An-Najah National University
Faculty of Graduate Studies

Efficiency and Feasibility Borders of Water Pumping Systems Powered by Electric Grid, Diesel Generators and PV Generators with PLC – Tracking of the Daily Solar Radiation Curve

By

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Dedication

To the soul of my father....

To my mother....

To my brothers and sisters....

To all friends and colleagues....

To everyone who works in this field....

I dedicate this work.

Acknowledgement

I would like to sincerely thank all those who helped me during the period of this work.

My deep gratitude to my beloved family, especially my mother for the endless care she has provided me, my sister Thekra for her support.

I would like to thank my supervisor Prof. Marwan Mahmoud for giving me the chance to work with him, and for his continuous support.

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Finally many thanks to my colleagues and all friends.

الإقرار

أنا الموقعأدناه مقدم الرسالة التي تحمل عنوان:

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<u>Declaration</u>

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 الطالب:**
Signature:	**التوقيع:**
Date:	**التاريخ:**

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Efficiency and Feasibility Borders of Water Pumping Systems Powered by Electric Grid, Diesel Generators and PV Generators with PLC – Tracking of the Daily Solar Radiation Curve

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Abstract

This research deals with comparison between four mechanisms in operating a supposed water pumping system. These mechanisms are PV generator, diesel generator, diesel motor and electrical grid. Referring to the research it is found that PV generator is more feasible than diesel generator where the cost of one cubic meter when using diesel generator is higher by about 80% than its cost when using PV generator. A vertical turbine pump was used instead of submersible one as it can be driven directly by a diesel motor and then the cost of one cubic meter of water is calculated and compared to PV water pumping system but also the last one is more feasible and more economical. When comparing PV generator with grid, the cost of water is very close to each other even that the cost of water by using grid is less than PV. Finally, load matching technique with dual PV water pumping systems is applied depending on the daily solar radiation curve, where the cost of one cubic meter is decreased of about 9% in comparison with one PV generator. Future works aspires to utilize sun tracking in addition to the matched load by PIC control.

Keywords: PV Generator, Diesel Generator, Solar Radiation, Pump Performance Curves, Feasibility of PV Pumping System, Payback Period, Load Matching.

CHAPTER ONE
INTRODUCTION

Introduction

Thousands of years ago man discovered fire, and realised that fire will make his life easier. Since that time this discovery was deserved to be considered as the most important event in human life, as fire provides warm, protect and help in food cooking. By the time man was continuing to improve his life. Firstly, people started depending on the sun as the main energy source, and then they started to find new methods of energy supply to improve their life until we reacheda total dependence on electricity in our life, which is generated by using traditional energy sources like coal and oil.

Traditional energy sources such as coal, oil and gas have problems in terms of availability, economical part and environmental pollution. The nonconventional energy sources are capable of solving the problem of energy supply in a decentralized manner and helping in sustaining cleanerenvironment [1]. This encourages using clean energy sources like solar energy, wind energy or biogas. Actually, alternative sources have been used since ancient times but in simple ways, for example Greeks and Romans built their homes and other buildings facing south in order to take advantage of the sun’s energy [2].Wind turbines were used to operate mills in order to produce flour. This clarifies that most of sources of clean energy were known previously, but because of the development in all life branches, new fields of solar energy applications were created.

Solar energy is the most common renewable source, since it doesn't need complicated measurements like wind energy which needs long time of measurements to determine the wind speed in a specific region.

In remote areas and regions which are not connected to the main grid, the diesel generator was the alternative solution. Previously, using diesel generator was feasible where the price of fuel was cheap compared with its price nowadays which did not encourageusing alternative energy sources. Solar energy is the most familiar source in Arab world.

Because of its geographical location, the Arab world is considered a good site to utilize solar energy. The high cost of PV cells prevented from establishing of large PV generators. Using power systems started by the beginning of the seventies of the past century.

Establishing wells in isolated areas was a good solution to supply water.These wells were firstly prepared by the government;which was the only responsible for them. This makes it easier to develop and control them continuously. Since wells were mainly used for supplying the inhabitants with water and rarely used for agriculture; the consumption of water on their sites is limited.

As solar energy technique becomes widespread, many projects were performed in different fields related to solar systems and PV water pumping systems. In 1990, M.Mahmoud. presented a paper based on an experiment executed in Jordan to find which is more feasible: to operate a water pumping system by a diesel generator or by a PV generator. It was found that PV generator is more reliable in rural areas than diesel generators since the average solar radiation is high enough, and the most important was that using PV in water pumping is more economical than diesel. In final results, it was concluded that the price of pumping one cubic meter when using a PV generator is about 40% less than its price when using a diesel motor [3].

Another research was performed in India by M. Kolhe et al aimed to prove that using stand – alone PV system is more economical than diesel – powered system. The paper discussed the economical issue for both systems and made a comparison between them. For example, in the 70's when diesel powered system was the best alternative source and the price of Watt peak of PV reached 50$, it is now about 1$and the cost of diesel fuel is increasing continuously, and by calculating the life cycle cost for both systems they found that stand – alone PV system should be considered for application since it is more feasible [4].

If the trend is to get a lower price of water, it is better to depend on solar tracking technique, which exploits the solar radiation during the whole day. Regarding this point, a paper was presented by M. Mahmoudet al. It was based on determination the optimum tilt angle of PV arrays [5].

In the last decade, there was a trend to use renewable energy in Palestine, especially solar energy. Because of the issues which face the conventional energy sources such as the depletion of fossil fuels, increase in oil prices, environmental problems and population increment, the alternative energy sources adoption became very important in Palestine. Regarding energy sources field, a study is proposed by Portland trust about renewable energy sector in Palestine, the study discussed the energy situation and the obstacles that face energy availability, also discussed the support to execute projects in clean energy sector. Besides what mentioned above, the study found that renewable energy adoption is useful in energy sector besides investment and environmental benefits [6].

Most of inhabitants in desert areas are Bedouins; and they are depending on spring water in their life, unlike people in urban areas they don’t consume too much water, which encourages in using solar cells for supplying water in the desert. It is expected that supplying water by pumping system powered by PV generators will be more feasible than that powered by diesel generator because of some reasons related to the increase of the price of diesel and decrease of the price of peak Watt of PV. All of these points will be discussed later.

This research deals with a hypothetical case; water will be pumped from a well of a specific depth and flow rate by designing a water pumping system. The pump in this pumping system is subjected to two choices of driving the motor, the first is to be powered by a PV generator, and the second is to be powered by a diesel generator. The thesis searches on comparing the two systems and determine which is more economical and environmentally sound.

In the second chapter, a brief explanation of the concept of centrifugal pumps and their types is presented. Also, this chapter concentrates on submersible pump types and shows their characteristic equations and curves as this type is used in this thesis.

Chapter three reviews the water pumping system designs in details by reviewing all needed requirements to design a complete water pumping system. Furthermore, the elements of both the pump and the well, which control the full design is introduced. The main point in this chapter is to see the pump performance curves and study how to use the best pump which fits the requirements.

In the fourth chapter, the research is starting to be more obvious. It starts with the first stage, where a PV generator is connected to a water pumping system. In this chapter, pumping system components will be reviewed, each item will be explained. PV modules will be identified in order to select the best one; also solar radiation in Palestine will be illustrated. Well characteristics are clarified with all equations and items related to depth and flow. All these components are studied to design a full pumping system powered by a PV generator and then finding the total cost of the system.

In Chapter five the PV generator is replaced with a diesel generator. The cost of the system with diesel generator is calculated. Chapter six introduces an economical analysis between the results of chapters four and five to find which is best to power the water pumping system.

In Chapter seven a new test is executed by driving a vertical turbine pump driven directly by a diesel motor and calculating the cost of one cubic meter of water.

Operating the pumping system by electrical grid is discussed in chapter eight in order to compare the feasibility of PV with grid. Also this chapter discusses net metering technique and find the payback period if it is applied on our design.

Finally, chapter nine introduces the dual PV water pumping system by tracking the daily solar radiation curve using matched load control. It searches in the increment of water quantity and the reduction of the cost of water.

CHAPTER TW0
CENTRIFUGAL PUMPS

2.1. Introduction

Pumps in general are devices that depend on converting mechanical energy into kinetic energy to lift and transfer fluids.

Pumps have existed since ancient time, where Mesopotamia had firstly used pumps in lifting water for irrigation. It was a simple design. Pumps were subjected to many stages in construction and by the time different types of pumps were founded, each has certain uses according to its design.

Centrifugal pump is one of pump types, and it is classified into different branches, one of them is called submersible pump which is the main subject in this research.

2.2. Centrifugal Pumps

2.2.1. Definition of centrifugal pumps

Centrifugal pumps are like other pumps in principle, but they have some positive characteristics that make them the most common and used type in the world. They are simple, inexpensive, have low maintenance cost and easy to treat with fluids without any obstacles, on other side they don’t work efficiently with high viscosity fluids.

2.2.2. Principle of Work

The pump converts mechanical power to water power. The fluid moves from the inlet to the impeller, which gives it a kinetic energy forcing it to move to the outlet, due to the difference in pressure [7].

The following figure shows a centrifugal pump sectional view.

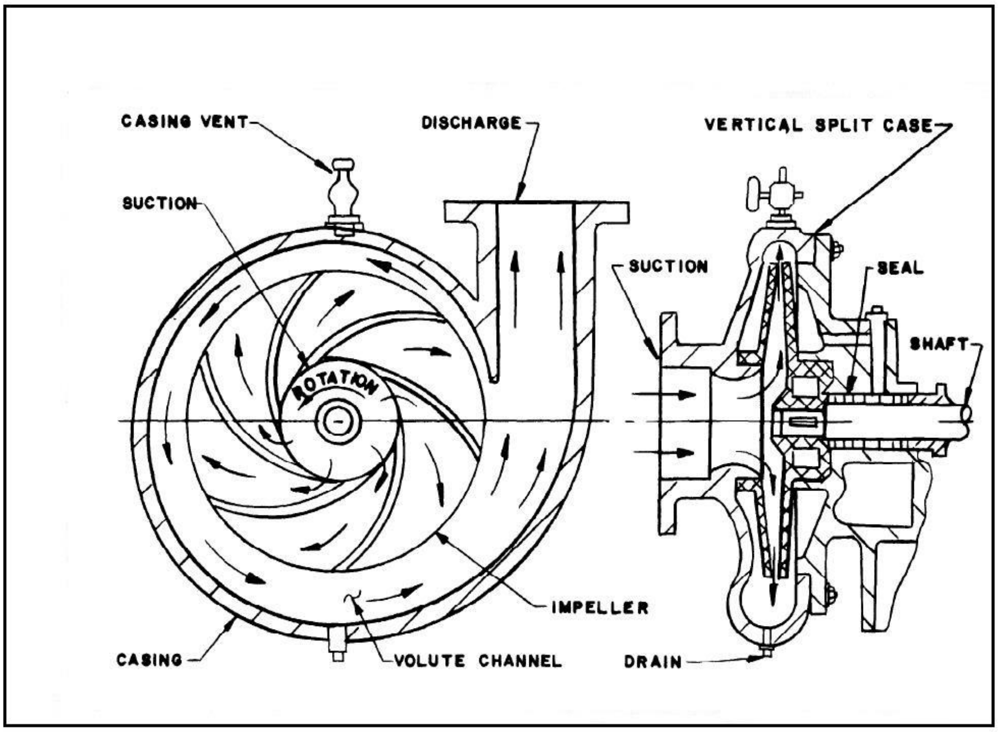

Fig.(2.1) - Centrifugal Pump Sectional View [8]

2.2.3. Types of centrifugal pumps

There are different types of centrifugal pumps; each has its own characteristic curves according to its applications such as submersible pumps, surface pumps, booster pumps, etc....

Regardless of other types, submersible pump is the one which discussed in this research.

2.3. Submersible Pumps

2.3.1. Definition of submersible pumps

Submersible pumps are multistage centrifugal pumps submerged in water by isolating the motor. Those pumps are commonly used in deep wells as they are put vertically in the well and push the water to surface easily without any problems. The motor is put in the well after isolating it from water.

Submersible pumps are very good to be used as they are easy to handle and have low maintenance cost.

Choosing submersible pumps depends on both pumping head and flow rate taking efficiency into account. Curves and catalogues are usually issued by each manufacturer to select the suitable pump.

2.3.2. Pump characteristics

Submersible pump characteristic curves show the relation between total head and flow rate. There are some items to determine the pump curve shape which are: flow rate (m^3/hour), total head (meter) and output power (kW,hp). These variables depend on pump speed and impeller diameter. For the same impeller, these variables are related to impeller speed according to the following affinity laws**[9]**:-

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \tag{2.1}$$

$$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2 \tag{2.2}$$

$$\frac{P_{o1}}{P_{o2}} = \left(\frac{N_1}{N_2}\right)^3 \tag{2.3}$$

Where;

Q is the flow rate (m^3/ hour),

H is the total pumping head (meter),

$\boldsymbol{P_o}$ is the output power (hydraulic power) of the pump (W)and

N is the impeller speed (rpm).

Flow rate and pumping head are the base of drawing the pump curve, besides the efficiency.

$$\eta_p = \frac{P_o}{P_i} = \frac{E_o}{E_i} \tag{2.4}$$

$\boldsymbol{E_o}$ is the output energy of the pump “hydraulic or water energy” – (kWh),

$\boldsymbol{E_i}$ is the input energy of the pump “brake energy” - (kWh),

$\boldsymbol{\eta_p}$ is the efficiency of the pump,

$\boldsymbol{P_o}$is the output power of the pump “water power in” - (kW) and

$\boldsymbol{P_i}$ is the input power of the pump “brake power in” - (kW, hp).

The output energy is derived in [3] to obtain the following single equation:

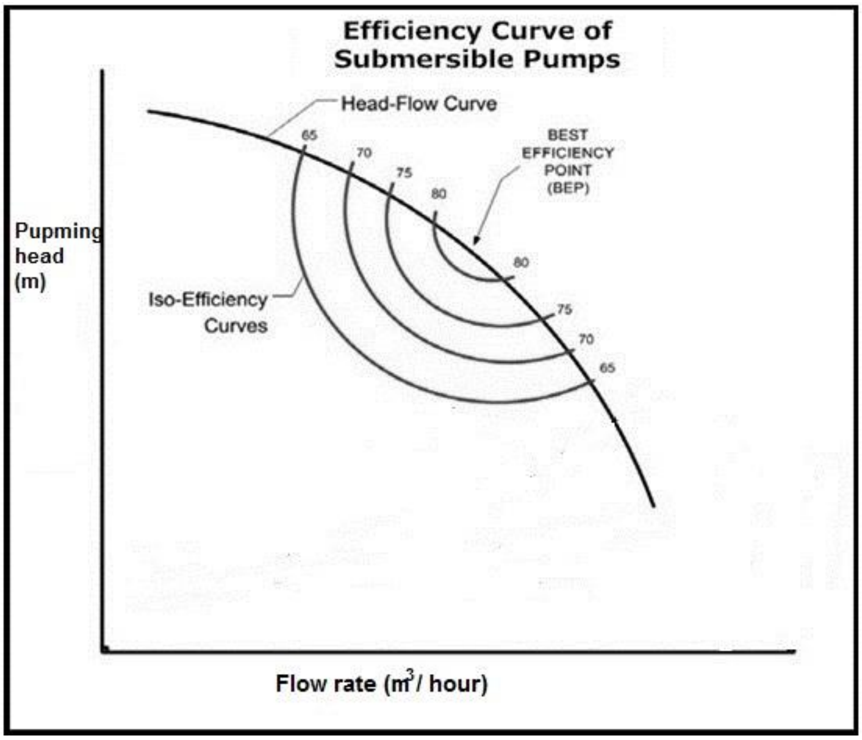

Fig. (2.2) – Efficiency curve of a submersible pump [10]

Fig.(2.2) shows a typical performance curves that define pump characteristic which used in choosing suitable pump for a specific design.

Those curves will be explained in detail in chapter three. BEP shown above stands for “Best Efficiency Point” which means the best operating point for any centrifugal pump. In other words, it is the flow rate where a pump has its highest efficiency” [11].

BEP is very important for the design because we always try to select a pump operating at this point. It is necessary to note that the performance of the pump is always less than the outlined point.

CHAPTER THREE

PUMPING SYSTEM DESIGN

3.1. Water Pumping System Design

As mentioned in chapter two, pumps characteristic curves depend on pumping head, flow rate and efficiency of the pump. Head and flow rate are items determined according to the status of the characteristics of the well and the requirement of the consumer site.

3.1.1. Main requirements of water pumping system

i. **The site**

   The pump used in this research is a submersible one so it is submerged inside the well. In other kinds of pumps as surface pumps, they must be close to the well or the water source.

ii. **Energy source**

   The availability of energy source is very important in order to operate the system, whether via main electrical network or through other power source as diesel driven electric generators.

iii. **The pump**

   In this work, we are focusing on centrifugal submersible pumps, since they are the most commonly utilized type in PV powered water pumping systems in remote areas.

3.1.2. Selecting the pump

Selecting the appropriate pump depends mainly on the following items:

- Flow rate where it is determined after studying the quantity of water needed for a specific area. The flow rate is called the pump discharge and it is expressed in m^3/hour.
- Pumping head which is which is “total dynamic head" includes elevation difference, suction, loss and pressure head of discharge point ®[1].

The following figure shows the arrangement of submersible pump in a well.

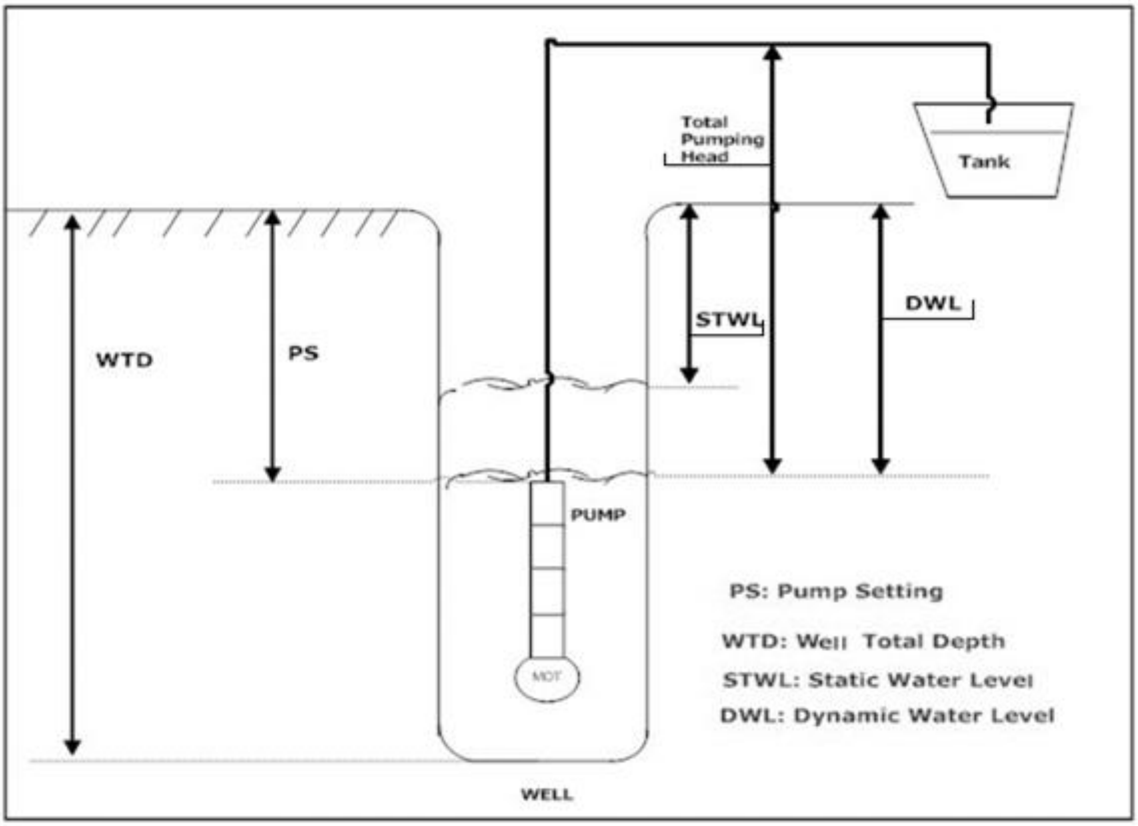

Fig .(3.1) – Arrangement of a submersible pump in a well with water levels andstorage tank.

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[1]Amoscope is used to measure the water level in the well.

- Efficiency of the pump

  The efficiency of the pump is given by dividing its output power by the input power. The output power is called the water power (P_o) obtained in kW referred to equations (2.4) and (2.5)

Selecting the appropriate motor for a specific pump depends on input power of the pump (brake power).

$$\eta_m = \frac{P_{om}}{P_i m} = \frac{E_{om}}{E_{im}} \qquad (3.1)$$

Where:

P_{om} is the output power of the motor (kW),

P_{ip} is the input power of the pump “brake power” - (kW or hp),

P_{im} is the input power of the motor “shaft power” - (kW) and

η_m is the efficiency of the motor.

3.2. Pump Performance Curves

Fig (3.2) shows three curves defining the pump, flow curve, NPSH curve and efficiency curve. Efficiency curves show the internal losses at different capacities. The highest efficiency is the best efficiency point (BEP) [12].These curves work together, in other words we need to look at the three curves when we choose the suitable pump.

