	0,75	1,6	80	20	400	5,3	2,8	1.6	-		-	34.9	32	28,4	27,4	15.5	-	-	-	-
EVM4 5N/1,1 M	EVM4 5N/1,1	1,1	1,6	80	30	400	6.5	4,0	2.3	-		-	44,1	40,6	36,3	35	19,8	-	-	-	-
EVM4 6N/1.1 M	EVM4 6N/1.1	1,1	1,6	80	30	400	6.5	4,0	2.3	-		-	53,2	48,2	43.5	42	24	-	-	-	-
EVM4 7N/1,5 M	EVM4 7N/1,5	1,5	1,6	90	40	400	9,5	5,7	3,3	-		-	61,8	56,5	50,9	49	27,7	-	-	-	-
EVM4 8N/1.5 M	EVM4 8N/1.5	1.5	1.6	90	40	400	9,5	5.7	3,3	-		-	71,6	65,8	58,2	57,1	33	-	-	-	-
EVM4 10N/2,2 M	EVM4 10N/2,2	2,2	1,6	90	60	400	13	7,6	4,4	-		-	88,2	81	72,5	70,6	39,6	-	-	-	-
EVM4 11N/2.2 M	EVM4 11N/2.2	2.2	1,6	90	60	400	13	7,6	4.4	-		-	98	90.2	81.8	78,6	45	-	-	-	-
EVM4 12N/2,2 M	EVM4 12N/2,2	2,2	1,6	90	60	400	13	7,6	4,4	-		-	106	97,4	87,2	84	47,5	-	-	-	-
-	EVM4 14N/3.0	3.0	1.6	100	-	-	-	10,9	6,3	-		-	127	116	105,7	102,2	60.5	-	-	-	-
-	EVM4 16N/3,0	3,0	1,6	100	-	-	-	10,9	6,3	-		-	142	130	118	116,7	67,6	-	-	-	-
-	EVM4 19F/4.0	4.0	2,5	112	-	-	-	14.2	8.2	-		-	168	154,2	138.2	134.6	75.2	-	-	-	-
-	EVM4 22F/4,0	4,0	2,5	112	-	-	-	14,2	8,2	-		-	195	180	163,5	158,1	88,9	-	-	-	-
EVM8 2N/0,75 M	EVM8 2N/0,75	0,75	1.6	80	20	400	5.3	2.8	1.6	-		-	-	-	21,1	20,8	19.2	17,1	10.4	-	-
EVM8 3N/1,1 M	EVM8 3N/1,1	1,1	1,6	80	30	400	6,5	4,0	2,3	-		-	-	-	32	31,8	29,5	26,8	16,7	-	-
EVM8 4N/1.5 M	EVM8 4N/1.5	1,5	1.6	90	40	400	9.5	5.7	3.3	-		-	-	-	42,8	42,2	40	36,1	22,6	-	-
EVM8 5N/2,2 M	EVM8 5N/2,2	2,2	1,6	90	60	400	13	7,6	4,4	-		-	-	-	53,6	53	49,1	44,3	28,3	-	-
EVM8 6N/2,2 M	EVM8 6N/2,2	2,2	1,6	90	60	400	13	7,6	4,4	-		-	-	-	64,4	64,2	59	53,6	33,8	-	-
-	EVM8 8N/3,0	3,0	1,6	100	-	-	-	7,6	6,3	-		-	-	-	85,7	85	80,2	72,5	45,8	-	-