The next figure clarifies how to determine the suitable pump if we get data about the total head and the flow rate. For example if the total head is 100 meter and the flow rate needed is $10m^3/hr$, the chosen pump will be the intersection point of both head axis and flow rate axis, as shown in Fig (3.2) that the pump chosen is the one appointed in red circle.

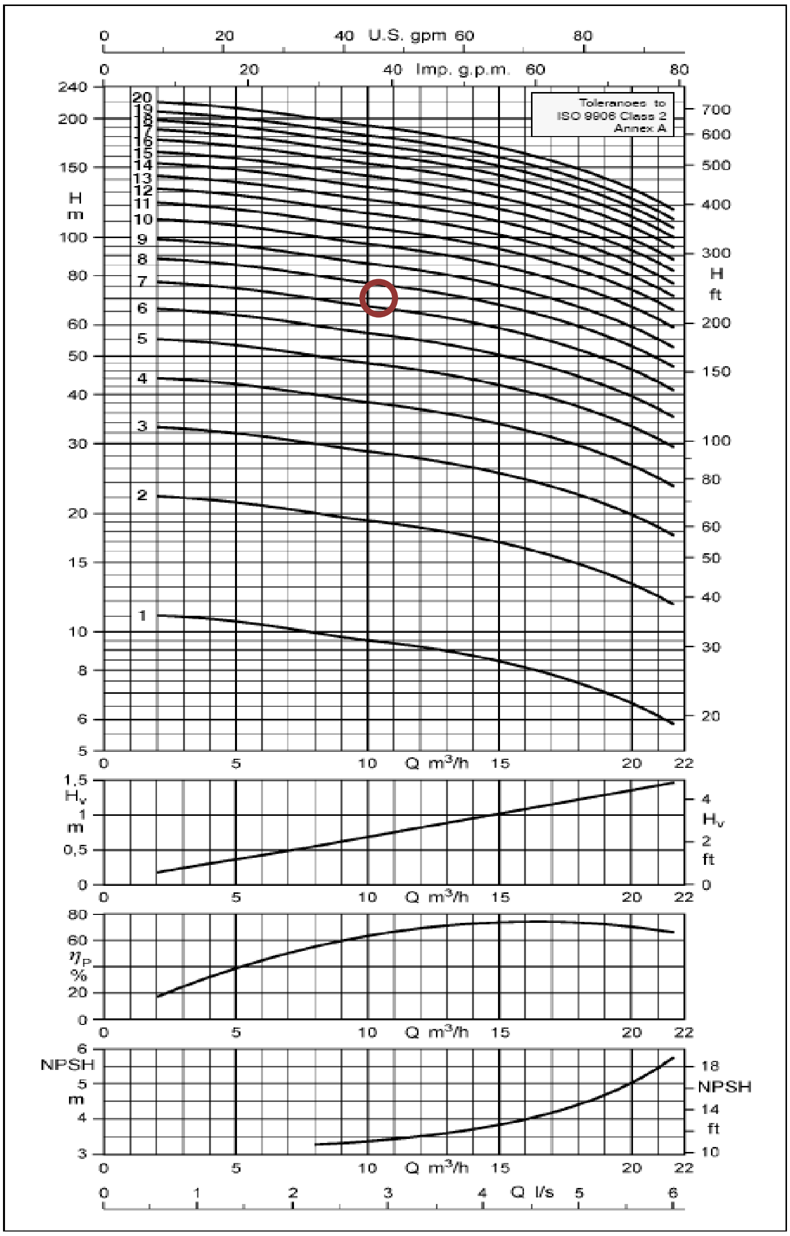

Fig.(3.2) – Performance curves of a typical submersible pump from the KSB catalogue (UPA 150C-16/ # of stages) [13]

CHAPTER FOUR
PV WATER PUMPING SYSTEMS

4.1. PV Water Pumping System Design

Desert areas are the best choice to prove the efficiency of using solar cells, as they are remote from grid. It is being talked about the most advantage use of PV, since the remote regions almost suffer from the lack of water. Solar cells present the best solution to solve water lack problem. Using PV systems have started in Arab world since the beginning of eighties of the past century, where PV price varied around (8 $ / Watt peak) which is high in comparison with the current prices.

4.2 Feeding Water Pumping System

The research discussed a case for a supposed well, and calculations were made for three cases depending on the feeding source, solar cells, diesel generator or electric grid.

4.3 PV Pumping System

4.3.1 Designing of the system

The PV water pumping system is designed as shown in Fig (4.1), where the system is supplied by PV generator followed by an inverter to convert DC output into AC, then they feed a submersible pump connected to an asynchronous motor.

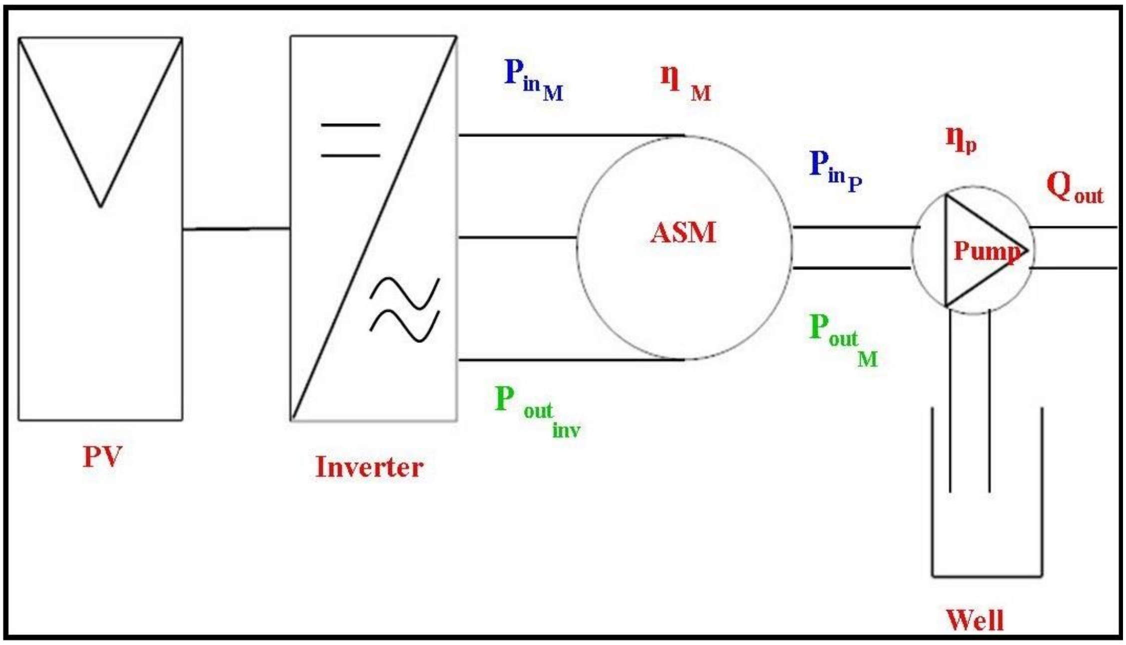

Fig.(4.1) – Configuration of PV powered pumping system

4.3.2 Pumping system components

- ***Pump***

Submersible pump is used to be set into the well. There are many kinds in the market, and most of them have the similar characteristics. The difference between them is efficiency. The selection of a suitable pump depends on the well characteristics, required pumping head and flow rate.

- ***Asynchronous Motor (Induction Motor)***

The motor pump is an induction motor type. It is submerged in the well with all necessary protection measures.

- ***Inverter***

Because of the current produced by PV generator is a direct current (DC), and the asynchronous motor is an AC motor, then we need an inverter to convert the DC output of PV generator to AC current.

Inverters work at 50 Hz frequency where input and output voltages depend on their design. In the market there are different inverters with different output line to line voltages (70V, 127V, 220V, 380V....).

The output voltage must not be sinusoidal to reduce the price. It can be square voltage since the induction motor represents a high inductive load and the design must be restricted to one suitable input voltage.

- ***Photovoltaic generator***

The PV generator consists of PV modules connected in series and in parallel to fulfil the requirements of the rated input voltage of the inverter and the nominal power of the induction motor driving the pump. On the other hand the PV module consists of series and parallel strings of solar cells.

Solar cells are made mainly of semiconductors as Silicon (Si). They are classified according to manufacturing method. Peak watt of the cell is the most important item in building any PV module.

The peak Watt of a PV module is given by multiplying the voltage and current at maximum power point [14].

$$\boldsymbol{P_{peak} = I_{mpp} X \ V_{mpp}} \qquad (4.1)$$

Where ;

P_{peak} is the peak Watt (W) produced by the PV module when it is exposed to standard conditions (STC),

I_{mpp} is the current at the maximum power point of the PV module and

V_{mpp} is the voltage at maximum power point of the PV module.

The following curve represents an IV curve for a PV cell or module

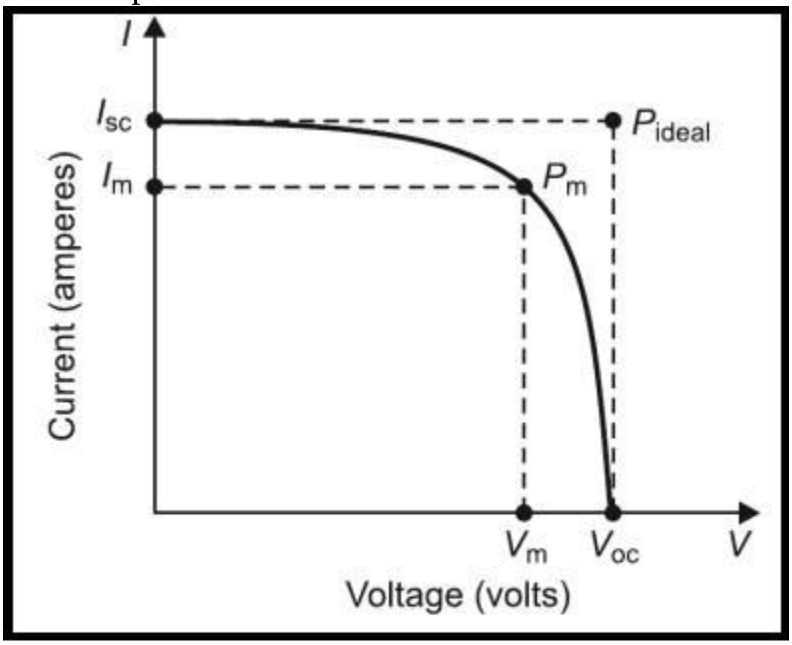

Fig . (4.2) – IV characteristic of PV module [15]

The I-V characteristic curve of PV module is obtained by a simple circuit. The PV module is connected to a variable load with the measuring equipment's (Voltmeter, Ammeter) as shown in Fig (4.3).

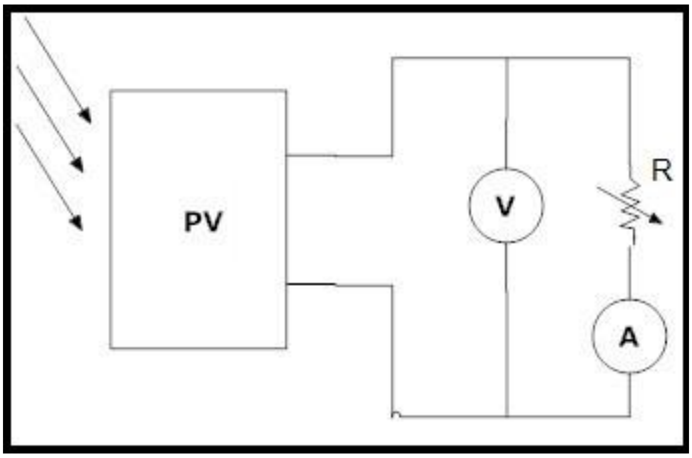

Fig . (4.3) – PV module connected to variable resistance for measuring the I-V characteristics

PV module is exposed to a solar radiation at STC, a current is passing through the variable resistive load. When the resistive load is being zero, it acts as short circuit and so the ammeter measures the short circuit current. The open voltage is found when the resistive load is infinite. For the resistance values between zero and infinite, we get the values of voltage and current to complete the I-V curve illustrated in Fig(4.2).

4.3.3 Standard test conditions

Standard Test Conditions which are known as (STC), are ideal conditions used to draw the I-V characteristic curve for PV modules in order to compare different cells or PV modules with one another under uniform conditions. STC is related to IEC 60904/DIN EN 60904 standards [16].

Standard Test Conditions are summarized in considering the performance of PV module at solar radiation of 1000W/m^2, at cell temperature of 25C° and air mass®[2] of 1.5.

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[2] airmass is the path which sun ray passes through atmosphere according to zenith angel.

4.4. PV Module Types

PV modules are classified into three types; each has its own characteristics;

a) Monocrystalline Silicon module which consists of monocrystalline cells connected in series. One cell has the parameters about $V_{OC} = 0.61V$, $I_{S.C} = 3.4A/100cm^2$ at standard conditions (STC). If any of these conditions changed then V_{OC} and $I_{S.C}$ will be recalculated [14].

b) Polycrystalline silicon module which consists of polycrystalline cells connected in series. Polycrystalline module is less efficient than monocrystalline type. One cell has the parameters about $V_{OC} = 0.58V$, $I_{S.C} = 2.8A/100cm^2$ at STC [14].

c) Thin film module which has high absorption coefficient, therefore about 10μm thickness is enough for one cell [14].

4.5. Well Characteristics

A supposed well of total pumping head of 100m in a rural area is used to supply water for the inhabitants. The aim is to find which is more economical; to feed the motor pump by diesel generator or by PV generator.

As mentioned previously, pumping head and flow rate are the most important items to start the series of equations and calculations. The pumping head is 100m and the volume of water ranges between ($50m^3$/ day and $500m^3$/day) with an increment of 25.

The objective in this chapter is to find the price of pumping the cubic meter of water the following scenario:-

1) Finding the suitable PV generator at specific well conditions. A series of calculations have to be made from the pump back to the PV. Starting in finding the hydraulic energy output in (kWh) from the pump at specific head and flow discharge referred to equation (2.5) in chapter two.
2) Referring to equation (2.2), the input energy of the pump will be found, taking into account that pump efficiency is in the range: 48% to 65%.

   The pump of 60% efficiency is considered to be an efficient pump as there are some factors affecting the performance of the pump; like the type, weight of impeller and friction which contribute in reducing the performance.
3) As shown in Fig (4.1), pump input energy is the same of the output energy of the asynchronous motor, so by using equation (3.2) we obtain the output energy of the motor with an assumed efficiency of 85%.
4) The inverter has mostly high efficiency; its efficiency is about (0% to 98%). Assuming that the inverter efficiency is 94% , and same conditions as mentioned in 3, the input of the motor is the output of the inverter.

$$E_{oinv} = \eta_{inv} * E_{iinv} \qquad (4.2)$$

5) Determination the peak watt of the PV generator.

   The steps above will be explained in numbers on section (4.7.1).

4.6. Solar Radiation

4.6.1 Solar radiation in Palestine

Palestine is located between longitudes 34.15° - 35.40°East, and latitudes 29.3° - 33.15° North. It is one of Arab countries which have high solar radiation. Solar radiation in Palestine reach in June and July about *8000Wh/m²-day* which is the highest radiation in the year, while in January and December the least radiation is estimated at*2800Wh/m²-day*. In average the daily solar radiation around the year in Palestine is *5400Wh/m²-day* [17]. Fig (4.4) shows the monthly solar radiation in Palestine.

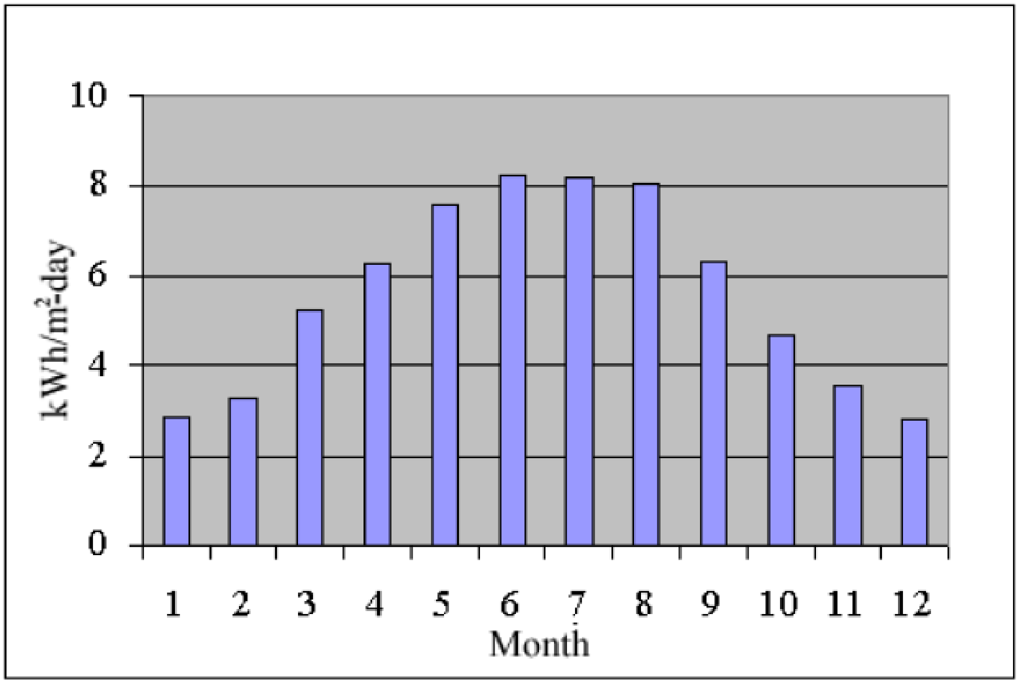

Fig (4.4) – Monthly solar radiation in Palestine [17]

4.6.2 Peak sun hour (PSH)

PSH is the equivalent number of hours per day when the daily solar energy is delivered by *1000* W/m^2*-day* [14]. For example, in June the average daily solar energy is *8.2*kWh/m^2 *– day*, this corresponds to PSH =8.2 hours.

4.6.3 PV module

Monocrystalline models are the modules used in this research, as they are more efficient than the other ones. So a specific model from market is chosen according to the needs to build the best PV generator.

In this case, a module of 72 monocrystalline cells connected in series, called SCHOTT module, is considered. The peak power of this module is 180 W_P. [18]. ®[3]

4.7 Cost of Pumping Systems

4.7.1. Power produced by PV

We want to design a PV water pumping system for a well of 100m, for 19 capacity values, in order to choose the best flow discharge of water.

For Q= 50m^3/day and H=100m ,

$$E_{oP} = E_{hyd} = 0.002725 \times V \times H$$

$$= 0.002725 \times 50m^3/day \times 100m$$

$$= 13.625 \text{ kWh} = \text{output energy of the pump}$$

$$\eta_P = 60\%$$

$$\eta_P = \frac{P_{oP}}{P_{iP}} = \frac{E_{oP}}{E_{iP}}$$

$$E_{iP} = 13.625 / 0.6 = 22.708 \text{ kWh}$$

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[3] See appendix A.

$E_{iP} = E_{oM} =$ output energy of motor

$\eta_M = \underline{P_{oM}} = \underline{E_{oM}}$

$P_{iM} E_{iM}$

$\eta_M = 85\%$

$E_{iM} = 22.708 / 0.85 = 26.716$ kWh

$E_{iM} = E_{oInv} = 26.716$ kWH

$\eta_{Inv} = 94\%$

$\eta_{Inv} = \underline{P_{oInv}} = \underline{E_{oInv}}$

$P_{iInv} E_{iInv}$

$E_{iInv} = 26.716 / 0.94$

$= 28.421$ kWh

Average daily of solar radiation = 5400 Wh/m^2

Solar irradiance = 1000W/m^2

$$\text{Peak watt of PV} = P_{p\text{-}pv} = \frac{E_{oInv} \text{ X } 1000}{5400}$$

$$\text{Peak watt of PV} = P_{p\text{-}pv} = \frac{E_{oInv} \text{ X } 1000}{5400} \text{ kW}$$

$$P_{P\text{-}PV} = \frac{28.421 \text{ X } 1000}{5400} = 5.263 \text{ kW}$$

The power found above is theoretical, and to be on safe side and to insure that the PV work properly, there is a safety factor of 15%, which has to be considered.

$P_{P\text{-}PV} = 5.263 \text{ X } 1.15 = 6.052$ kW $= 6052$ W

If each module has a power of 180W, V_{mpp} is 36.2V and I_{mpp} is 4.97A. The peak watt of the PV generator in our design is 6052 W, so we can find the number of modules needed.

Number of modules = 6052 / 180 = 33.6 modules

Fractions are not considered, then 34 modules will be used, and arranged them in strings, each string contains of 8 modules connected in series.

$$\text{No of PV modules connected in series} = \frac{\text{Nominal input voltage of inverter}}{\text{Nominal PV module voltage at mpp}}$$

$$= 280 / 36.2$$

$$= 7.735 \quad \text{equivalent to 8 strings}$$

This is equivalent to 8 PV modules in one string.

$$\text{No of PV strings in paralle} = \frac{\text{Total No of modules}}{\text{No of PV modules in each string}}$$

$$= 34 / 8$$

$$= 4.25 \quad \text{(equivalent to 5 strings)}$$

Total number of modules in the system = No of strings X modules in a strings

= 5 X 8

= 40 modules

Peak power of the system = Peak watt of module X No of modules

= 180 W X 40 modules

= 7200 W

The designed PV generator is illustrated in Fig (4.5).

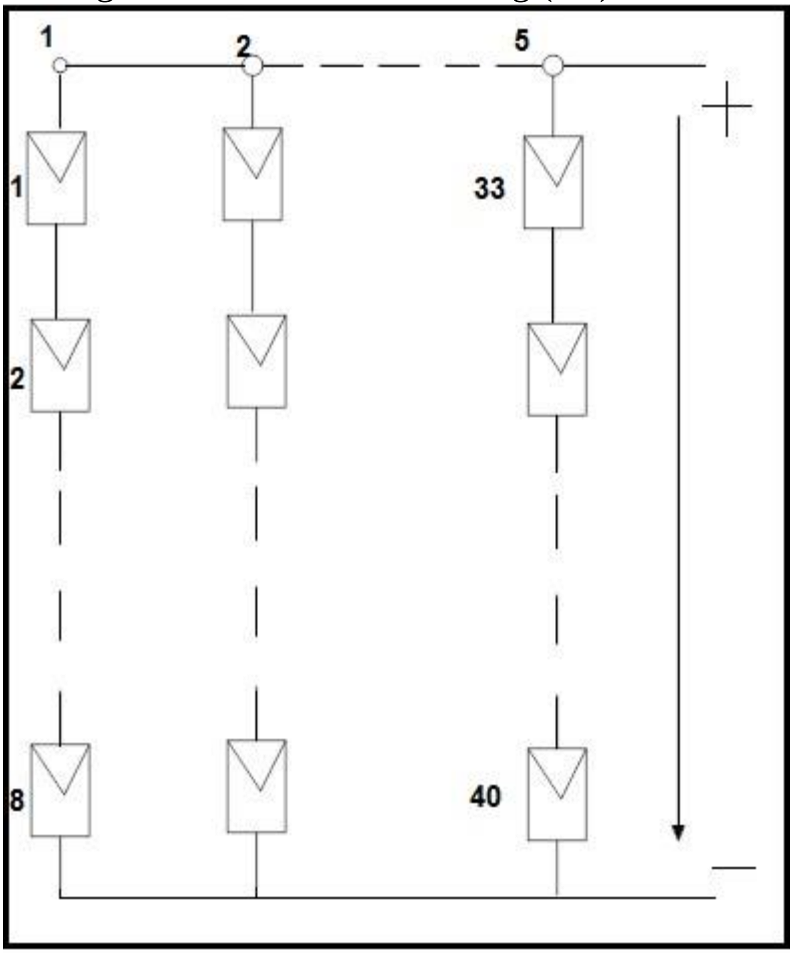

Fig (4.5) – Interconnection of PV module constituting the PV generator

The obtained increase of the peak power result in increasing the safety factors to be 1.37 instead of 1.15.

Repeating the steps above, we can find the total power produced by the PV generator for each flow rate as illustrated in table (4.1).

Table (4.1) - The power produced by PV array on different daily volume values

Daily volume of water (m^3/day)	Hydraulic energy (Eout of pump) kWh	Input energy of pump (shaft power) kWh	Input energy of ASM (kWh)	Input energy of inverter (kWh)	PV watt peak (W)	Actual PV watt peak (W)	No. of module needed	Actual No. of module needed	No. of modules in a string	Actual No. of modules in string	Actual No. of strings	Real No of modules	Power produced by PV (W)
0	13.6	22.7	26.7	28.4	5263.1	6052.6	33.6	34	7.7	8	5	40	7200
75	20.4	34.1	40.1	42.6	7894.7	9078.9	50.4	51	7.7	8	7	56	10080
100	27.3	45.4	53.4	56.8	10526.3	12105.2	67.3	68	7.7	8	9	72	12960
125	34.1	56.8	66.8	71.1	13157.8	15131.5	84.1	85	7.7	8	11	88	15840.0
150	40.9	68.1	80.1	85.3	15789.4	18157.8	100.9	101	7.7	8	13	104	18720.0
175	47.7	79.5	93.5	99.5	18421.0	21184.1	117.7	118	7.7	8	15	120	21600.0
200	54.5	90.8	106.9	113.7	21052.6	24210.4	134.5	135	7.7	8	17	136	24480.0
225	61.3	102.2	120.2	127.9	23684.1	27236.7	151.3	152	7.7	8	20	160	28800.0
250	68.1	113.5	133.6	142.1	26315.7	30263.0	168.1	169	7.7	8	22	176	31680.0
275	74.9	124.9	146.9	156.3	28947.3	33289.3	184.9	185	7.7	8	24	192	34560.0
300	81.8	136.3	160.3	170.5	31578.8	36315.6	201.8	202	7.7	8	26	208	37440.0
325	88.6	147.6	173.7	184.7	34210.4	39342.0	218.6	219	7.7	8	28	224	40320.0
350	95.4	159.0	187.0	198.9	36842.0	42368.3	235.4	236	7.7	8	30	240	43200.0
375	102.2	170.3	200.4	213.2	39473.5	45394.6	252.2	253	7.7	8	32	256	46080.0
400	109.0	181.7	213.7	227.4	42105.1	48420.9	269.0	270	7.7	8	34	272	48960.0
425	115.8	193.0	227.1	241.6	44736.7	51447.2	285.8	286	7.7	8	36	288	51840.0
450	122.6	204.4	240.4	255.8	47368.2	54473.5	302.6	303	7.7	8	38	304	54720.0
475	129.4	215.7	253.8	270.0	49999.8	57499.8	319.4	320	7.7	8	41	328	59040.0
500	136.3	227.1	267.2	284.2	52631.4	60526.1	336.3	337	7.7	8	43	344	61920.0

4.7.2. Life cycle of PV generator

Each machine or item has a design life time after which it will be useless. PV generators are one of the most efficient energy sources, but after a period of time their efficiency will be reduced because of exposure to sun and other environmental factors.

After about 7 to 10 years of using PV, it is being noted that the efficiency starts to decline gradually, which affects the produced energy. The design life cycle of photovoltaic is between 20 and 24 years, when PV generators will become useless and scrapped.

The operation of getting rid of PV modules is by selling them as scrapped materials. It is called salvage value and costs about2% of the capital cost of PV.

4.7.3. Annual cost of PV generator

The next step is to find the total cost of PV water pumping system, including fixed and running costs. PV water pumping system has just maintenance as a running cost; it only has the fixed cost represented by the price of devices shown in figure (4.1). The following points show how to calculate the total cost:

i. PV cost = $2\$ / W_P$

ii. Structure cost = $200\$ / kW_p$

iii. Wiring and installation = $40\$ / kW_p$

iv. Inverter cost = $800\$ / kW_{in}$

v. Installation cost = $250\$/kW_p$

vi. Pump cost is determined from market after choosing the suitable pump for each flow discharge.

vii. Salvage value of PV is about 2% from its capital cost.

viii. Total cost of the system is the summation of all terms above.

ix. By using economics the annual cost can be found at interest of 8%, and life cycle of 22 years.

Table (4.2) shows the name of pump used at each flow rate referring to KSB catalogues, and the cost for each pump is given from the company®[4][13].

[4]See appendix B.

Table (4.2) - Names of Pumps Used in the Designed PV Water Pumping System and their Prices

Flow Rate (m^3/day)	Pump Name	Price of the pump (US$)
50	UPA 150C - 16 / 10 STAGES	2323
75	UPA 150C - 16 / 11 STAGES	2385
100	UPA 150C - 16 / 14 STAGES	2703
125	UPA 150C - 30 / 12 STAGES	2933
150	UPA 150C - 30 / 13 STAGES	3028
175	UPA 150C - 30 / 14 STAGES	3118
200	UPA 150C - 48 / 10 STAGES	3745
225	UPA 150C - 48 / 11 STAGES	3936
250	UPA 150C - 48 / 12 STAGES	4114
275	UPA 150C - 48 / 13 STAGES	4462
300	UPA 150C - 60 / 12 STAGES	4125
325	UPA 150C - 60 / 12 STAGES	4125
350	UPA 150C - 60 / 13 STAGES	4160
375	UPA 150C - 60 / 15 STAGES	4737
400	UPA 150C - 60 / 16 STAGES	5050
425	UPA 200B - 80 / 5d	5784
450	UPA 200B - 80 / 5d	5784
475	UPA 200B - 80 / 5	5784
500	UPA 200B - 80 / 5	5784

Applying the steps mentioned above to find the total cost on one value of discharge which is $50m^3$/ day.

Total primary cost = $(2\$/W_P\ X\ 7200W) + (200\$/KW_P\ X\ 7.2KW) +$

$(\ 40\$/KW_P\ X\ 7.2KW) + (\ 800\$/KW\ X\ 28.420KW)\ +$

$(250\$/kW_p\ X\ 7.2) + (2323.566\$) - 0.02\ X\ 14400$

$= 42700.320\$$

This is called the net present value, and we find the annual value from equation (4.3). [19]

$$A = NPV\ X\ RF(i, T) \tag{4.3}$$

Where;

A is the annual value ($/year),

NPV is the net present value ($),

RF(i,T) is the capital recovery factor,

i is the interest value (it is assumed 8%) and

T represents the time.

For interest 8% and life cycle 22 years, the coefficient tables equals to 0.098030 [20] ®[5].

Total annual cost $= 42700.32\$\ X\ 0.098030$

$= 4185.912\ \$$

Table (4.3); repeats the steps above to find the annual cost for the other values of flow

[5] See appendix C.

Table (4.3) - The annual cost of PV water pumping system on different daily volume values

Daily volume of water (m^3/day)	Power produced by PV (W)	PV cost (US$)	Cost of support structure (US$)	Wiring & installation cost (US$)	Inverter power (W)	Inverter cost (US$)	Installation (US$)	Salvage value (US$)	motor pump cost (US$)	Total PV cost (US$) - present value	Annual cost (US$)
50	7200	14400	1440	288	28420.9	3789.5	1800.0	-288.0	2323.6	23753.0	2328.5
75	10080	20160	2016	403.2	42631.4	5684.2	2520.0	-403.2	2385.1	32765.3	3212.0
100	12960	25920	2592	518.4	56841.9	7578.9	3240.0	-518.4	2703.1	42034.1	4120.6
125	15840	31680	3168	633.6	71052.4	9473.6	3960.0	-633.6	2933.1	51214.7	5020.6
150	18720	37440	3744	748.8	85262.8	11368.4	4680.0	-748.8	3028.3	60260.7	5907.4
175	21600	43200	4320	864	99473.3	13263.1	5400.0	-864.0	3118.5	69301.6	6793.6
200	24480	48960	4896	979.2	113683.8	15157.8	6120.0	-979.2	3745.1	78879.0	7732.5
225	28800	57600	5760	1152	127894.2	17052.6	7200.0	-1152.0	3936.3	91548.9	8974.5
250	31680	63360	6336	1267.2	142104.7	18947.3	7920.0	-1267.2	4114.1	100677.4	9869.4
275	34560	69120	6912	1382.4	156315.2	20842.0	8640.0	-1382.4	4462.8	109976.8	10781.0
300	37440	74880	7488	1497.6	170525.7	22736.8	9360.0	-1497.6	4125.4	118590.2	11625.4
325	40320	80640	8064	1612.8	184736.1	24631.5	10080.0	-1612.8	4125.4	127540.9	12502.8
350	43200	86400	8640	1728	198946.6	26526.2	10800.0	-1728.0	4160.2	136526.5	13383.7
375	46080	92160	9216	1843.2	213157.1	28420.9	11520.0	-1843.2	4737.5	146054.4	14317.7
400	48960	97920	9792	1958.4	227367.5	30315.7	12240.0	-1958.4	5050.5	155318.1	15225.8
425	51840	103680	10368	2073.6	241578.0	32210.4	12960.0	-2073.6	5784.4	165002.8	16175.2
450	54720	109440	10944	2188.8	255788.5	34105.1	13680.0	-2188.8	5784.4	173953.5	17052.7
475	59040	118080	11808	2361.6	269999.0	35999.9	14760.0	-2361.6	5784.4	186432.3	18276.0
500	61920	123840	12384	2476.8	284209.4	37894.6	15480.0	-2476.8	5784.4	195383.0	19153.4

1) The factor needed to convert present value to annual value at interest 8% & 22 years = .098030

CHAPTER FIVE
WATER PUMPING SYSTEM FED BY DIESEL GENERATOR

5.1. System Layout

The second scenario is to power the water pumping system by a diesel generator instead of PV generator as shown in Fig (5.1), where a submersible pump is connected to an asynchronous motor which is powered by diesel generator set. [19]

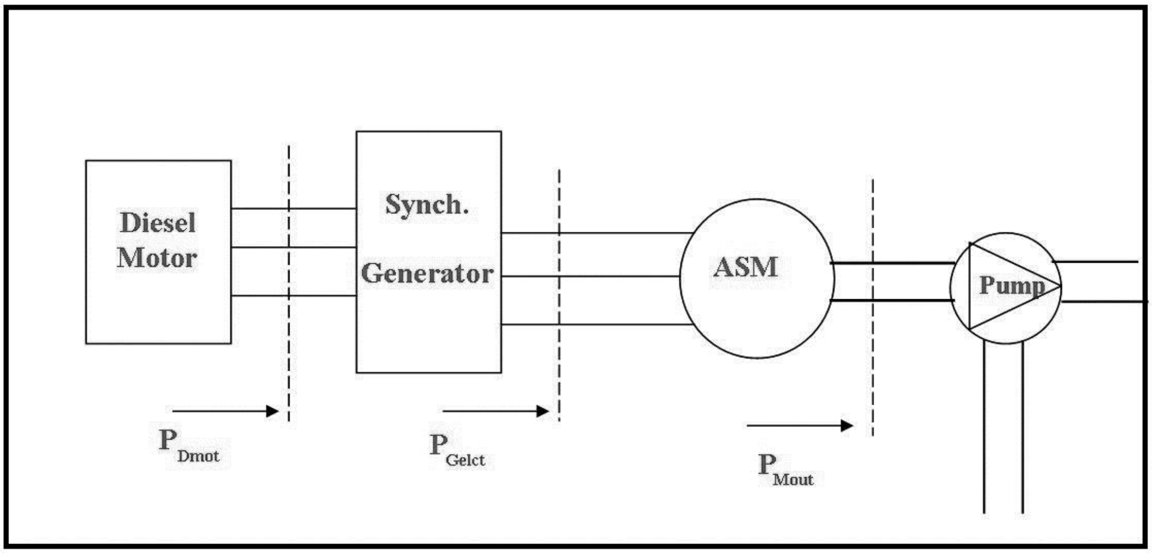

Fig (5.1) – Water pumping system powered by diesel generator

5.2. Diesel Generator

5.2.1. Why to use a diesel generator

Using a diesel generator is the second choice to operate a pump. It was used frequently in the past in desert areas, where PV generators were not common and their cost was too high in comparison with diesel generators.

Using a PV generator or a diesel generator in feeding water pumping system depends on the case itself. A PV generator is not always more economical and has less cost than diesel generator or grid, a series of calculations are made to help the designer in selecting the best feeding source.

5.2.2. Diesel generator efficiency

The generator sets which exist in the market are composed of a diesel motor and a synchronous generator. The efficiency of a generator set is the output power divided into the input power.

The efficiency of the generator is affected by some factors which are mechanical losses, exhaust heat, cooling fan losses [21], load, and fuel consumption. Losses are inversely proportional with efficiency while load is directly proportional with it.

5.3. Generator Set Layout

Fig. (5.2) clarifies the generator set construction and the equations connecting between the diesel engine and the synchronous motor.

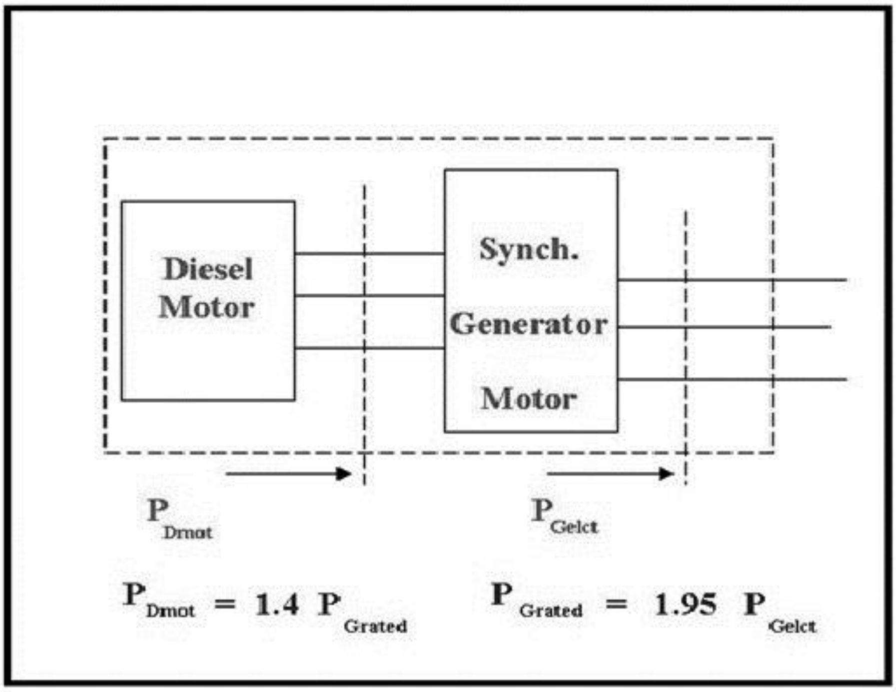

Fig (5.2) – Generator set layout

5.4. Strategy of Calculating the Total Cost of the Diesel Generator

There are some points that have to be taken into account in finding the total cost of diesel generator. The capital cost of the generator is not enough to be considered, there are some items classified as running cost paid throughout the period of using the generator.

5.4.1. Capital cost

The capital cost of generator is the price in the market, which is paid one time. The average life time of the generator is between 12 to 14 years.

5.4.2. Fuel cost

Fuel cost is considered a running cost which is restricted by fuel consumption. Fuel consumption of the diesel engine is provided by the engine manufacturer on the engine data sheet, where the load percentage determines the consumption [21]. On the other hand the fuel consumption can be calculated by Nayar equation.

5.4.3. Nayar equation

$$F_{CG} = A_G * P_G + B_G * P_{RG} \tag{5.1}$$

$\boldsymbol{F_{CG}}$ is the fuel consumption of the diesel generator (litre/hr)

$\boldsymbol{A_G}$ is a constant = 0.246 litre/kWh,

$\boldsymbol{P_G}$ is the output power of diesel generator (kW),

$\boldsymbol{B_G}$ is a constant = 0.08145 litre/kWh and

$\boldsymbol{P_{RG}}$ is the rated power of diesel generator (kW)

Nayar equation is used to calculate the fuel consumption of diesel generator, the results should not be accurate but it is so close to the real one.

5.4.4. Maintenance cost of diesel generator

Diesel generator needs regular maintenance throughout its life cycle. This includes maintenance operations including oils and fuel filters to insure that the generator works perfectly and on its high performance.

5.4.5. Running cost of diesel generator

The following are the points which need attention and cares in diesel generator maintenance.

- **Fuel filter:** Because of daily use of a diesel generator, water contamination problem will occur. Water inside the fuel tank should be removed, in an operation called fuel filtering. Fuel filtering is done every 400 hours with a cost assessed of about 12$.
- **Oil filter:** As mentioned above that water can damage the engine so oil filtering is needed. Oil filter for generator is changed every 200 hours, which costs about 17$
- **Air filter:** the performance of the engine is affected Because the air is polluted then the air filter have to be changed periodically. The time needed to the air filter to be changed is about 600 hours which costs about 35$.

- **Generator maintenance:** The diesel generator needs a general periodic maintenance to insure that it works perfectly. It is accomplished by specialists after working of about 6000 hours. The cost of generator maintenance is about 400$.
- **Overhaul**: Because of the length of the use duration of the generator, it needs an overhaul changing. Generator overhaul is executed every seven years which is evaluated about two times during generator life cycle and costs about 2000$.
- **Oil and fuel cost**: Fuel cost is mentioned before in section (5.4.3). Oil costs about 4$/litre, with a capacity of 16 litre of oil.

All the points which are mentioned above represent the running cost of generator, added to the capital cost of it to get the total cost. Then by using economical tables, it will be easier to find the annual cost of using the generator.

5.5. Total Cost of the Diesel Generator

The total cost of the generator is divided into two parts, fixed cost and running cost. Taking into account all calculations and considerations to choose the best generator for each water flow value.

Starting with a flow rate of $50m^3$/day, and finding the annual cost of using diesel generator, where 8 hours has to be considered as the working hours. The calculations which were made in section (4.6.1) in table (4.1) are completed.

5.5.1. Fixed cost of the diesel generator

To find the capital cost of the generator, it is important to choose the suitable diesel generator. Referring to the figure (5.1), the calculation starts where the input energy of the asynchronous motor was found.

$$P_{in\ (ASM)} = P_{out\ (sync\ G)} = \frac{E_{in\text{-}ASM}}{8\ hr} = \frac{26.716\ kWh}{8} = 3.339\ kW$$

Rated power of diesel generator $= 1.95 \times P_{in\text{-}ASM}$

$= 6.512$ kW

The next step is to find the standard rated generator in the market, which is found in complex power unit (kVA), with a power factor of about 0.83.