-	EVM8 10N/4,0	4,0	1,6	112	-	-	-	10,9	8,2	-		-	-	-	107	106	98,4	87,9	56,5	-	-
-	EVM8 11N/4,0	4,0	1,6	112	-	-	-	14,2	8,2	-		-	-	-	117	116,2	108	97,8	61,4	-	-
-	EVM8 12N/5,5	5,5	1.6	132	-	-	-	14,2	11.5	6.6		-	-	-	129	127,1	118.4	107,5	67,8	-	-
-	EVM8 14N/5,5	5,5	1,6	132	-	-	-	-	11,5	6,6		-	-	-	150	148,3	137,5	124,8	79,1	-	-
-	EVM8 15F/5.5	5.5	2,5	132	-	-	-	-	11,5	6,6		-	-	-	162	160,7	148,7	134,2	86,6	-	-
-	EVM8 16F/7,5	7,5	2,5	132	-	-	-	-	15,3	8,8		-	-	-	171	170	157,8	140,9	90,4	-	-
-	EVM8 18F/7,5	7,5	2,5	132	-	-	-	-	15,3	8,8		-	-	-	193	191,2	176,2	158	102	-	-
-	EVM8 20F/7,5	7,5	2,5	132	-	-	-	-	15,3	8,8		-	-	-	219	217,2	202,3	183,2	121	-	-
EVM16 2F/2.2 M	EVM16 2F/2,2	2.2	1,6	90	60	400	13	7.6	4.4	-		-	-	-	-	-	-	29	26,2	21,1	10,6
-	EVM16 3F/3,0	3,0	1,6	100	-	-	-	10.9	6,3	-		-	-	-	-	-	-	43,6	38,1	30,7	15,4
-	EVM16 4F/4.0	4,0	1.6	112	-	-	-	14,2	8,2	-		-	-	-	-	-	-	58,2	52	42,3	22,3
-	EVM16 5F/5,5	5,5	1,6	132	-	-	-	-	11,5	6,6		-	-	-	-	-	-	73,8	67,1	54,9	29,5
-	EVM16 6F/5,5	5,5	1,6	132	-	-	-	-	11,5	6,6		-	-	-	-	-	-	88,3	79,8	65	35,8
-	EVM16 7F/7,5	7,5	1,6	132	-	-	-	-	15,3	8,8		-	-	-	-	-	-	103	92,5	76,5	41,3
-	EVM16 8F/7.5	7.5	1.6	132	-	-	-	-	15,3	8,8		-	-	-	-	-	-	119	108	88,1	49,2
-	EVM16 10F/11	11	2,5	160	-	-	-	-	20,4	11,8		-	-	-	-	-	-	148	132,2	108,9	59
-	EVM16 12F/11	11	2.5	160	-	-	-	-	20.4	11.8		-	-	-	-	-	-	181	164.5	138	77,6
-	EVM16 14F/15	15	2,5	160	-	-	-	-	27,6	15.9		-	-	-	-	-	-	207	186,5	152,3	82,6
-	EVM16 15F/15	15	2.5	160	-	-	-	-	27.6	15.9		-	-	-	-	-	-	226	207	171.8	100
-	EVM16 16F/15	15	2,5	160	-	-	-	-	27,6	15,9		-	-	-	-	-	-	236	215,2	181	108