Rated complex power of generator = 6.512 kW / 0.83

= 7.846 kVA

The standard generator in the market is 10 kVA.

The output power of diesel motor = 1.4 X Rated power of diesel generator

= 1.4 X 6.512

= 9.1168 kW

= 12.221hp

The rated power which is found in the market is 20 hp.

The capital cost of a diesel generator of 20 hp = 10000US$

Annual cost of generator = 10000 US$ X 0.1213

= **1213 US$ / year**

5.5.2. Running cost of the diesel generator

- **Annual cost of the fuel consumption**

  $\mathbf{F_{CG} = A_G \times P_G + B_G \times P_{RG}}$

  = 0.246 L/kWh X 9.1168 + 0.08145 X (20hp X0.746)

  = **3.3458 L / hr**

Annual fuel cost = 3.3458 L/hr X 8 hr X 365 day X 2 $/L

= **20194.72 $ / year**

- **Annual cost of the fuel filter**

  Number of working hours / year = 2920 hrs

  The fuel filter has to be changed each 400 hrs.

  Number of times that the fuel filter is changed yearly $= \frac{2920}{400}$

  = 7.3

  ≡ 7 times

  Annual cost of fuel filter = 12 $ X 7

  = **84 $ / year**

- **Annual cost of the oil filter**

  The oil filter has to be changed each 200 hrs.

  Number of times that the oil filter is changed yearly $= \frac{2920}{200}$

$= 14.6$

$\equiv$ 15 times

Annual cost of oil filter = 17 \$ X 15

= **255 \$ / year**

- **Annual cost of the air filter**

The oil filter has to be changed each 600 hrs.

Number of times that the air filter is changed yearly $= \frac{2920}{600}$

$= 4.8$

$\equiv$ 5 times

Annual cost of air filter = 35 \$ X 5

= **175 \$ / year**

- **Annual cost of the maintenance**

The diesel generator has to be maintained each 6000 hours.

Number of times that the fuel filter is changed yearly $= \frac{2920}{6000}$

$= 0.487$

$\equiv$ once each 2 years

By using economical tables, to find the annual cost of maintenance for the diesel generator for 2 years, we get the annual cost of air filter [20].

Annual cost of maintenance = 400 \$ X 0.56007

= **224.308 \$ / year**

- **Annual cost of the oil consumption**

The oil is changed in diesel generator each 200 hours.

Number of times that the fuel filter is changed yearly $= \frac{2920}{200}$

$= 14.6$

$\equiv 15$ times

Annual cost of oil consumption = 4 $/L X 16 L X 15

= **960 $ / year**

- **Annual cost of the overhaul**

The overhaul of the diesel generator is executed each 7 years. And as known the life cycle of the generator is about 14 years.

Annual cost of overhaul = 2000 $ X 0.19207

= **384.14 $ / year**

5.5.3. Annual cost of the diesel generator

Total annual cost of using diesel generator = ∑ annual cost of all item

= **23489.448 $ / year**

The calculations above were repeated for all values of flow rate as in tables (5.1) and (5.2).

Table (5.1) - Fuel consumption of the diesel generator

Daily volume of water (m^3/day)	Input energy of ASM (kWh)	Output power of diesel generator (kW)	Rated power of diesel generator (kW)	Rated apparent power kVA (calculated)	Standard rated apparent power(kVA)	Output power of diesel motor (kW)	Output power of diesel motor(hp)	Standard output power of diesel motor(hp)	Actual output power of diesel motor(kW)	Fuel consumption (liter/hour)
50	26.7	3.3	6.5	7.8	10	9.1	12.2	20.0	14.9	3.5
75	40.1	5.0	9.8	11.8	22	13.7	18.3	20.0	14.9	4.6
100	53.4	6.7	13.0	15.7	22	18.2	24.4	25.0	18.7	6.0
125	66.8	8.3	16.3	19.6	30	22.8	30.6	40.0	29.8	8.0
150	80.1	10.0	19.5	23.5	30	27.4	36.7	40.0	29.8	9.2
175	93.5	11.7	22.8	27.5	30	31.9	42.8	50.0	37.3	10.9
200	106.9	13.4	26.0	31.4	50	36.5	48.9	50.0	37.3	12.0
225	120.2	15.0	29.3	35.3	50	41.0	55.0	60.0	44.8	13.7
250	133.6	16.7	32.6	39.2	50	45.6	61.1	75.0	56.0	15.8
275	146.9	18.4	35.8	43.2	50	50.1	67.2	75.0	56.0	16.9
300	160.3	20.0	39.1	47.1	50	54.7	73.3	100.0	74.6	19.5
325	173.7	21.7	42.3	51.0	70	59.3	79.4	100.0	74.6	20.7
350	187.0	23.4	45.6	54.9	70	63.8	85.5	100.0	74.6	21.8
375	200.4	25.0	48.8	58.8	70	68.4	91.7	100.0	74.6	22.9
400	213.7	26.7	52.1	62.8	70	72.9	97.8	100.0	74.6	24.0
425	227.1	28.4	55.4	66.7	70	77.5	103.9	125.0	93.3	26.7
450	240.4	30.1	58.6	70.6	80	82.1	110.0	125.0	93.3	27.8
475	253.8	31.7	61.9	74.5	80	86.6	116.1	125.0	93.3	28.9
500	267.2	33.4	65.1	78.5	80	91.2	122.2	150.0	111.9	31.5

1) **Rated power of diesel engine = 1.95 * output power of ASM**

2) **Assumed power factor = 0.83**

3) **Output power of diesel motor = 1.4 * Rated power of diesel engine**

4) **No of working hours per year = 8*365 = 2920 hours**

Table (5.2) - The Annual cost of operating pumping system powered by a diesel generator

Daily volume of water (m^3/day)	Fuel consumption (litr/hour)	Annual cost of fuel consumption (2US$/litre)	Total annual cost of filters, maintenance & overhaul (US$)	Standard genartor used (kVA)	Net present value of diesel generator (US$)	Annual cost of the diesel generator (US$)	Total annual cost (US$)
50	3.5	20194.4	2083.0	10	10000	1213.0	23489.9
75	4.6	26743.2	2083.0	22	12900	1564.8	30390.4
100	6.0	35066.1	2083.0	22	12900	1564.8	38713.3
125	8.0	46937.6	2083.0	30	15000	1819.5	50839.5
150	9.2	53486.3	2083.0	30	15000	1819.5	57388.2
175	10.9	63583.5	2083.0	30	15000	1819.5	67485.5
200	12.0	70132.2	2083.0	50	16500	2001.5	74216.1
225	13.7	80229.5	2083.0	50	16500	2001.5	84313.3
250	15.8	92100.9	2083.0	50	16500	2001.5	96184.8
275	16.9	98649.6	2083.0	50	16500	2001.5	102733.5
300	19.5	114069.6	2083.0	50	16500	2001.5	118153.5
325	20.7	120618.3	2083.0	70	18000	2183.4	124884.1
350	21.8	127167.0	2083.0	70	18000	2183.4	131432.9
375	22.9	133715.8	2083.0	70	18000	2183.4	137981.6

Daily volume of water (m^3/day)	Fuel consumption (litr/hour)	Annual cost of fuel consumption (2US$/litre)	Total annual cost of filters, maintenance & overhaul (US$)	Standard genartor used (kVA)	Net present value of diesel generator (US$)	Annual cost of the diesel generator (US$)	Total annual cost (US$)
400	24.0	140264.5	2083.0	70	18000	2183.4	144530.3
425	26.7	155684.4	2083.0	70	18000	2183.4	159950.3
450	27.8	162233.1	2083.0	80	19000	2304.7	166620.3
475	28.9	168781.9	2083.0	80	19000	2304.7	173169.0
500	31.5	184201.8	2083.0	80	19000	2304.7	188589.0

1) Interest rate = 8%
2) Yearly working hours= 8*365 = 2920 hours
3) The fuel filter is replaced each 400 hours
4) Annual cost of fuel filter =84 $
5) The oil filter is replaced each 200 hours
6) Annual cost of oil filter =255 $
7) The air filter is replaced each 600 hours
8) Annual cost of air filter = 175 $
9) Maintenance is executed each 6000 hours
10) The factor of annual cost for 3 years = 0.56077
11) Annual cost of maintenance = 224.308 $
12) Oil is consumed each 200 hours
13) Annual cost of oil consumption = 960 $
14) Overhaul is changed each 7 years
15) The factor of annual cost for 7u years = 0.12130
16) Annual cost of oil consumption = 384.7 $
17) The factor of annual cost for 14 years = 0.12130

CHAPTER SIX
ECONOMICAL ANALYSIS

6.1. Environmental Aspect

When comparing between PV generator and diesel generator, the comparison is set on more one then direction, each aspect will be discussed briefly.

Starting in the environmental effect as it is the main reason to tend towards the renewable resources instead of other traditional resources. Global warming and air pollution are severe environmental problems facing the world as a result of the gases emission like CO_2, NO_2 and SO_2 from fossil fuels [22]. Those gases are called pollutants which have negative impact on health and on the surrounding climate. Also global warming effect and Ozone depletion are results of emitted pollutants from traditional energy sources. Pollutants are gases emitted from fossil fuels in specific rates during combustion operation.

Regarding the PV cells, there is no gas emission or any other source of pollution. This aspect is important to scientists and those who care and know about the bad environmental impact. This is important to improve people awareness of the renewable energy and it is positive environmental impacts and not just economically.

6.2. Investment Aspect

Nowadays, the whole world tends to adoption the clean energy sources as the main source. All developed countries follow the direction of reducing the dependence on traditional energy sources because of their negative impacts.

There is a big orientation towards the renewable resources, and specifically in Palestine there are many experiments supported by the government to establish PV generators to supply houses with electricity.

It seems that the existence of companies' support and finance PV power projects will be a good investment in the country, especially that Palestine suffer from occupation obstacles therefore, the interest in this sector will create jobs and may help in solving the problem of unemployment.

6.3. Economical Aspect

This is the most important aspect to discuss. It is the side which is important to the public, as it has direct financial and economic impacts on them. The PV system uses no fuel and has very low maintenance, while diesel generator needs more operation and maintenance cost [23].

The scenario is based on finding the price of the water cubic meter when using both systems. After finding the annual cost of each PV generator and diesel generator, the result is divided on 365 days and then dividing the daily cost on the flow rate. The result will be the price of one cubic meter of water pumped to the residents [24].

Table (6.1) shows that the price of one cubic meter of water when using PV generator, while table (6.2) shows it when using a diesel generator. Combining the two tables together, we get the curves shown in Fig. (6.1).

Table (6.1) - The cost of pumping one cubic meter when using a PV generator

Daily volume of water (m^3/day)	Annual cost of water US$/year	Daily cost of water US$/year	One cubic meter price US$/$m^3$
50	2328.5	6.4	0.1276
75	3212.0	8.8	0.1173
100	4120.6	11.3	0.1129
125	5020.6	13.8	0.1100
150	5907.4	16.2	0.1079
175	6793.6	18.6	0.1064
200	7732.5	21.2	0.1059
225	8974.5	24.6	0.1093
250	9869.4	27.0	0.1082
275	10781.0	29.5	0.1074
300	11625.4	31.9	0.1062
325	12502.8	34.3	0.1054
350	13383.7	36.7	0.1048
375	14317.7	39.2	0.1046
400	15225.8	41.7	0.1043
425	16175.2	44.3	0.1043
450	17052.7	46.7	0.1038
475	18276.0	50.1	0.1054
500	19153.4	52.5	0.1050

Table (6.2) - The cost of pumping one cubic meter when using a diesel generator

Daily volume of water (m^3/day)	Annual cost of water US$/year	Daily cost of water US$/year	One cubic meter price US$/$m^3$
50	23489.9	64.4	1.28
75	30390.4	83.3	1.11
100	38713.3	106.1	1.06
125	50839.5	139.3	1.11
150	57388.2	157.2	1.05
175	67485.5	184.9	1.06
200	74216.1	203.3	1.02
225	84313.3	231.0	1.03
250	96184.8	263.5	1.05
275	102733.5	281.5	1.02
300	118153.5	323.7	1.08
325	124884.1	342.1	1.05
350	131432.9	360.1	1.03
375	137981.6	378.0	1.01
400	144530.3	396.0	0.99
425	159950.3	438.2	1.03
450	166620.3	456.5	1.01
475	173169.0	474.4	0.10
500	188589.0	516.7	1.03

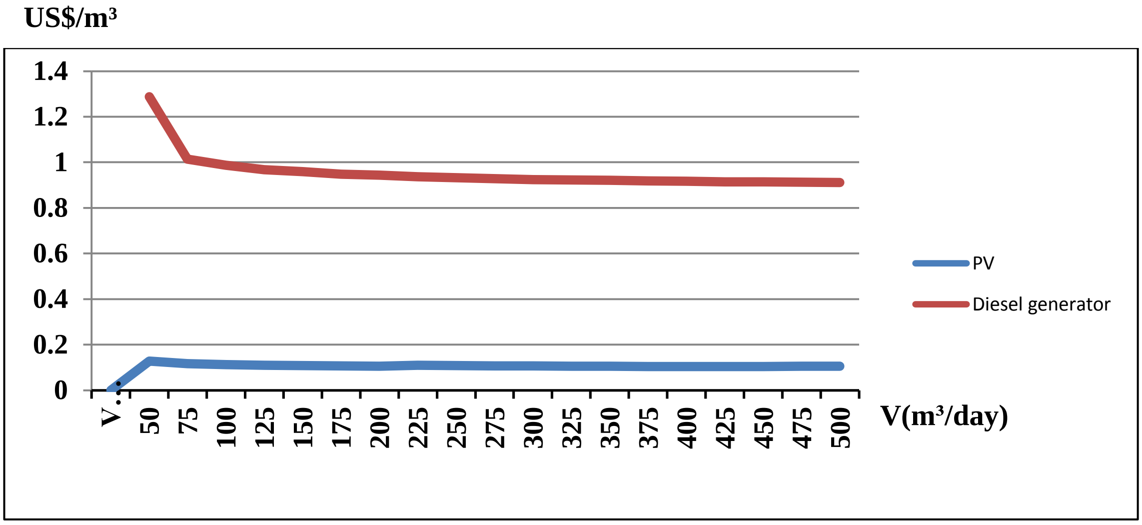

Fig (6.1) - The cost of pumping one cubic meter of water when using a PV generator and a diesel generator

As a result of curve (6.1), it is obvious that using a PV generator is more economical than using a diesel generator.

6.4. Equivalent Hydraulic Energy Feasibility Borders

The result of the research is so clear that using PV is more economical than using diesel generator, but usually the curve is not as seen in curve (6.1). Usually, both curves of diesel generator and PV generator intersect in point called the equivalent hydraulic energy border.

This intersection point determine at what flow rate is better to use PV generator and when to use diesel generator. Curve (6.2) is a roughly curve to clarify the equivalent hydraulic energy border.

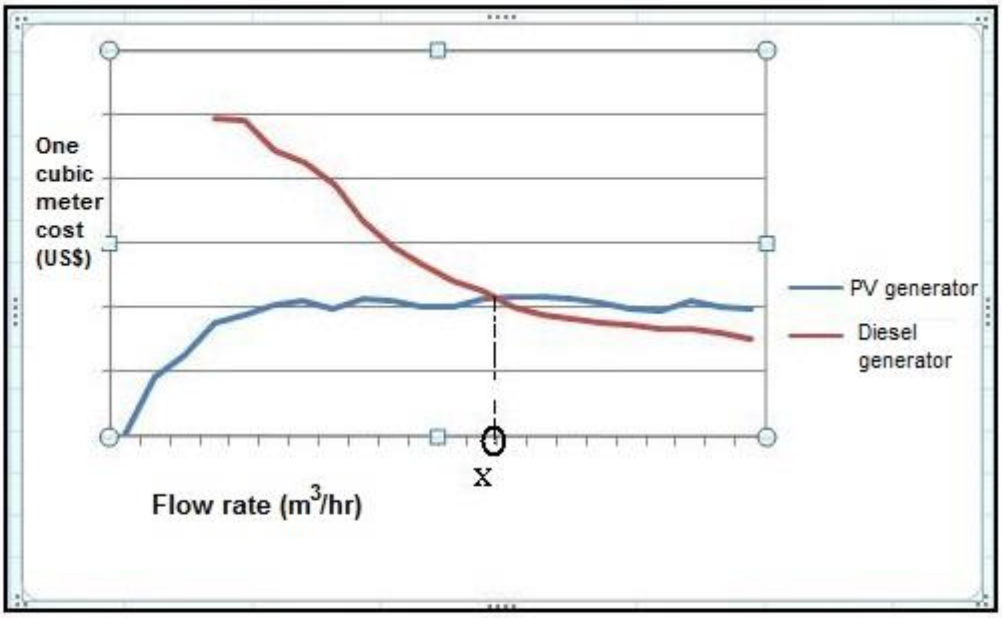

Fig (6.2) – A curve to clarify the best flow rate point to work on PV generator

Point (X) is the intersection point between both curves; Diesel generator and PV generator. As shown above that at flow rate less than X value, the price of cubic meter of water is less when using

PV generator, while on a value bigger than X, it is more economical to use diesel generator.

In this research the two curves didn't intersect, and it is hard to choose a perfect point of flow rate because in all cases we get that PV is more economical than diesel generator.

6.5. Economical Analysis Summary

Referring to the curve in Fig (6.1) it is found out that using PV generator to power the pumping station is more feasible than diesel generator where there is a big difference in water cost between the two systems. The cost of one cubic meter using PV generator was less than the other one by about 80%. The big difference between them is referring to many factors, the most important of them is that diesel fuel is costly compared to peak power price of PV, besides PV system doesn't have running cost counter to diesel generator.

CHAPTER SEVEN
VERTICAL TURBINE PUMP DRIVEN DIRECTLY BY A DIESEL MOTOR

7.1 Operating a Vertical Turbine Pump by a Diesel Motor

The vertical turbine pumps are another type of centrifugal pumps which is frequently used in the irrigation field. In this chapter we used a vertical turbine pump driven by a diesel motor , and compared the annual cost of it with the annual cost of using PV generator to feed a submersible pump. The following figure shows the a sketch of the system.

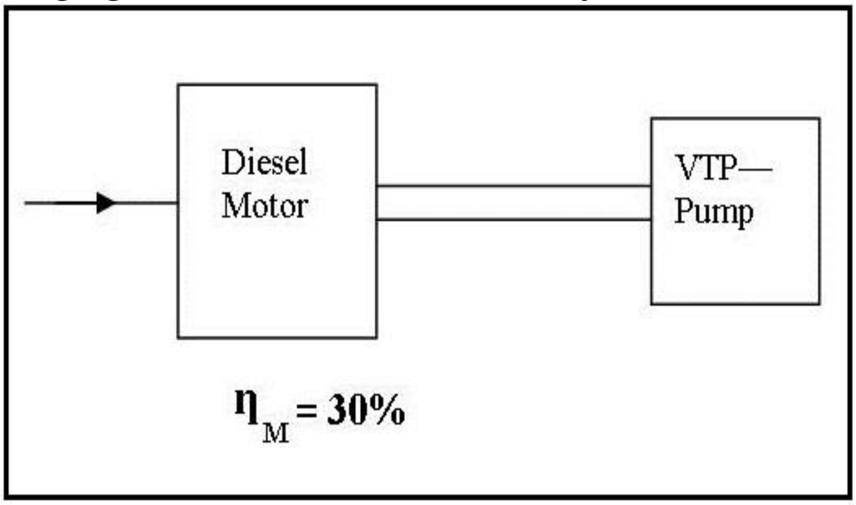

Fig (7.1) –A vertical turbine pump driven by a diesel motor

Firstly, the output power of the vertical turbine pump is calculated as shown in equation (7.1) below. [3]

$$P_o = 2.725 \, X \, Q \, X \, H \qquad (7.1)$$

Where;

$\boldsymbol{P_o}$ is the output power of the pump “hydraulic power” – (W),

$\boldsymbol{Q}$ is the flow rate of water - (m^3/h) and

$\boldsymbol{H}$ is the total head.

7.2. The Economical Study

7.2.1. Selecting the pump

Choosing the suitable pump depends on the flow rate and well head by using equation (7.1), and then choosing the diesel motor.

As in previous chapters, the supposed head is 100m and the volume of the water ranges between $50m^3$ and $500m^3$. The operating hours were supposed to be 2 hours for volumes (50,75,100,125,150 and 175) and 4 hours for the other values.

For the volume $5om^3$/day, the flow rate is $25m^3$/hr.

$P_{out\text{-}pump} = 2.725 \text{ X } Q \text{ X } H$

$= 2.725 \text{ X } 25 \text{ X } 100$

$= 6812.5 \text{ W}$

The supposed efficiency of the vertical turbine pump is 50%.

$P_{out\text{-}pump} = P_{in\text{-}pump} \text{X } \eta$

$P_{in\text{-}pump} = 13625 \text{ W}$

= 18.2 hp (the standard input power of VTP in the markets is 20 hp)

The estimated price of a vertical turbine pump of 20hp is about 8000$.

The input power of the pump equals the output power of the diesel motor.

$P_{out\text{-}motor} = P_{in\text{-}pump} = 20 \text{ hp}$

The actual output power of the motor is got by multiplying the calculated power by 2, this step is very important to choose the suitable motor to operate the pump.

$P_{out\text{-}motor(act)}$ = 40 hp

$P_{out\text{-}motor} = P_{in\text{-}motor} \ X \ \eta_{motor}$

Where the efficiency of the diesel motor is about 30%.

$P_{in\text{-}motor}$= 133.3hp

= 133.3 X 0.747

= 999.6 kw

Table (7.1) shows the results for the other values of daily water flow rate as calculated for 50m^3/day.

Table (7.1) - The vertical turbine pump and the diesel motor used at different daily volume values

Daily volume of water (m^3/day)	Flow rate (m^3/h)	Hydraulic power (W)	Input power of pump (W)	Input power of pump (hp)	Standard power in market (hp)	Pump price (US$)	Actual output power of motor (hp)	Price of diesel motor (US$)	Input power diesel (hp)	Actual power of diesel motor (kW)
50	25.0	6812.5	13625.0	18.2	20.0	8000.0	40.0	7000.0	133.3	99.6
75	37.5	10218.8	20437.5	27.4	30.0	8300.0	60.0	8500.0	200.0	149.4
100	50.0	13625.0	27250.0	36.5	40.0	9500.0	80.0	11000.0	266.7	199.2
125	62.5	17031.3	34062.5	45.6	50.0	9500.0	100.0	12000.0	333.3	249.0
150	75.0	20437.5	40875.0	54.7	60.0	9500.0	120.0	12500.0	416.7	311.3
175	87.5	23843.8	47687.5	63.8	75.0	9500.0	150.0	14000.0	500.0	373.5
200	50.0	13625.0	27250.0	36.5	40.0	9500.0	80.0	11000.0	266.7	199.2
225	56.3	15328.1	30656.3	41.0	50.0	9500.0	100.0	12000.0	333.3	249.0
250	62.5	17031.3	34062.5	45.6	50.0	9500.0	100.0	12000.0	333.3	249.0
275	68.8	18734.4	37468.8	50.2	60.0	9500.0	120.0	12500.0	416.7	311.3
300	75.0	20437.5	40875.0	54.7	60.0	9500.0	120.0	12500.0	416.7	311.3
325	81.3	22140.6	44281.3	59.3	60.0	9500.0	120.0	12500.0	416.7	311.3
350	87.5	23843.8	47687.5	63.8	75.0	9500.0	150.0	14000.0	500.0	373.5
375	93.8	25546.9	51093.8	68.4	75.0	12000.0	150.0	14000.0	500.0	373.5
400	100.0	27250.0	54500.0	73.0	75.0	12000.0	150.0	14000.0	500.0	373.5
425	106.3	28953.1	57906.3	77.5	100.0	12000.0	200.0	16000.0	666.7	498.0
450	112.5	30656.3	61312.5	82.1	100.0	12000.0	200.0	16000.0	666.7	498.0
475	118.8	32359.4	64718.8	86.6	100.0	12000.0	200.0	16000.0	666.7	498.0
500	125.0	34062.5	68125.0	91.2	100.0	12000.0	200.0	18000.0	666.7	498.0

1) Total pumping head = 100m
2) The assumed efficiency of the diesel motor = 30%
3) The assumed efficiency of the vertical turbine pump = 50%
4) operating hours =2hr for (50 - 175)m^3/day
5) operating hours =4hr for (200 - 500)m^3/day

7.2.2.The fuel consumption

The input power of the diesel motor at ($V=50m^3$/day) was 99.6 kW, then the fuel consumption will be as follows.

$P_{in\text{-}motor}$ = 99.6 kW

$E_{in\text{-}motor}$ = 99.6 kW X 1 hour

= 99.6 kWh

1 litre of diesel ≡ 3.5 kWh

The diesel consumption = (99.6kWh X 1 hr) / 3.5 kWh

= 28.5 litre /hour

Total diesel consumption = 57 litre

The total cost of the system contains of the price of the pump and the diesel motor which is called capital cost, which also includes well head cost, the right angle gear cost, discharge plate, well columns pipes and steel rods. The running cost includes the cost of fuel and other expenses which were mentioned in chapter five like filters, maintenance and overhaul.

Table (7.2) shows the total cost for values which were found in table (7.1), and it is followed by a curve compares between the cost of one cubic meter of water when using PV system and using vertical turbine pump driven by a diesel motor.

Table (7.2) - The annual cost of operating a vertical turbine pump by a diesel motor

Daily volume of water (m^3/day)	Pump price (US$)	Annual cost of the pump (US$/ year)	Price of diesel motor (US$)	Annual cost of the motor (US$/ year)	Daily consumption of diesel (litre/day)	Fuel yearly cost(US$/ year)	Annual cost of fuel filter (US$/year)	Annual cost of oil filter (US$/year)	Annual cost of air filter (US$/year)	Annual cost of maintenance (US$/year)	Annual cost ofoil consumption (US$/year)	Annual cost of overhaul (US$/year)	Total cost of accessories (US$)	Annual cost of accessories (US$/year)	Total annual cost (US$/year)
50	8000.0	784.2	7000.0	686.2	56.9	33757.3	24.0	68.0	70.0	69.6	256.0	280.2	18400.0	1803.8	37799.3
75	8300.0	813.6	8500.0	833.3	85.4	50635.9	24.0	68.0	70.0	69.6	256.0	280.2	18400.0	1803.8	54854.3
100	9500.0	931.3	11000.0	1078.3	113.8	67514.6	24.0	68.0	70.0	69.6	256.0	280.2	18400.0	1803.8	72095.7
125	9500.0	931.3	12000.0	1176.4	142.3	84393.2	24.0	68.0	70.0	69.6	256.0	280.2	18400.0	1803.8	89072.4
150	9500.0	931.3	12500.0	1225.4	177.9	105491.5	24.0	68.0	70.0	69.6	256.0	280.2	18400.0	1803.8	110219.7
175	9500.0	931.3	14000.0	1372.4	213.4	126589.8	24.0	68.0	70.0	69.6	256.0	280.2	18400.0	1803.8	131465.0
200	9500.0	931.3	11000.0	1078.3	227.7	135029.1	48.0	119.0	105.0	120.8	512.0	384.1	18400.0	1803.8	140131.4
225	9500.0	931.3	12000.0	1176.4	284.6	168786.4	48.0	119.0	105.0	120.8	512.0	384.1	18400.0	1803.8	173986.7
250	9500.0	931.3	12000.0	1176.4	284.6	168786.4	48.0	119.0	105.0	120.8	512.0	384.1	18400.0	1803.8	173986.7
275	9500.0	931.3	12500.0	1225.4	355.7	210983.0	48.0	119.0	105.0	120.8	512.0	384.1	18400.0	1803.8	216232.4
300	9500.0	931.3	12500.0	1225.4	355.7	210983.0	48.0	119.0	105.0	120.8	512.0	384.1	18400.0	1803.8	216232.4
325	9500.0	931.3	12500.0	1225.4	355.7	210983.0	48.0	119.0	105.0	120.8	512.0	384.1	18400.0	1803.8	216232.4
350	9500.0	931.3	14000.0	1372.4	426.9	253179.6	48.0	119.0	105.0	120.8	512.0	384.1	18400.0	1803.8	258576.0
375	12000.0	1176.4	14000.0	1372.4	426.9	253179.6	48.0	119.0	105.0	120.8	512.0	384.1	18400.0	1803.8	258821.1
400	12000.0	1176.4	14000.0	1372.4	426.9	253179.6	48.0	119.0	105.0	120.8	512.0	384.1	18400.0	1803.8	258821.1
425	12000.0	1176.4	16000.0	1568.5	569.1	337572.9	48.0	119.0	105.0	120.8	512.0	384.1	18400.0	1803.8	343410.4
450	12000.0	1176.4	16000.0	1568.5	569.1	337572.9	48.0	119.0	105.0	120.8	512.0	384.1	18400.0	1803.8	343410.4
475	12000.0	1176.4	16000.0	1568.5	569.1	337572.9	48.0	119.0	105.0	120.8	512.0	384.1	18400.0	1803.8	343410.4
500	12000.0	1176.4	18000.0	1764.5	569.1	337572.9	48.0	119.0	105.0	120.8	512.0	384.1	18400.0	1803.8	343606.4

1) Accessories cost are:- well head cost=3000$
2) Discharge plate =400$
3) Well columns pipe =90$/3m
4) stainless steel rods =25$/m
5) The factor needed to convert present value to annual value = .098030
6) The cost of the filters, maintenance, overhaul & oil consumption were calculated as in chapter five

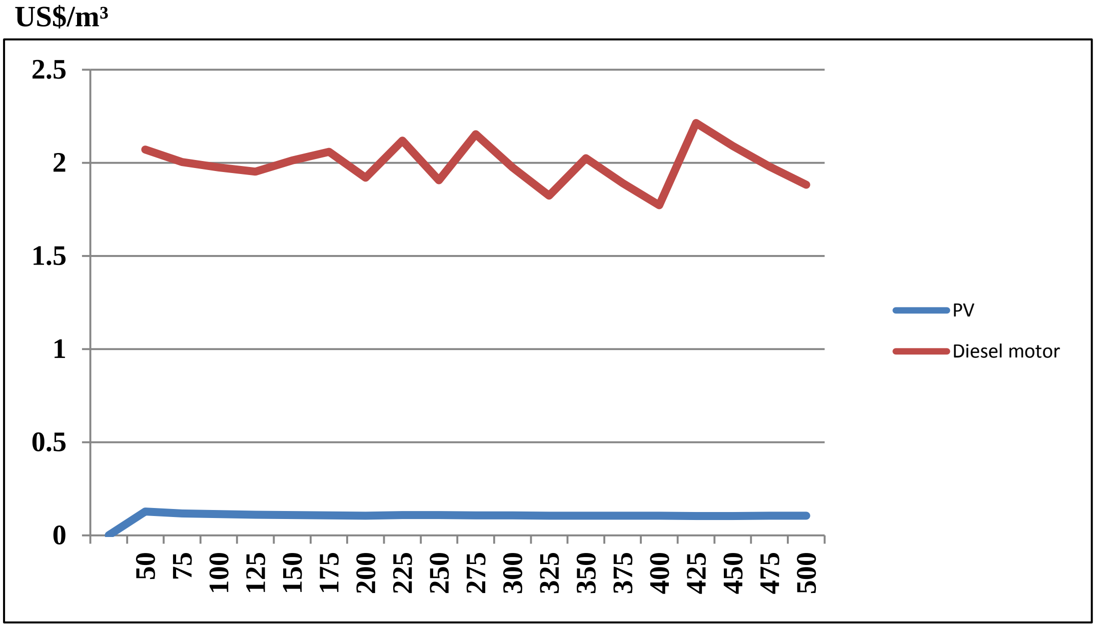

Fig (7.2) - The cost of pumping one cubic meter of water when using a PV generator and a diesel motor

As shown in Fig (7.2) that pumping water using PV generator is more feasible and less cost than it by using diesel motor. Where the cost of one cubic meter of pumped water by PV system is less by about 90% than using diesel motor.

This approves for the second time that pumping water by PV system is more feasible than using either diesel generator or diesel motor in case of the site is off grid, otherwise the electric grid is the most feasible system.

CHAPTER EIGHT
OPERATING PUMPING SYSTEM BY ELECTRICAL GRID

8.1. Introduction

Palestine is considered as one of the most countries suffering from problems related to providing electricity, as it is provided from Israel. This encourages using other sources as diesel generator or solar PV systems. However in some cases, it is better to feed the load from the electrical grid, since it is more feasible than using PV in such cases. Therefore it is not true to judge that using PV will be more economical than electricity until making a complete analysis.

This chapter is looking over the feasibility of using the grid in powering the pumping system instead of PV generator.

8.2. Feeding the Pumping System by Electrical Grid

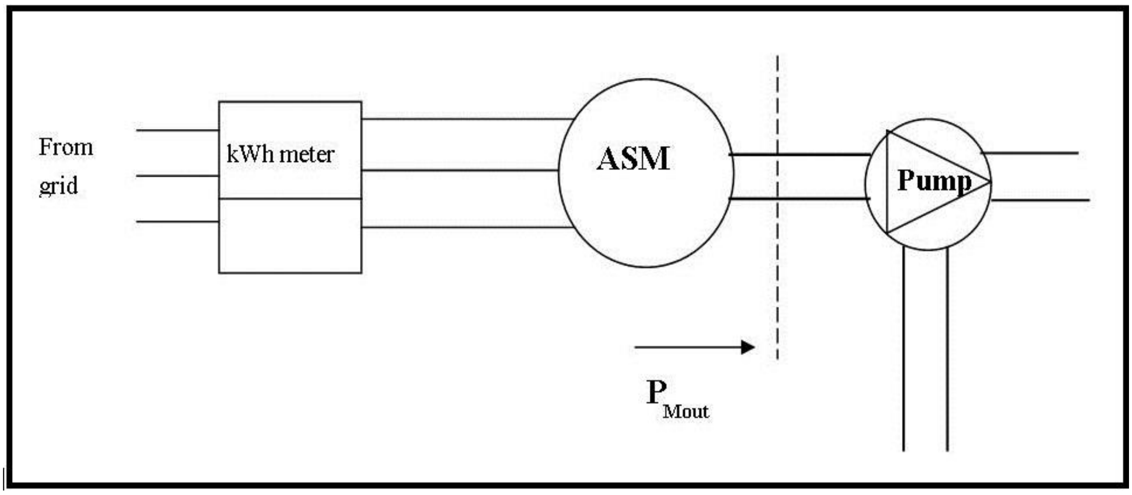

Fig (8.1) – Water pumping system powered by electrical grid

8.3. Economical Analysis when the System is tied to Grid

Now we transfer to discover whether using electric grid is more feasible than using PV or not. Operating the pump on electricity has just a running cost which represented in the cost of kWh of consumption.

We assumed that the region is not far from the electrical grid and we have two choices to operate the pump, by PV or grid. Table (8.1) presents the cost of one cubic meter of water when powering the system from grid and the table is followed by a figure contains two curves of one water cubic meter price for both systems; PV generator and electrical grid.

Table (8.1) - The cost of pumping one cubic meter of water when powering the pumping system from grid

Daily volume of water (m^3/day)	Hydraulic energy (E_{out} of pump) kWh	Input energy of pump (shaft power) kWh	Output energy of ASM (kWh)	Input energy of ASM (kWh)	Cost of electricity (US$/ day)	Cost of one cubic meter of water (US$/ day)
50	13.6	22.7	22.7	26.7	4.9	0.10
75	20.4	34.1	34.1	40.1	7.4	0.10
100	27.3	45.4	45.4	53.4	9.9	0.10
125	34.1	56.8	56.8	66.8	12.4	0.10
150	40.9	68.1	68.1	80.1	14.8	0.10
175	47.7	79.5	79.5	93.5	17.3	0.10
200	54.5	90.8	90.8	106.9	19.8	0.10
225	61.3	102.2	102.2	120.2	22.3	0.10
250	68.1	113.5	113.5	133.6	24.7	0.10
275	74.9	124.9	124.9	146.9	27.2	0.10
300	81.8	136.3	136.3	160.3	29.7	0.10
325	88.6	147.6	147.6	173.7	32.2	0.10
350	95.4	159.0	159.0	187.0	34.6	0.10
375	102.2	170.3	170.3	200.4	37.1	0.10
400	109.0	181.7	181.7	213.7	39.6	0.10
425	115.8	193.0	193.0	227.1	42.1	0.10
450	122.6	204.4	204.4	240.4	44.5	0.1
475	129.4	215.7	215.7	253.8	47.0	0.1
500	136.3	227.1	227.1	267.2	49.5	0.1

1) al pumping head = 100 m ,
2) Assumed efficiency of the motor = 85% ,
3) Assumed efficiency of the pump = 60% ,
4) Price of 1kWh = 0.68 NIS/kWh = 0.1853 \$/kWh

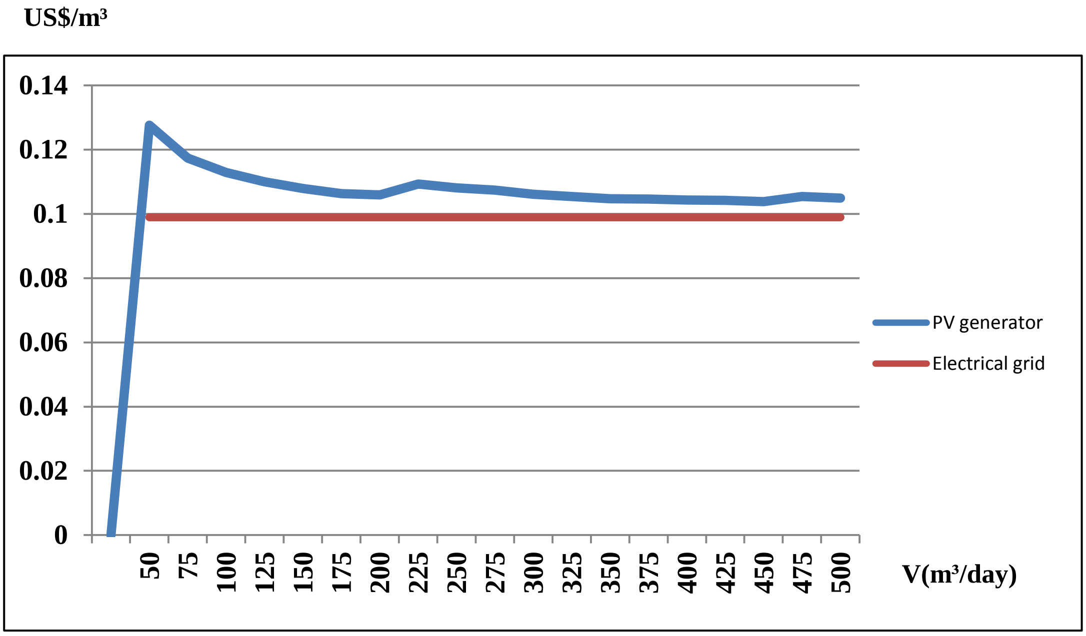

Fig (8.2) - The cost of pumping one cubic meter of water when using a PV generator and a diesel motor.

Depending on the results obtained in section (8.3) it is found that operating the pump via grid is more feasible than PV generator, but also the two curves are so close to each other where the price of one cubic meter of water by using electricity is around 8% less than using a PV generator, therefore in the future if such a comparison is done for a similar system, it is expected that PV curve may intersect with the grid one or it will be under it, which means that the cost of water when feeding the pumping system by PV will decrease.

8.4. Net Metering Technique

8.4.1. Definition of net metering

Net metering technique is an electricity policy for consumers who own renewable energy facilities which allow them to use electricity whenever needed while contributing their production to the grid. [25]

8.4.2. Using net metering technique

Fig.(8.3) shows how the kWh meter is connected to PV and to grid to find the net energy produced by the solar system.

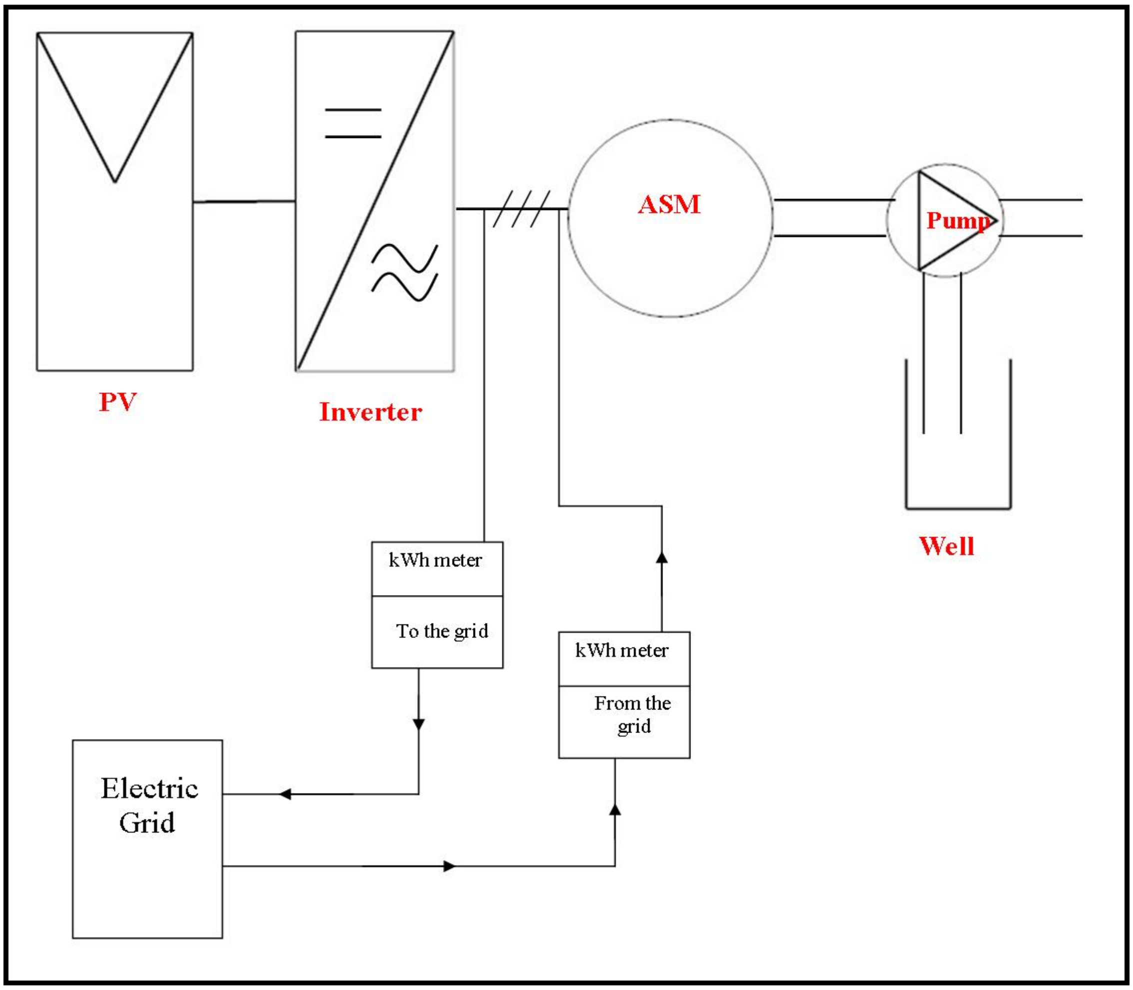

Fig (8.3) – A water pumping system is powered by a PV generator and using net metering

The principle of net metering is based on an idea considered as been accepted to public. It is easier to convince people in PV by putting forward net metering idea, and that the municipality can buy the electricity generated from the solar system in a cost exceeds the cost of kWh sold. It is not easy to convince customers in environmental aspects or even in the payback period specially those who are simple people.