Pump type EVM	kW	Maximum working pressure [MPa]	Motor size	Absorbed Current (A) Three-phase 230V	400V	690V	l/min m³/h	Q=Capacity 200 12	300 18	400 24	500 30	600 36	800 48	1000 60	1200 72
								H=Total head							
EVM30 2F/4	4	1,6	112		7,6	-		39	36,5	33	28	21			
EVM30 3F/5.5	5.5	1.6	132	-	10.6	6.1		58.5	54.8	49.5	42	31.5			
EVM30 4F/7,5	7,5	1,6	132		13,9	8,0		78	73	66	56	42			
EVM30 5F/11	11	1.6	160	-	20,1	11.6		95.3	89.2	80.3	67.9	52.3			
EVM30 6F/11	11	1.6	160		20,1	11,6		112,6	105,4	94,6	79,8	62,5			
EVM30 7F/15	15	1.6	160	-	26.8	15.4		134,3	125	113	96.6	75.3			
EVM30 8F/15	15	2,5	160		26,8	15,4		156	144	130	114	88			
EVM30 9F/18.5	18.5	2.5	160	-	32.3	18.6		175.5	163	148	128.5	100			
EVM30 10F/18,5	18,5	2,5	160		32,3	18,6		195	182	166	143	112			
EVM30 11F/22	22	2.5	180	-	39.7	22.9		214.5	201.5	183	157	123			
EVM30 12F/22	22	2.5	180		39,7	22,9		234	221	200	171	134			
EVM60 2F/5.5	5.5	1.6	132	-	10.6	6.1		-	-	30	29	27.8	24.7	20.2	14.5
EVM60 3F/7,5	7.5	1,6	132		13.9	8.0		-	-	43	41.4	39.3	34.7	28.5	20
EVM60 4F/11	11	1.6	160	-	20.1	11.6		-	-	59.5	57.2	54.6	48.8	40.3	29
EVM60 5F/15	15	1.6	160		26,8	15.4		-	-	71.5	69	66	58.4	48.8	35
EVM60 6F/15	15	1.6	160	-	26.8	15.4		-	-	83.5	80.6	77	68.3	57	41
EVM60 7F/18.5	18.5	1.6	160		32.3	18.6		-	-	103,5	99.8	95.6	85	71.2	52
EVM60 8F/22	22	1.6	180	-	39.7	22.9		-	-	120	115.7	110.5	98.2	83	62