Table (8.2) shows payback period, which clarify the number of years needed to get the cost of PV system back where the price of the energy produced by PV is assumed as in Israel which is 1.05 NIS / kWh.

Table (8.2) - Finding payback period of operating the pumping system by a PV generator using net metering

Daily volume of water (m^3/day)	Power produced by PV (W)	Net present value of PV water pumping system (US$)	Daily peak power of PV (kWp)	Energy produced by PV (kWh)	Yearly cost of purchased energy (US$ / year)	Cost of energy purchased to municipality after 22 years (US$)
50	7200	23753.0	7.2	50.4	1944.7	19836.1
75	10080	32765.3	10.1	70.6	2722.6	27770.6
100	12960	42034.1	13.0	90.7	3500.5	35705.1
125	15840	51214.7	15.8	110.9	4278.4	43639.5
150	18720	60260.7	18.7	131.0	5056.3	51574.0
175	21600	69301.6	21.6	151.2	5834.2	59508.4
200	24480	78879.0	24.5	171.4	6612.0	67442.9
225	28800	91548.9	28.8	201.6	7778.9	79344.6
250	31680	100677.4	31.7	221.8	8556.8	87279.0
275	34560	109976.8	34.6	241.9	9334.7	95213.5
300	37440	118590.2	37.4	262.1	10112.5	103147.9
325	40320	127540.9	40.3	282.2	10890.4	111082.4
350	43200	136526.5	43.2	302.4	11668.3	119016.9
375	46080	146054.4	46.1	322.6	12446.2	126951.3
400	48960	155318.1	49.0	342.7	13224.1	134885.8
425	51840	165002.8	51.8	362.9	14002.0	142820.2
450	54720	173953.5	54.7	383.0	14779.9	150754.7
475	59040	186432.3	59.0	413.3	15946.7	162656.4
500	61920	195383.0	61.9	433.4	16724.6	170590.8

1) Power produced by PV is got from table(4.1)
2) Assuming no. of operating hours = 7 hrs
3) Price of purchased energy to municipality = 1.05 nis/kWh
4) Price of purchased energy from municipality = 0.68 nis/kWh
5) The factor needed to convert annual value to present value at interest 8% & 6 years = 4.6229

Although the results found in figure (8.1) prove that powering the pumping system by grid is more economical since the cost of water cubic meter is less than that when powering by PV. We tried to find the payback period (PBP) in case of operating a pumping system by PV generator if the net metering is applied, but also the result was negative as we found that the payback period is too long and equals to the PV lifecycle.

CHAPTER NINE
LOAD MATCHING OF PV WATER PUMPING SYSTEM USING PLC CONTROL

9.1. Load Matching

It is found in the previous chapters that using PV generator is better than using diesel generator. As shown previously that one pump was connected to the system, and the annual cost of the whole system has been calculated to find the price of one cubic meter of water.

Now by using control system, the PV generator will be connected to two pumps of different power, then by doing a series of calculations to prove weather using load matching is more economical or not. This is called load matching.

A project in Jordan was executed where load matching technique is applied and a paper was proposed about that project and the results was very encouraging where about 16% increment in daily water pumped and also the price of one cubic meter of water decrease [26].

9.2. How to Select the Pumps

Regarding to the daily solar radiation curve, two or three pumps have to be selected according to the periods shown in Fig.(9.1).

The principle is based on setting two suitable pumps and connecting them to the PV generators, and choosing the pumps comes after calculations.

The scenario is starting from the following figure to calculate the power of the pumps that will be used, where Fig.(9.1) represents the daily solar radiation curve.

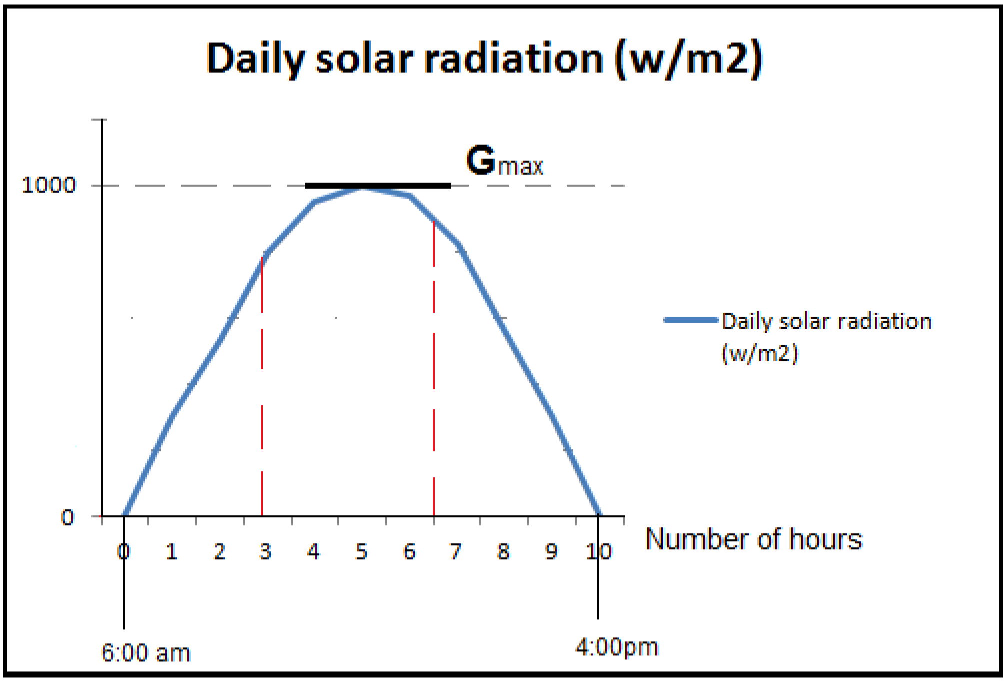

Fig (9.1) – An illustration for the daily solar radiation

It is supposed in the above figure that the sun radiation continues for 10 hours, as expected noon time has the most radiation. Load matching technique is useful to use a pump with high rated power in a time with high radiation, while using a pump with small rated power in the rest of the day.

Referring to figure (8.5), integration will be made to calculate the power of the pumps that will be used.

- First period (6:00am - 9:30am), where $G_{max} = 1000\ W/m^2$

$$E_1 = \int_0^{3.5} G_{max} . \sin \frac{\Pi t}{10} dt$$

$$E_1 = -G_{max} * \frac{10}{\Pi} \cos \frac{\Pi t}{10} \Big|$$

$$E_1 = \frac{10\ G_{max}}{\Pi} [\cos \frac{3.5\Pi}{10} - 1]$$

$$E_1 = 1738\ Wh$$

PSH * 1000 = 1738

PSH = 1.738hr

- Second period (9:30am - 1:00pm)

$$E_2 = \int_{3.5}^{7} G_{max} . \sin \frac{\Pi t}{10} dt$$

$$E_2 = \frac{10\, G_{max}}{\Pi}\left[\cos\frac{7\Pi}{10} - \cos\frac{3.5\Pi}{10}\right]$$

E_2 = 3316.07 Wh

PSH * 1000 = 3316.07

PSH = 3.316hr

- Third period (1:00pm - 4:00pm)

$$E_2 = \int_{7}^{10} G_{max} . \sin \frac{\Pi t}{10} dt$$

$$E_2 = \frac{10\, G_{max}}{\Pi}\left[\cos\frac{10\Pi}{10} - \cos\frac{7\Pi}{10}\right]$$

E_2 = 1312.12 Wh

PSH = 1.312hr

According to the above results, two pumps will be connected, a small rated power pump will operate at both periods the first and the third periods, and the second period will operate on a higher rated power pump. The solution key is finding the peak sun hour and continuing reversely to reach to the power of the pump.

9.3. Selecting the pumps

9.3.1. Small rated power pump selection

The small rated power pump is set to operate on the first and third periods where peak sun hour is 1.736hr . Starting from flow rate 50m^3/day and referring to table (4.1), the peak power of PV generator is 7200W.

Taking into account the following:

$\eta_{inv} = 94\%$ and $\eta_{pump\ motor} = 51\%$

$E_{out-PV} = 7200\ W \times 1.736$

$= 12513.6\ Wh$

$E_{out-Inv} = 12513.6 \times 0.94$

$= 11762.784\ Wh$

$E_{out-pump} = E_{hyd} = 11762.784 \times 0.51$

$= 5999.0198\ Wh$

$E_{hyd} = 5.999\ kWh$

$E_{oP} = E_{hyd} = 0.002725 \times Q \times H$

$$Q = \frac{5.999}{0.002725 \times 100m}$$

$= 22.0148 m^3/day$

The total period is about three and half hours.

$Q = 22.0148 / 3.5 = 6.2899\ m^3/hr$

The best pump to be used is found as following

$$P_{in\text{-}pump} = \frac{2.725 \text{ X } 100m \text{ X } 6.2899m^3/hr}{0.45}$$

$$= 3808.9 \text{ W} = 5.105hp$$

Repeating the steps above for the third period, we get a daily flow rate of $16.6m^3$, but we use the same pump of the first period.

9.3.2. Big rated power pump selection

The big rated power pump is set to operate on the second period where peak sun hour is 3.316hr. Starting from flow rate $50m^3$/day and referring to table (4.1), the peak power of PV generator is 7200W.

Taking into account the following:

η_{inv} = 94% and $\eta_{pump\ motor}$ = 51%

$$E_{out-PV} = 7200 \text{ W X } 3.316$$

$$= 23875.2 \text{ Wh}$$

$$E_{out-Inv} = 23875.2 \text{ X } 0.94$$

$$= 22442.688 \text{ Wh}$$

$$E_{out\text{-}pump} = E_{hyd} = 22442.688 \text{ X } 0.51$$

$$= 11445.7709 \text{ Wh}$$

$$E_{hyd} = 11.445 \text{ kWh}$$

$$E_{oP} = E_{hyd} = 0.002725 \text{ X Q X H} \ldots\ldots\ldots\ldots\ldots. (2.1)$$

$$Q = \frac{11.445}{0.002725 \text{ X } 100m}$$

$$= 42 \text{ m}^3/\text{ day}$$

The total period is about three and half hours.

$Q = 42 / 3.5 = 12.08 \ m^3/hr$

The best pump to be used is found as following

$$P_{in\text{-}pump} = \frac{2.725 \text{ X } 100m \text{ X } 12.08m^3/hr}{0.45}$$

$$= 7267.16 \text{ W} = 9.7415hp$$

The total flow rate through the day will be

$Q_{tot} = 42 + 16.6 + 22 = 80.6 \ m^3 / day$

9.3.3. System design

The following figure shows the dual PV system controlled by PLC.

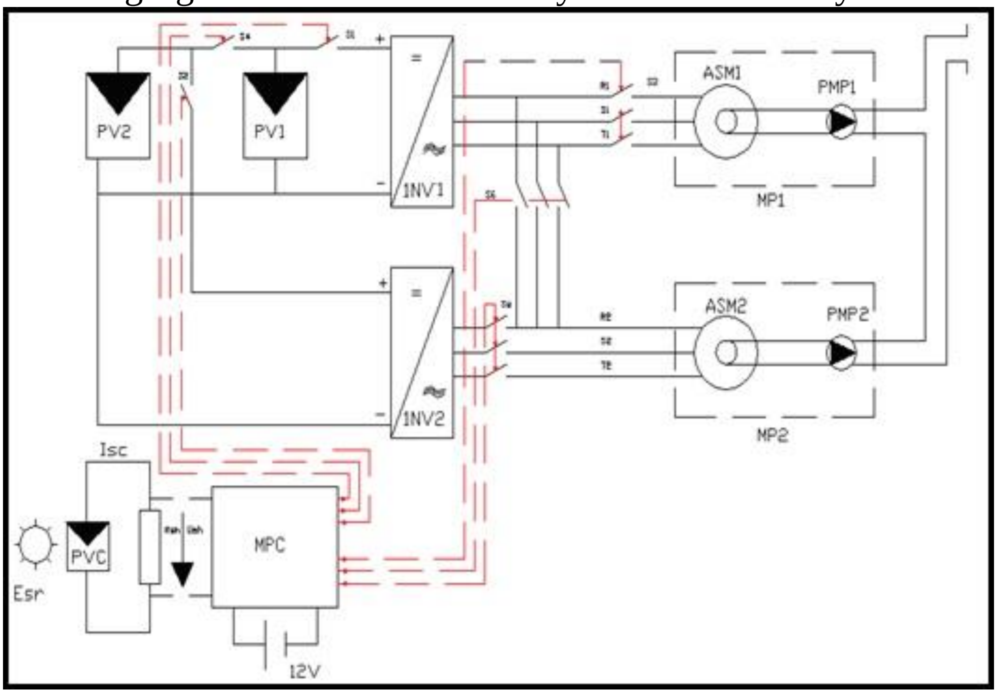

Fig.(9.2) – Dual photovoltaic water pumping system with solar matched load control [26]

9.3.4. Economical study of dual PV system with PLC control

Tables (9.1) and (9.2) show the pumps selected to perform load matching and table (9.3) shows the quantity of water produced after applying load matching technique.

Table (9.1) - Choosing the pump of the small rated power "6:00 - 9:30AM" and "1:00 - 4:00PM"

Daily volume of water (m^3/day)	Peak watt of PV (W)	Output energy of PV (Wh)	Output energy of inverter (Wh)	Input energy of motor pump (Wh)	Hydraulic energy of pump (kWh)	Flow rate (m^3/hour)	Daily volume (m^3/day)	Output power of the pump (W)	Input power of the pump (W)	Brake power of pump (hp)
50	7200	12513.6	11762.8	11762.8	6.0	22.0	6.3	1714.0	3808.9	5.1
75	10080	17519.0	16467.9	16467.9	8.4	30.8	8.8	2399.6	5332.5	7.1
100	12960	22524.5	21173.0	21173.0	10.8	39.6	11.3	3085.2	6856.0	9.2
125	15840	27529.9	25878.1	25878.1	13.2	48.4	13.8	3770.8	8379.6	11.2
150	18720	32535.4	30583.2	30583.2	15.6	57.2	16.4	4456.4	9903.1	13.3
175	21600	37540.8	35288.4	35288.4	18.0	66.0	18.9	5142.0	10712.5	14.4
200	24480	42546.2	39993.5	39993.5	20.4	74.9	21.4	5827.6	12140.9	16.3
225	28800	50054.4	47051.1	47051.1	24.0	88.1	25.2	6856.0	14283.4	19.1
250	31680	55059.8	51756.2	51756.2	26.4	96.9	27.7	7541.6	15711.7	21.1
275	34560	60065.3	56461.4	56461.4	28.8	105.7	30.2	8227.2	16454.5	22.1
300	37440	65070.7	61166.5	61166.5	31.2	114.5	32.7	8912.8	17825.7	23.9
325	40320	70076.2	65871.6	65871.6	33.6	123.3	35.2	9598.4	19196.9	25.7
350	43200	75081.6	70576.7	70576.7	36.0	132.1	37.7	10284.0	20568.1	27.6
375	46080	80087.0	75281.8	75281.8	38.4	140.9	40.3	10969.6	21939.3	29.4
400	48960	85092.5	79986.9	79986.9	40.8	149.7	42.8	11655.2	21191.3	28.4
425	51840	90097.9	84692.0	84692.0	43.2	158.5	45.3	12340.8	22437.9	30.1
450	54720	95103.4	89397.2	89397.2	45.6	167.3	47.8	13026.4	23684.4	31.7
475	59040	102611.5	96454.8	96454.8	49.2	180.5	51.6	14054.8	25554.3	34.3
500	61920	107617.0	101159.9	101159.9	51.6	189.3	54.1	14740.4	26800.8	35.9

1) The peak sun hour = 1.738hr
2) Output energy f the PV = PSH * peak power of PV
3) Assumed efficiency of inverter = 94%
4) Assumed efficiency of motor pump = 51%
5) Flow rate(m3/day) = hydraulic energy /(head *0.002725)
6) Output power of the pump = 2.725 * head * Q
7) Assumed efficiency of the pump = (0.45-0.55)

Table (9.2) - Choosing the pump of the large rated power "9:30AM - 1:00 PM"

Daily volume of water (m^3/day)	Peak watt of PV (W)	Output energy of PV (Wh)	Output energy of inverter (Wh)	Input energy of motor pump (Wh)	Hydraulic energy of pump (kWh)	Flow rate (m^3/hour)	Daily volume (m^3/day)	Output power of the pump (W)	Input power of the pump (W)	Brake power of pump (hp)
50	7200	23875.2	22442.7	22442.7	11.4	42.0	12.0	3270.2	7267.2	9.7
75	10080	33425.3	31419.8	31419.8	16.0	58.8	16.8	4578.3	10174.0	13.6
100	12960	42975.4	40396.8	40396.8	20.6	75.6	21.6	5886.4	12524.2	16.8
125	15840	52525.4	49373.9	49373.9	25.2	92.4	26.4	7194.5	14988.5	20.1
150	18720	62075.5	58351.0	58351.0	29.8	109.2	31.2	8502.6	17005.1	22.8
175	21600	71625.6	67328.1	67328.1	34.3	126.0	36.0	9810.7	19621.3	26.3
200	24480	81175.7	76305.1	76305.1	38.9	142.8	40.8	11118.7	22237.5	29.8
225	28800	95500.8	89770.8	89770.8	45.8	168.0	48.0	13080.9	26161.8	35.1
250	31680	105050.9	98747.8	98747.8	50.4	184.8	52.8	14389.0	27671.1	37.1
275	34560	114601.0	107724.9	107724.9	54.9	201.6	57.6	15697.1	30186.6	40.5
300	37440	124151.0	116702.0	116702.0	59.5	218.4	62.4	17005.1	32702.2	43.8
325	40320	133701.1	125679.1	125679.1	64.1	235.2	67.2	18313.2	33296.8	44.6

Daily volume of water (m^3/day)	Peak watt of PV (W)	Output energy of PV (Wh)	Output energy of inverter (Wh)	Input energy of motor pump (Wh)	Hydraulic energy of pump (kWh)	Flow rate (m^3/hour)	Daily volume (m^3/day)	Output power of the pump (W)	Input power of the pump (W)	Brake power of pump (hp)
350	43200	143251.2	134656.1	134656.1	68.7	252.0	72.0	19621.3	32702.2	43.8
375	46080	152801.3	143633.2	143633.2	73.3	268.8	76.8	20929.4	34882.3	46.8
400	48960	162351.4	152610.3	152610.3	77.8	285.6	81.6	22237.5	37062.5	49.7
425	51840	171901.4	161587.4	161587.4	82.4	302.4	86.4	23545.6	37976.8	50.9
450	54720	181451.5	170564.4	170564.4	87.0	319.2	91.2	24853.7	40086.6	53.7
475	59040	195776.6	184030.0	184030.0	93.9	344.4	98.4	26815.8	43251.3	58.0
500	61920	205326.7	193007.1	193007.1	98.4	361.2	103.2	28123.9	45361.1	60.8

1) The peak sun hour = 3.316hr
2) Output energy f the PV = PSH * peak power of PV
3) Assumed efficiency of inverter = 94%
4) Assumed efficiency of motor pump = 51%
5) Flow rate(m3/day) = hydraulic energy /(head *0.002725)
6) Output power of the pump = 2.725 * head * Q
7) Assumed efficiency of the pump = (0.45-0.62)

Table(9.3) - The quantity of water produced when applying load matching

Volume of water (m^3/day)	Daily flow rate during first period (m^3/day)	Daily flow rate during second period (m^3/day)	Daily flow rate during third period (m^3/day)	Total quantity of water during the day (m^3/day)
50	22.0	42.0	16.6	80.6
75	30.8	58.8	23.3	112.9
100	39.6	75.6	29.9	145.1
125	48.4	92.4	36.6	177.4
150	57.2	109.2	43.2	209.7
175	66.0	126.0	49.9	241.9
200	74.9	142.8	56.5	274.2
225	88.1	168.0	66.5	322.6
250	96.9	184.8	73.1	354.8
275	105.7	201.6	79.8	387.1
300	114.5	218.4	86.4	419.3
325	123.3	235.2	93.1	451.6
350	132.1	252.0	99.7	483.8
375	140.9	268.8	106.4	516.1
400	149.7	285.6	113.0	548.3
425	158.5	302.4	119.7	580.6
450	167.3	319.2	126.3	612.8
475	180.5	344.4	136.3	661.2
500	189.3	361.2	142.9	693.5

9.3.5. Economical analysis of dual PV system with PLC control

The procedure of calculating the cost of the system is symmetrical to which was calculated in section (4.5.3) – table (4.2), but the difference is that two pumps have to be used here and the water quantity will increased.

A series of calculations is made presented in tables (9.4) ®[6], (9.5), (9.6), (9.7) and figure (9.3), showing that the price of water cubic meter when applying load matching is so close to it when PV generator operating one pump but still higher.

[6] See appendix B.

Table (9.4) - Types of pumps used in load matching with PLC control and their prices

	The pumps used according to table (8.1)		The pumps used according to table (8.2)	
Daily volume of water (m^3/day)	Pump Name	Cost (US$)	Pump Name	Cost (US$)
50	upa-150C - 16 / 7 stages	2210	upa-150C - 16 / 10 stages	2323
75	upa-150C - 16 / 8 stages	2280	upa-150C - 16 / 17 stages	3121
100	upa-150C - 16 / 10 stages	2323	upa-150C - 16 / 21 stages	3300
125	upa-150C - 16 / 14 stages	2703	upa-150C - 30 / 16 stages	3318
150	upa-150C - 16 / 15 stages	2790	upa-150C - 30 / 19 stages	3650
175	upa-150C - 16 / 19 stages	3220	upa-150C - 30 / 20 stages	3730
200	upa-150C - 30 / 14 stages	3118	upa-150C - 48 / 13 stages	4462
225	upa-150C - 30 / 16 stages	3318	upa-150C - 48 / 16 stages	4900
250	upa-150C - 30 / 18 stages	3570	upa-150C - 48 / 16 stages	4900
275	upa-150C - 30 / 19 stages	3650	upa-150C - 48 / 16 stages	4900
300	upa-150C - 30 / 20 stages	3730	upa-150C - 48 / 17 stages	5000
325	upa-150C - 30 / 22 stages	3900	upa-150C - 48 / 17 stages	5000
350	upa-150C - 48 / 13 stages	4462	upa-150C - 60 / 17 stages	5350
375	upa-150C - 48 / 14 stages	4750	upa-150c-60-18	5600
400	upa-150C - 48 / 13 stages	4462	upa-200-11-13D	6100
425	upa-150C - 48 / 14 stages	4750	upa-200-11-13D	6100
450	upa-150C - 48 / 15 stages	4820	upa-200-11-13D	6100
475	upa-150C - 48 / 17 stages	5000	upa-200-11-13D	6100
500	upa-150C - 48 / 17 stages	5000	upa-200-11-13D	6100

Table (9.5) - Net present value for PV system operating the small rated power pump

Daily volume of water (m^3/day)	Input power of the pump (W)	Output power of inverter (W)	Input power of inverter (W)	Input energy of inverter (W)	Total peak power (W)	Total cost of PV pumping system (US$)
50	3808.9	3808.9	4052.0	24312.1	5760	19563.6
75	5332.5	5332.5	5672.8	34037.0	8640	27986.3
100	6856.0	6856.0	7293.6	43761.8	10080	32853.9
125	8379.6	8379.6	8914.5	53486.7	12960	41586.6
150	9903.1	9903.1	10535.3	63211.6	14400	46498.2
175	10712.5	10712.5	11396.3	68377.9	15840	51145.1
200	12140.9	12140.9	12915.8	77494.9	17280	55786.7
225	14283.4	14283.4	15195.1	91170.5	20160	64866.1
250	15711.7	15711.7	16714.6	100287.6	21600	69861.7
275	16454.5	16454.5	17504.7	105028.4	23040	74101.8
300	17825.7	17825.7	18963.5	113780.8	24480	78876.8
325	19196.9	19196.9	20422.2	122533.2	27360	87269.8
350	20568.1	20568.1	21880.9	131285.5	28800	92526.7
375	21939.3	21939.3	23339.7	140037.9	30240	97509.7
400	21191.3	21191.3	22544.0	135263.9	30240	96585.2
425	22437.9	22437.9	23870.1	143220.6	31680	101462.1
450	23684.4	23684.4	25196.2	151177.3	33120	106121.0
475	25554.3	25554.3	27185.4	163112.3	36000	114948.3
500	26800.8	26800.8	28511.5	171069.0	37440	119537.2

Table (9.6) - Net present value for PV system operating the large rated power pump

Daily volume of water (m^3/day)	Input power of the pump (W)	Output power of inverter (W)	Input power of inverter (W)	Input energy of inverter (W)	Total peak power (W)	Total cost of PV pumping system (US$)
50	7267.2	7267.2	7731.0	30924.1	7200	26148.4
75	10174.0	10174.0	10823.4	43293.7	10080	35739.8
100	12524.2	12524.2	13323.7	53294.7	11520	41586.1
125	14988.5	14988.5	15945.2	63780.9	14400	50969.2
150	17005.1	17005.1	18090.6	72362.3	15840	56308.8
175	19621.3	19621.3	20873.7	83495.0	18720	65681.5
200	22237.5	22237.5	23656.9	94627.6	21600	75590.7
225	26161.8	26161.8	27831.7	111326.6	24480	86177.6
250	27671.1	27671.1	29437.3	117749.3	25920	91168.0
275	30186.6	30186.6	32113.5	128453.8	28800	100713.5
300	32702.2	32702.2	34789.6	139158.3	30240	106045.1
325	33296.8	33296.8	35422.1	141688.5	31680	110079.1
350	32702.2	32702.2	34789.6	139158.3	30240	106079.9
375	34882.3	34882.3	37108.9	148435.5	33120	115568.6
400	37062.5	37062.5	39428.2	157712.7	30240	110681.0
425	37976.8	37976.8	40400.8	161603.2	36000	126305.0
450	40086.6	40086.6	42645.3	170581.2	37440	131628.6
475	43251.3	43251.3	46012.0	184048.1	40320	141378.0
500	45361.1	45361.1	48256.5	193026.0	41760	146701.6

Table (9.7) - The Cost of pumping one cubic meter of water with and without applying load matching

Normal PV pumping system				load matching pumping system			
Daily volume of water (m^3/day)	Present value of PV system (US$)	Annual cost of PV system (US$)	Cost of one cubic meter of water (US$/$m^3$)	Daily volume of water (m^3/day)	Present value of PV system (US$)	Annual cost of PV system (US$)	Cost of one cubic meter of water (US$/$m^3$)
50	23753.0	2328.5	0.128	80.6	45712.0	4481.1	0.152
75	32765.3	3212.0	0.117	112.9	63726.1	6247.1	0.152
100	42034.1	4120.6	0.113	145.1	74440.0	7297.4	0.138
125	51214.7	5020.6	0.110	177.4	92555.8	9073.2	0.140
150	60260.7	5907.4	0.108	209.7	102807.0	10078.2	0.132
175	69301.6	6793.6	0.106	241.9	116826.5	11452.5	0.130
200	78879.0	7732.5	0.106	274.2	131377.3	12878.9	0.129
225	91548.9	8974.5	0.109	322.6	151043.7	14806.8	0.126
250	100677.4	9869.4	0.108	354.8	161029.7	15785.7	0.122
275	109976.8	10781.0	0.107	387.1	174815.3	17137.1	0.121
300	118590.2	11625.4	0.106	419.3	184921.9	18127.9	0.118
325	127540.9	12502.8	0.105	451.6	197348.9	19346.1	0.117
350	136526.5	13383.7	0.105	483.8	198606.6	19469.4	0.110
375	146054.4	14317.7	0.105	516.1	213078.3	20888.1	0.111
400	155318.1	15225.8	0.104	548.3	207266.2	20318.3	0.102
425	165002.8	16175.2	0.104	580.6	227767.1	22328.0	0.105
450	173953.5	17052.7	0.104	612.8	237749.6	23306.6	0.104
475	186432.3	18276.0	0.105	661.2	256326.3	25127.7	0.104
500	195383.0	19153.4	0.105	693.5	266238.8	26099.4	0.103

The factor needed to convert present value to annual value at interest 8% & 22 years = .098030

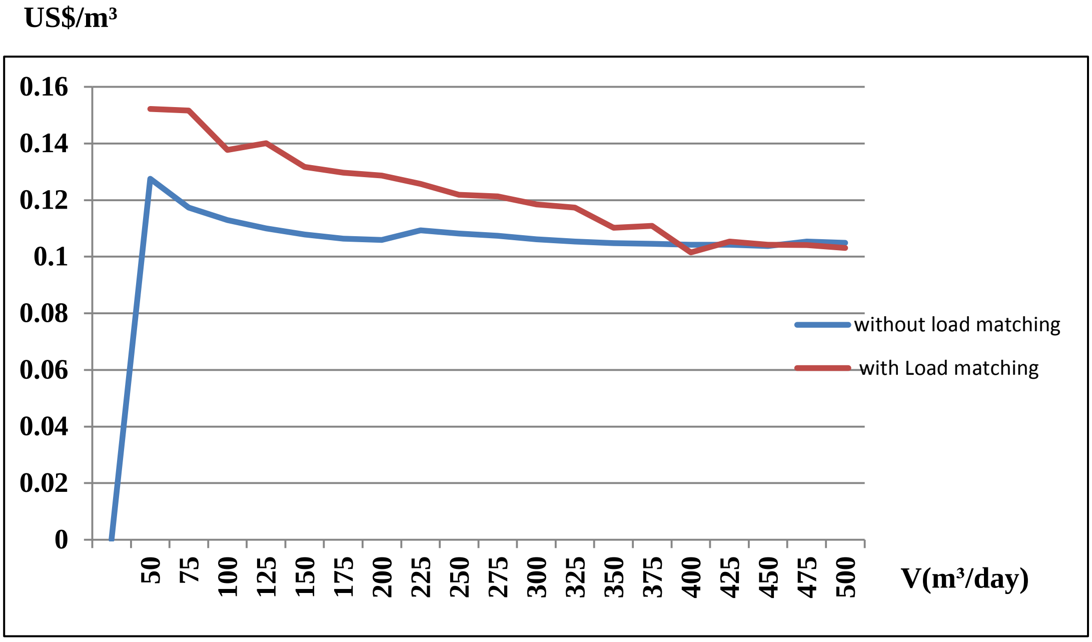

Fig (9.3) - The cost of pumping one cubic meter of water with and without load matching

The previous results proved that load matching by tracking the sun is not feasible than connecting one pump, and so connecting to grid is also more feasible than load matching, where the price of one cubic meter calculated in section (6.3) is less than which is calculated by applying load matching by tracking in about (10% - 12%). This leads to try matching two loads in a different way; by replacing the two pumps of different power into two equal small pumps and then find weather it is more feasible or not.

The principle is based on operating both pumps together at the time of high solar radiation, and one pump is operating at little radiation time, and all of that of course is executed by tracking the daily solar radiation using PLC control.

Table.(9.8) shows the cost of one cubic meter of water when matching on two symmetrical pumps and then the table is followed by Fig. (9.4) compares the cost of one cubic meter of dual PV system with matched load and normal PV system.

Table (9.8) - The cost of pumping one cubic meter of water when matching two small equal rated power pumps

Daily volume of water (m^3/day)	Net present value of PV system (US$)	Annual cost (US$/year)	Cost of cubic meter of water (US$/$m^3$)
80.6	39127.2	3835.6	0.130
112.9	55972.5	5487.0	0.133
145.1	65707.8	6441.3	0.122
177.4	83173.1	8153.5	0.126
209.7	92996.4	9116.4	0.119
241.9	102290.1	10027.5	0.114
274.2	111573.3	10937.5	0.109
322.6	129732.1	12717.6	0.108
354.8	139723.4	13697.1	0.106
387.1	148203.6	14528.4	0.103
419.3	157753.5	15464.6	0.101
451.6	174539.5	17110.1	0.104
483.8	185053.5	18140.8	0.103
516.1	195019.4	19117.8	0.101
548.3	193170.4	18936.5	0.095
580.6	202924.2	19892.7	0.094
612.8	212241.9	20806.1	0.093
661.2	229896.6	22536.8	0.093
693.5	239074.4	23436.5	0.093

The factor needed to convert present value to annual value at interest 8% & 22 years = 0.098030

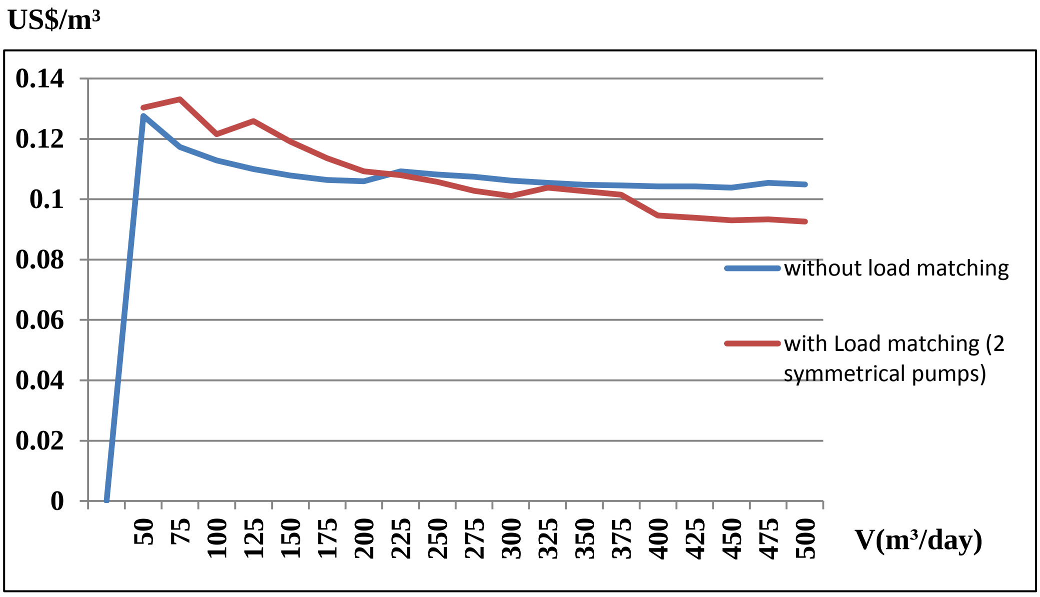

Fig (9.4) - The cost of pumping one cubic meter of water with and without load matching - Using two symmetrical pumps

9.4. Summary and Results

The quantity of water increased when applying load matching controlled by PLC by tracking the solar radiation in a value ranged between (27% and 30%) but the cost of water in the first case where two pumps of different power connected to dual PV systems used was higher than that when one PV array was used.

In the second case the pump of the high power was replaced by operating two small ones, and the results was shown on fig.(9.3), where the cost of water decreased at the daily flow rate of 200m^3/day. Dual PV water pumping system by matched loads seems to be more feasible at high flow rates because as shown in figure (9.4) we found that also at daily volume 350 m^3/day.

CHAPTER TEN
CONCLUSIONS

10.1. Conclusions

From this thesis it was shown that for rural areas which have no electric grid that it is more economical feasible to depend PV to power water pumping systems, the feasibility was clear in the big difference of the cost of water when comparing PV generator to diesel generator.

According to the regions tied to grid they have the choice to power the pumping system by electric grid. This research compared between electrical grid and PV generator and it was found that powering the water pumping system by grid is more feasible than by PV generator. On the other side the payback period of water pumping system powered by PV was short which was considered as an encouraging point to support using solar energy especially in agriculture and irrigation sectors where the government support them and continuously presents loan for farmers and who works on projects related to them.

Another scenario was discussed in this thesis. It was a dual PV water pumping system by load matching, this technique contributed in increasing the daily flow rate of water by about 9% above its original value, besides that the cost of one cubic meter decreased at high flow rates.

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APPENDICES

Appendix - A: SCHOTT Perform TM Mono Series

Appendix- B: UPA Series of KSB Pumps

Appendix- C: Compound Interest Factor Table

APPENDIX – A

EN

SCHOTT PERFORM™ MONO series

SCHOTT PERFORM™ MONO 180/185/190/195

At a glance

- Monocrystalline high efficiency cells >17.6 %
- High annual energy yield
- Positive power tolerance
- Elegant design
- Double the required standard
- 25 years linear performance guarantee

The global German company SCHOTT Solar started developing and manufacturing components for the solar industry in 1958.

Monocrystalline high efficiency cells >17.6 %: The exceptionally high cell efficiency of the SCHOTT PERFORM™ MONO series ensures a high module power. Module efficiencies of up to 14.9 % are possible.

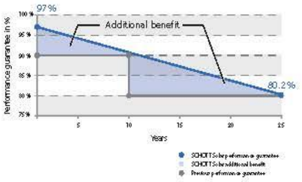
High annual energy yield: The particularly high module efficiency delivers optimum yields for small areas. More power per module ensures high annual energy yields.

Positive power tolerance: SCHOTT Solar modules achieve a positive power tolerance of the nominal rating. This ensures a high energy output.

Elegant design: The dark mono cells with the black Aluminum frame look aesthetically pleasing while providing excellent efficiency. Also, the elegant design reassures a high degree of security for your investment because the solid module frame secures superior torsional resistance.

Double the required standard: SCHOTT Solar tests its modules for twice as long as required by the IEC.

25 years linear performance guarantee*: SCHOTT Solar guarantees for a period of one year from date of delivery that the module power output will be at least 97 % of the rated power output. Due to its long and successful experience in solar technology, the manufacturer guarantees from year two through year twenty five that the module power output will degrade no more than 0.7 % per year of the rated power output from the date of original sale by SCHOTT Solar. Moreover, SCHOTT Solar offers a product guarantee of 10 years*.



** on the basis of the Conditions on Guarantees valid at the date of purchase available on www.schottsolar.com/performance-guarantee*

SCHOTT solar

Technical Data

Data at standard test conditions (STC)

Module type		SCHOTT PERFORM™ MONO			
Nominal power [Wp]	P_{mpp}	≥ 180	≥ 185	≥ 190	≥ 195
Voltage at nominal power [V]	U_{mpp}	36.2	36.3	36.4	36.5
Current at nominal power [A]	I_{mpp}	4.97	5.10	5.22	5.34
Open-circuit voltage [V]	U_{OC}	44.8	45.0	45.2	45.4
Short-circuit current [A]	I_{SC}	5.40	5.43	5.46	5.49
Module efficiency (%)	η	13.7	14.1	14.5	14.9

STC (1,000 W/m²; AM 1.5; cell temperature 25°C)
Power tolerance (as measured by flasher): -0 W / +4.99 W

Data at normal operating cell temperature (NOCT)

Nominal power [Wp]	P_{mpp}	130	134	137	141
Voltage at nominal power [V]	U_{mpp}	32.9	32.8	32.9	33.0
Open-circuit voltage [V]	U_{OC}	39.3	40.2	41.0	41.9
Short-circuit current [A]	I_{SC}	4.30	4.32	4.35	4.37
Temperature [°C]	T_{NOCT}	46.0	46.0	46.0	46.0

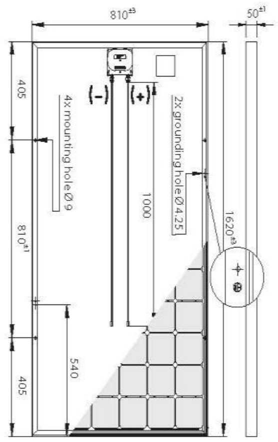
NOCT (800 W/m², AM 1.5, windspeed 1 m/s, ambient temperature 20°C)

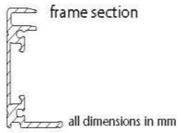
Data at low irradiation

At a low irradiation intensity of 200 W/m² (AM 1.5 and cell temperature 25°C) 96 % of the STC module efficiency (1,000 W/m²) will be achieved.

Temperature coefficients

Power [%/K]	P_{mpp}	-0.44
Open-circuit voltage [%/K]	U_{OC}	-0.33
Short-circuit current [%/K]	I_{SC}	+0.03





Characteristic data

Solar cells per module	72
Cell type	monocrystalline (pseudo-square, 125 mm x 125 mm)
Junction box	IP65 with three bypass diodes
Connector	Tyco-Connector IP67
Dimensions junction box [mm]	110 x 115 x 25
Front panel	low iron solar glass 3.2 mm
Backside panel	foil
Frame material	anodised aluminium, black

Dimensions and weight

Dimensions [mm]	1,620 x 810
Thickness [mm]	50
Weight [kg]	15.5

Limits

Maximum system voltage [V_{DC}]	1,000
Maximum reverse current I_R [A]*	17
Operating module temperature [°C]	-40 ... +85
Maximum load (to IEC 61215 ed. 2)	pressure: 5,400 N/m² or 550 kg/m² suction: 5,400 N/m² or 550 kg/m²
Application classification (to IEC 61730)	A
Fire classification (to IEC 61730)	C

** No external voltage in excess of U_{oc} shall be applied to the module.*

Permission and certificates

The modules are certified to IEC 61215 ed. 2 and IEC 61730, Electrical Protection Class II and the CE-guidelines. Moreover SCHOTT Solar is certified and registered to ISO 9001 and ISO 14001.