Appendix (3)

Specifications of Kyocera KD135SX – 135W

Electrical Performance under Standard Test Conditions (*STC)	
Maximum Power (Pmax)	135W (+5%/-5%)
Maximum Power Voltage (Vmpp)	17.7V
Maximum Power Current (Impp)	7.63A
Open Circuit Voltage (Voc)	22.1V
Short Circuit Current (Isc)	8.37A
Max System Voltage	600V
Temperature Coefficient of Voc	-8.0×10^{-2} V/°C
Temperature Coefficient of Isc	5.02×10^{-3} A/°C
*STC: Irradiance 1000W/m^2, AM1.5 spectrum, cell temperture 25°C	
Electrical Performance at 800W/m^2, *NOCT, AM1.5	
Maximum Power	95W
Maximum Power Voltage (Vmpp)	15.7V
Maximum Power Current (Impp)	6.10A
Open Circuit Voltage (Voc)	20.0V
Short Circuit Voltage (Isc)	6.79A
*NOCT (Nominal Operating Cell Temperature): 47.9°C	

Cells	
Number per Module	36
Module Characteristics	
Length x Width x Depth	59.1in x 26.3in x 1.8in
Weight	27.5lbs
Cable	(+) 29.9in,(-) 72.4in

Appendix (4)

Table of interest at i = 10%

10%								10%
	Single Payments		Uniform-Series Payments				Uniform Gradient	
n	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A	Gradient Present Worth P/G	Gradient Annual Series A/G
1	1.1000	0.9091	1.00000	1.0000	1.10000	0.9091		
2	1.2100	0.8264	0.47619	2.1000	0.57619	1.7355	0.8264	0.4762
3	1.3310	0.7513	0.30211	3.3100	0.40211	2.4869	2.3291	0.9366
4	1.4641	0.6830	0.21547	4.6410	0.31547	3.1699	4.3781	1.3812
5	1.6105	0.6209	0.16380	6.1051	0.26380	3.7908	6.8618	1.8101
6	1.7716	0.5645	0.12961	7.7156	0.22961	4.3553	9.6842	2.2236
7	1.9487	0.5132	0.10541	9.4872	0.20541	4.8684	12.7631	2.6216
8	2.1436	0.4665	0.08744	11.4359	0.18744	5.3349	16.0287	3.0045
9	2.3579	0.4241	0.07364	13.5795	0.17364	5.7590	19.4215	3.3724
10	2.5937	0.3855	0.06275	15.9374	0.16275	6.1446	22.8913	3.7255
11	2.8531	0.3505	0.05396	18.5312	0.15396	6.4951	26.3963	4.0641
12	3.1384	0.3186	0.04676	21.3843	0.14676	6.8137	29.9012	4.3884
13	3.4523	0.289[illegible]	0.04078	24.5227	0.14078	7.1034	33.3772	4.6988
14	3.7975	0.2633	0.03575	27.9750	0.13575	7.3667	36.8005	4.9955
15	4.1772	0.2394	0.03147	31.7725	0.13147	7.6061	40.1520	5.2789
16	4.5950	0.2176	0.02782	35.9497	0.12782	7.8237	43.4164	5.5493
17	5.0545	0.1978	0.02466	40.5447	0.12466	8.0216	46.5819	5.8071
18	5.5599	0.1799	0.02193	45.5992	0.12193	8.2014	49.6395	6.0526
19	6.1159	0.1635	0.01955	51.1591	0.11955	8.3649	52.5827	6.2861
20	6.7275	0.1486	0.01746	57.2750	0.11746	8.5136	55.4069	6.5081
21	7.4002	0.1351	0.01562	64.0025	0.11562	8.6487	58.1095	6.7189
22	8.1403	0.1228	0.01401	71.4027	0.11401	8.7715	60.6893	6.9189
23	8.9543	0.1117	0.01257	79.5430	0.11257	8.8832	63.1462	7.1085
24	9.8497	0.1015	0.01130	88.4973	0.11130	8.9847	65.4813	7.2881
25	10.8347	0.0923	0.01017	98.3471	0.11017	9.0770	67.6964	7.4580
26	11.9182	0.0839	0.00916	109.1818	0.10916	9.1609	69.7940	7.6186
27	13.1100	0.0763	0.00826	121.0999	0.10826	9.2372	71.7773	7.7704
28	14.4210	0.0693	0.00745	134.2099	0.10745	9.3066	73.6495	7.9137
29	15.8631	0.0630	0.00673	148.6309	0.10673	9.3696	75.4146	8.0489
30	17.4494	0.0573	0.00608	164.4940	0.10608	9.4269	77.0766	8.1762
31	19.1943	0.0521	0.00550	181.9434	0.10550	9.4790	78.6395	8.2962
32	21.1138	0.0474	0.00497	201.1378	0.10497	9.5264	80.1078	8.4091
33	23.2252	0.0431	0.00450	222.2515	0.10450	9.5694	81.4856	8.5152
34	25.5477	0.0391	0.00407	245.4767	0.10407	9.6086	82.7773	8.6149
35	28.1024	0.0356	0.00369	271.0244	0.10369	9.6442	83.9872	8.7086
40	45.2593	0.0221	0.00226	442.5926	0.10226	9.7791	88.9525	9.0962
45	72.8905	0.0137	0.00139	718.9048	0.10139	9.8628	92.4544	9.3740
50	117.3909	0.0085	0.00086	1163.91	0.10086	9.9148	94.8889	9.5704
55	189.0591	0.0053	0.00053	1880.59	0.10053	9.9471	96.5619	9.7075
60	304.4816	0.0033	0.00033	3034.82	0.10033	9.9672	97.7010	9.8023
65	490.3707	0.0020	0.00020	4893.71	0.10020	9.9796	98.4705	9.8672
70	789.7470	0.0013	0.00013	7887.47	0.10013	9.9873	98.9870	9.9113
75	1271.90	0.0008	0.00008	12709	0.10008	9.9921	99.3317	9.9410
80	2048.40	0.0005	0.00005	20474	0.10005	9.9951	99.5606	9.9609
85	3298.97	0.0003	0.00003	32980	0.10003	9.9970	99.7120	9.9742
90	5313.02	0.0002	0.00002	53120	0.10002	9.9981	99.8118	9.9831
95	8556.68	0.0001	0.00001	85557	0.10001	9.9988	99.8773	9.9889
96	9412.34	0.0001	0.00001	94113	0.10001	9.9989	99.8874	9.9898
98	11389	0.0001	0.00001		0.10001	9.9991	99.9052	9.9914
100	13781	0.0001	0.00001		0.10001	9.9993	99.9202	9.9927

جامعة النجاح الوطنية
كلية الدراسات العليا

التحليلات الفنية والاقتصادية لاستخدام الطاقة الشمسية، الديزل والشبكات الكهربائية لضخ المياه في الضفة الغربية

إعداد
ديانا سليم صلاح

إشراف
د. عماد بريك

قدمت هذه الأطروحة استكمالاً لمتطلبات الحصول على درجة الماجستير في هندسة المياه والبيئة بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين

2012م

التحليلات الفنية والاقتصادية لاستخدام الطاقة الشمسية, الديزل والشبكات الكهربائية لضخ المياه في الضفة الغربية

إعداد

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الملخص

هذه الأطروحة تصف التحليلات الفنية والاقتصادية لاستخدام الطاقة الشمسية,الديزل والشبكات الكهربائية لضخ المياه في الضفة الغربية.

المنطقة المستهدفة في هذا البحث هي شمال الضفة الغربية حيث توجد المياه الجوفية التي تخدم سكان المنطقة، وخصوصا المزارعين.

سنبدأ بدراسة طبيعة المياه الجوفية في المنطقة من حيث العمق، ومعدل ضخ المياه، وأيضا دراسة نظام ضخ المياه الحالي ، والذي يعمل على الديزل، وذلك بتوزيع استبيان للمزارعين وأصحاب الآبار.

ثم الاستفادة من الخبرات الدولية في هذا المجال لمعرفة التكوين الأمثل لهذه المنطقة وقد استخدمت البيانات التي تم جمعها من الميدان كمدخل لبرنامج اكسل الذي تم تصميمه للتعامل مع النظام الشمسي.

وتم أجراء دراسة لتحليل الجدوى والتدفقات النقدية من استخدام مصادر الطاقة المختلفة من أجل ضخ المياه وذلك لعدد من السيناريوهات, وقد أجريت التحليلات الاقتصادية أيضا من خلال البرنامج الذي تم تصميمه حيث تم عمل نموذج رياضي محوسب من خلاله يتم تحليل ودراسة تكلفة ضخ المتر المكعب الواحد من الماء وحسب المعطيات وسيناريوهات مختلفة لاختيار التصميم الأمثل والذي يؤدي إلى أقل التكاليف, وقد تم التحقق من البرنامج الرياضي المصمم من خلال مقارنة نتائج البرنامج مع الحسابات اليدوية.

وتمت دراسة ثلاثة سيناريوهات لنظام ضخ المياه بالطاقة الشمسية في هذه الأطروحة؛ وهذه السيناريوهات هي كالتالي: السيناريو الأول وهو عبارة عن النظام الشمسي ذو التيار المتردد مع وجود نظام تخزين (البطاريات), السيناريو الثاني عبارة عن النظام الشمسي ذو التيار المتردد مع نظام تخزين للماء (التنكات) والسيناريو الثالث عبارة عن النظام الشمسي ذو التيار الثابت مع نظام تخزين للماء (التنكات).

وقد تم حساب تكلفة كيلو واط ساعة المنتجة من كل سيناريو ومقارنتها مع تلك التي ينتجها باستخدام مولدات الديزل, التكلفة لكل كيلو واط ساعة لجميع السيناريوهات من نظام ضخ المياه بالطاقة الشمسية تتراوح بين (0.2−0.5) دولار/كيلو واط, وكانت التكلفة لكل كيلو واط ساعة للمولدات الديزل في المتوسط 0.46 دولار/كيلو واط .

وكانت تكلفة الضخ للمتر المكعب الواحد من الماء باستخدام الخلايا الشمسية يتراوح بين(0.01−0.19) دولار/م^3 , بينما كانت تكلفة المتر المكعب الواحد للماء الناتج من الضخ باستخدام الديزل يعادل بالمتوسط 1.07 دولار/م^3.