Power measurement accuracy: ±4 %

The **installation manual** contains additional information on installation and operation. SCHOTT Solar AG reserves the right to make specification changes in this datasheet without notice. All information complies with the requirements of the standard EN 50380.

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SCHOTT solar

APPENDIX –B

KSB 50 Hz **UPA 150C**

UPA 150C - 16 for Well Diameters of 150 mm (6 inches) and above

Pumps with submersible motors for ... – Type of current / voltage .... **three-phase** (3 ~) / **400 V**
– Starting .... **d.o.l.** (D) or **star-delta** (Y-Δ)

	Pump	Motor					Motor lead 2), flat	
	Discharge head Q = 0 m³/h	Rated power	Max. temperature of the fluid pumped v ≥ 0.2 m/s (0.0 m/s)	Rated current	Efficiency	Power factor	Number x cross-section of conductors (use under water, 400 V and ≤ +30 °C)	
UPA 150C - 16 / ...	H_0 m	P_N kW	t_{max} 1) °C	I_N A	η_M %	cos φ ---	d.o.l mm²	Y-Δ mm²
1 + DN 100 - 0.75	11.2	0.75	30 (30)	2.1	70.0	0.76	4 x 1.5	–
2 + DN 100 - 1.5	22	1.5	30 (30)	3.9	73.0	0.77	4 x 1.5	–
3 + DN 100 - 2.2	32.5	2.2	30 (30)	6.2	75.0	0.75	4 x 1.5	–
4 + DN 100 - 3.0	44	3.0	30 (30)	8.0	76.0	0.76	4 x 1.5	–
5 + DN 100 - 3.0	54	3.0	30 (30)	8.0	76.0	0.76	4 x 1.5	–
6 + DN 100 - 3.7	65	3.7	30 (30)	9.2	77.5	0.80	4 x 1.5	–
7 + UMA 150D 5/21	80	4.5	42 (39)	12.0	76.5	0.74	4 x 2.5	3/4 x 2.5
7 + DN 100 - 5.5	79	5.5	30 (20)	13.0	76.5	0.80	4 x 1.5	–
8 + UMA 150D 5/21	91	5.0	40 (36)	12.7	76.0	0.78	4 x 2.5	3/4 x 2.5
8 + DN 100 - 5.5	90	5.5	30 (20)	13.0	76.5	0.80	4 x 1.5	–
9 + UMA 150D 5/21	102	5.5	37 (33)	13.6	75.5	0.80	4 x 2.5	3/4 x 2.5
9 + DN 100 - 5.5	100	5.5	30 (20)	13.0	76.5	0.80	4 x 1.5	–
10 + UMA 150D 7/21	113	6.5	38 (34)	16.0	77.5	0.79	4 x 2.5	3/4 x 2.5
10 + DN 100 - 7.5	110	7.5	30 (20)	18.4	74.0	0.79	4 x 1.5	–
11 + UMA 150D 7/21	124	7.0	35 (31)	16.8	77.0	0.81	4 x 2.5	3/4 x 2.5
11 + DN 100 - 7.5	121	7.5	30 (20)	18.4	74.0	0.79	4 x 1.5	–
12 + UMA 150D 7/21	134	7.5	33 (28)	17.8	76.5	0.82	4 x 2.5	3/4 x 2.5
12 + DN 100 - 7.5	131	7.5	30 (20)	18.4	74.0	0.79	4 x 1.5	–
13 + UMA 150D 7/21	145	7.5	30 (24)	17.8	76.5	0.82	4 x 2.5	3/4 x 2.5
13 + DN 100 - 7.5	140	7.5	30 (20)	18.4	74.0	0.79	4 x 1.5	–
14 + UMA 150D 9/21	157	8.5	33 (28)	20.0	78.5	0.81	4 x 2.5	3/4 x 2.5
15 + UMA 150D 9/21	168	9.0	31 (25)	20.5	78.0	0.82	4 x 2.5	3/4 x 2.5
16 + UMA 150D 9/21	178	9.3	28 (22)	21.0	77.5	0.83	4 x 2.5	3/4 x 2.5
17 + UMA 150D 13/21	193	10.5	36 (32)	25.0	81.0	0.76	4 x 2.5	3/4 x 2.5
18 + UMA 150D 13/21	204	11.0	35 (30)	25.5	80.5	0.78	4 x 2.5	3/4 x 2.5
19 + UMA 150D 13/21	215	11.5	33 (28)	26.5	80.5	0.79	4 x 2.5	3/4 x 2.5
20 + UMA 150D 13/21	225	12.0	32 (26)	27.0	80.5	0.80	4 x 2.5	3/4 x 2.5

1) also see page 36 2) 3/4 = 1 x 3-core + 1 x 4-core, 90° spacing.

Dimensions / Weights / Horizontal Installation 1)

	L_P ≈ mm		L_A ≈ mm		m_A ≈ kg		D_{max} ≈ mm			Installation 2)
	for motor		incl. motor		incl. motor		d.o.l.	d.o.l.	Y-Δ	
UPA 150C - 16 / ...	DN	UMA	DN	UMA	DN	UMA	DN	UMA	UMA	
1	337	--	619	--	17	--	139	--	--	v + h
2	397	--	734	--	20	--	139	--	--	v + h
3	458	--	825	--	23	--	139	--	--	v + h
4	518	--	950	--	27	--	139	--	--	v + h
5	579	--	1011	--	28	--	139	--	--	v + h
6	639	--	1201	--	36	--	139	--	--	v + h
7	700	731	1404	1399	44	63	139	142	142	v + h
8	760	760	1465	1459	46	66	139	142	142	v + h
9	821	821	1525	1520	47	67	139	142	142	v + h
10	881	913	1655	1632	52	70	139	142	142	v + h
11	942	973	1716	1692	53	72	139	142	142	v + h
12	1002	1034	1776	1753	55	73	139	142	142	v + h
13	1063	1094	1837	1813	56	74	139	142	142	v + h
14	--	1155	--	1904	--	79	--	142	142	v + h
15	--	1215	--	1964	--	80	--	142	142	v + h
16	--	1276	--	2025	--	81	--	142	142	v + h
17	--	1336	--	2165	--	90	--	142	142	v + h
18	--	1397	--	2226	--	91	--	142	142	v + h
19	--	1457	--	2286	--	93	--	142	142	v + h
20	--	1518	--	2347	--	94	--	142	142	v + h

1) Including check valve with threaded end and standard motor leads. 2) v = vertical / h = horizontal.

UPA 150C - 16 / ..., number of stages 1 - 20

The characteristic curves shown are for preliminary selection only. Exact selection data will be provided in our quotation.

Selection

The pressure losses H_v in the check valve are not considered in the pump characteristic curves.

Legend ...

H_v: Head losses in the check valve

η_p: Pump efficiency (not considering check valve)

NPSH: Net positive suction head required by the pump

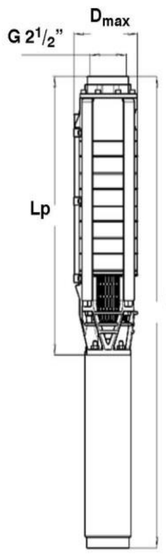
Pump End G $2^1/_2$"

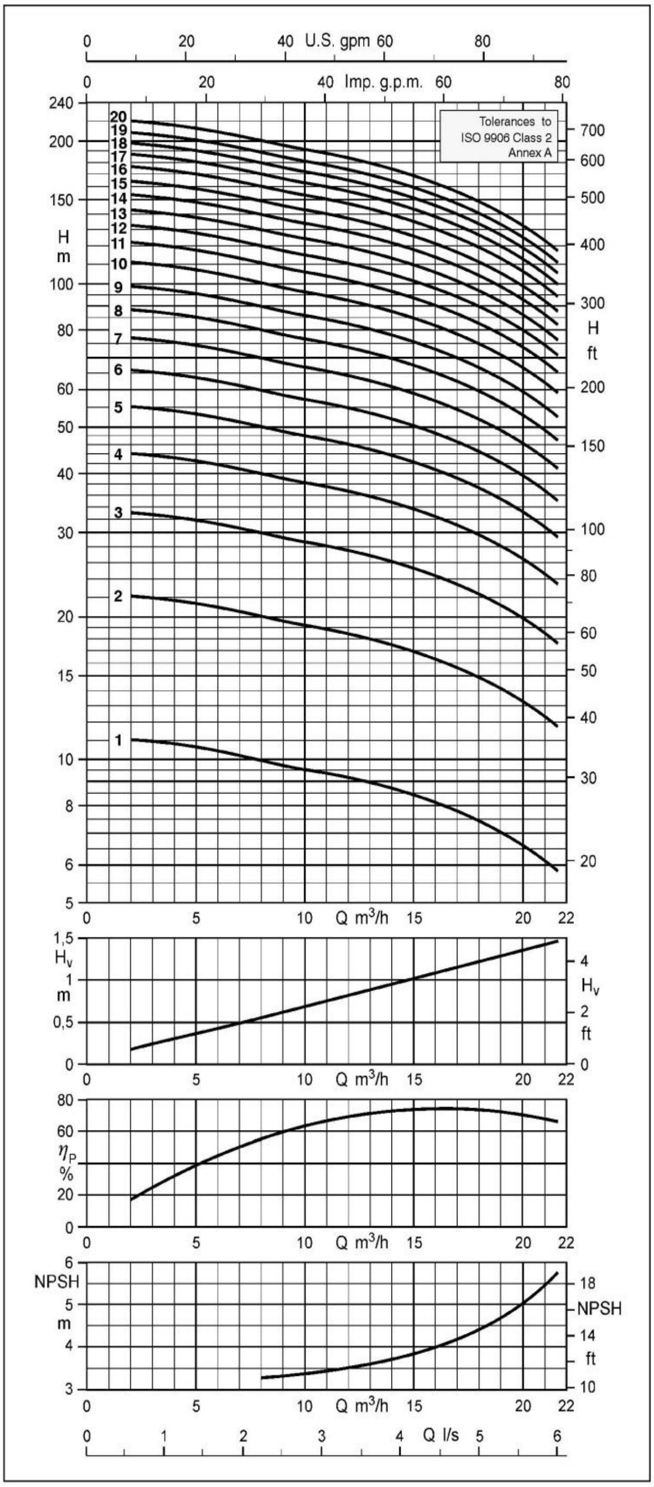
The information given below is based on the model with check valve and threaded end.

The changes in the main dimensions resulting from different threaded or flanged ends are specified in the table below.

	Overall length (mm)	D_{max} (mm)
G $2^1/_2$"	40	see page 40
G 3"	48	
G 4"	93	
DN 50	77	165
DN 65	77	185
DN 80	77	200

Threaded end to DIN ISO 228, Part 1.
Flanged end to DIN 2501, Part 1





UPA 150C - 16 for Well Diameters of 150 mm (6 inches) and above

Pumps with submersible motors for ... - Type of current / voltage .... **three-phase** (3 ~) / **400 V**
- Starting .... **d.o.l.** (D) or **star-delta** (Y-Δ)

	Pump	Motor					Motor lead [2], flat	
	Discharge head $Q = 0\ m^3/h$	Rated power	Max. temperature of the fluid pumped $v \geq 0.2$ m/s (0.0 m/s)	Rated current	Effi-ciency	Power factor	Number x cross-section of conductors (use under water, 400 V and ≤ +30 °C)	
UPA 150C - 16 / ...	H_0 m	P_N kW	t_{max} [1] °C	I_N A	η_M %	cos φ ---	d.o.l. mm²	Y-Δ mm²
21 + UMA 150D 13/21	236	13.0	30 (24)	29.0	80.0	0.81	4 x 2.5	3/4 x 2.5
22 + UMA 150D 13/21	246	13.0	29 (22)	29.0	80.0	0.81	4 x 2.5	3/4 x 2.5
23 + UMA 150D 13/21	256	13.0	28 (22)	29.0	80.0	0.81	4 x 2.5	3/4 x 2.5
24 + UMA 150D 15/21	269	14.0	33 (28)	30.5	82.0	0.82	4 x 4.0	3/4 x 2.5
25 + UMA 150D 15/21	280	15.0	32 (26)	32.5	81.5	0.83	4 x 4.0	3/4 x 2.5
26 + UMA 150D 15/21	290	15.0	30 (25)	32.5	81.5	0.83	4 x 4.0	3/4 x 2.5
27 + UMA 150D 18/21	305	16.0	32 (27)	36.5	82.5	0.78	4 x 4.0	3/4 x 2.5
28 + UMA 150D 18/21	315	16.5	31 (25)	37.0	82.0	0.79	4 x 4.0	3/4 x 2.5
29 + UMA 150D 18/21	326	17.0	30 (24)	38.0	82.0	0.79	4 x 4.0	3/4 x 2.5
30 + UMA 150D 18/21	336	17.5	29 (22)	39.0	82.0	0.80	4 x 4.0	3/4 x 2.5
31 + UMA 150D 18/21	347	18.0	27 (21)	39.5	82.0	0.81	4 x 4.0	3/4 x 2.5
32 + UMA 150D 18/21	357	18.5	26 (19)	40.5	81.5	0.81	4 x 4.0	3/4 x 2.5
33 + UMA 150D 22/21	373	20.0	33 (28)	44.0	83.5	0.79	4 x 4.0	3/4 x 2.5
34 + UMA 150D 22/21	383	20.0	33 (27)	44.0	83.5	0.79	4 x 4.0	3/4 x 2.5
35 + UMA 150D 22/21	394	21.0	32 (26)	46.0	83.5	0.80	4 x 4.0	3/4 x 2.5
36 + UMA 150D 22/21	404	22.0	31 (25)	47.5	83.5	0.81	4 x 4.0	3/4 x 2.5
37 + UMA 150D 22/21	415	22.0	30 (24)	47.5	83.5	0.81	4 x 4.0	3/4 x 2.5
38 + UMA 150D 22/21	425	22.0	29 (23)	47.5	83.5	0.81	4 x 4.0	3/4 x 2.5
39 + UMA 150D 26/21	441	24.0	36 (31)	52.0	85.0	0.80	4 x 6.0	3/4 x 4.0
40 + UMA 150D 26/21	451	24.0	35 (30)	52.0	85.0	0.80	4 x 6.0	3/4 x 4.0
43 + UMA 150D 26/21	483	26.0	33 (27)	55.0	84.5	0.82	4 x 6.0	3/4 x 4.0
45 + UMA 150D 26/21	504	26.0	31 (26)	55.0	84.5	0.82	4 x 6.0	3/4 x 4.0
48 + UMA 150D 30/21	542	29.0	33 (27)	63.0	84.5	0.80	4 x 6.0	3/4 x 4.0
52 + UMA 150D 30/21	583	30.0	30 (24)	65.0	84.5	0.80	4 x 6.0	3/4 x 4.0

1) also see page 36 2) 3/4 = 1 x 3-core + 1 x 4-core, 90° spacing

Dimensions / Weights / Horizontal Installation [1]

	$L_P \approx$ mm	$L_A \approx$ mm	$m_A \approx$ kg	$D_{max} \approx$ mm		Installation [2]
	for motor	incl. motor	incl. motor	d.o.l.	Y-Δ	
UPA 150C - 16 / ...	UMA	UMA	UMA	UMA	UMA	
21	1578	2407	95	142	142	v + h
22	1639	2468	97	142	142	v + h
23	1699	2528	98	142	142	v + h
24	1760	2634	103	142	142	v + h
25	1820	2694	104	142	142	v + h
26	1881	2755	105	142	142	v + h
27	1941	2860	112	142	142	v + h
28	2002	2921	113	142	142	v + h
29	2062	2981	114	142	142	v + h
30	2123	3042	116	142	142	v + h
31	2183	3102	117	142	142	v + h
32	2244	3163	118	142	142	v + h
33	2304	3313	128	142	142	v + h
34	2365	3374	129	142	142	v + h
35	2425	3434	130	142	142	v + h
36	2486	3495	132	142	142	v + h
37	2546	3555	133	142	142	v + h
38	2607	3616	135	142	142	v + h
39	2667	3781	145	142	142	v + h
40	2728	3842	146	142	142	v + h
43	on request					
45						
48						
52						

1) Including check valve with threaded end and standard motor leads. 2) v = vertical / h = horizontal.

UPA 150C - 16 / ..., number of stages 21 - 52

The characteristic curves shown are for preliminary selection only. Exact selection data will be provided in our quotation.

Selection

The pressure losses H_v in the check valve are not considered in the pump characteristic curves.

Legend ...

H_v : Head losses in the check valve

η_p: Pump efficiency (not considering check valve)

NPSH: Net positive suction head required by the pump

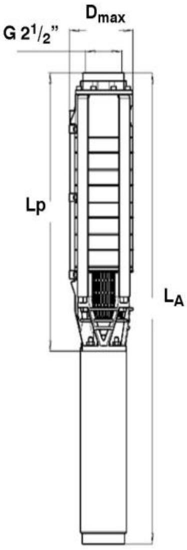
Pump End G 2¹/₂"

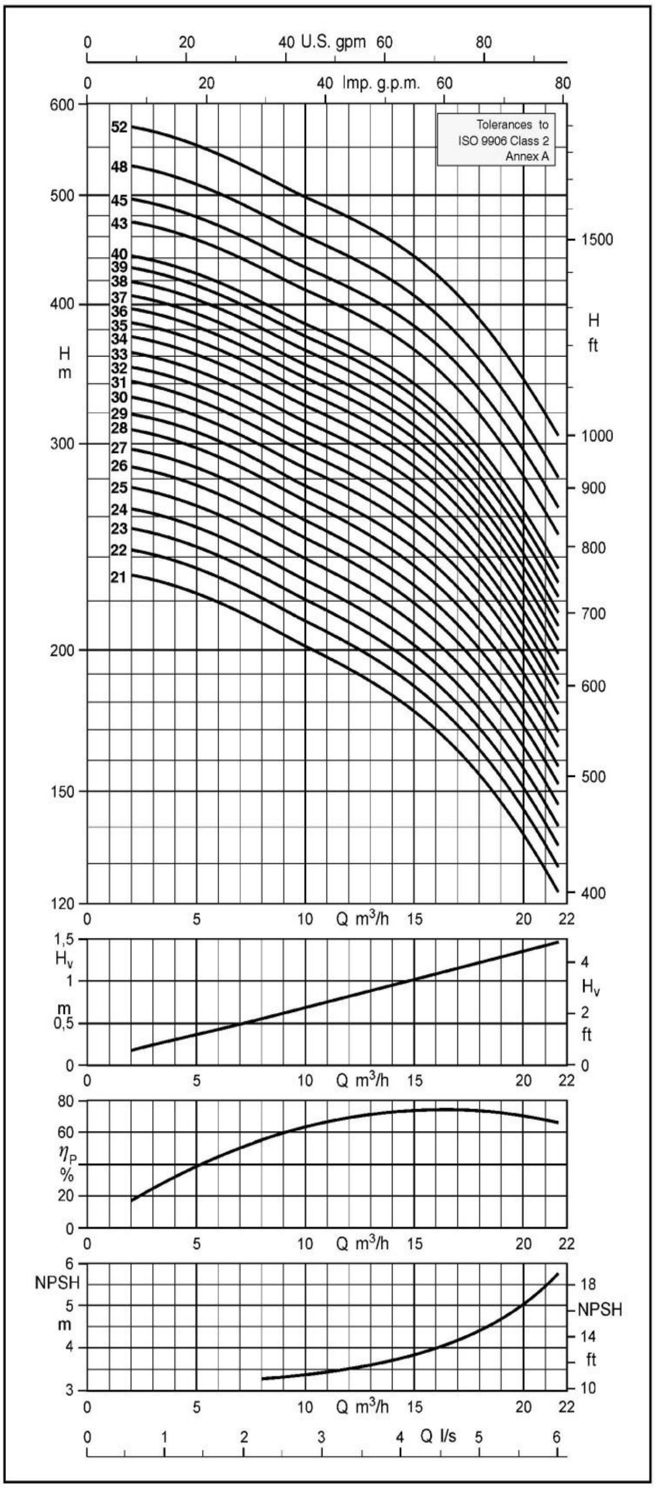
The information given below is based on the model with check valve and threaded end.

The changes in the main dimensions resulting from different threaded or flanged ends are specified in the table below.

	Overall length (mm)	D_{max} (mm)
G 2¹/₂"	40	see page 42
G 3"	48	
G 4"	93	
DN 50	77	165
DN 65	77	185
DN 80	77	200

Threaded end to DIN ISO 228, Part 1.
Flanged end to DIN 2501, Part 1





UPA 150C - 30 for Well Diameters of 150 mm (6 inches) and above

Pumps with submersible motors for ... - Type of current / voltage .... **three-phase** (3 ~) / **400 V**
- Starting .... **d.o.l.** (D) or **star-delta** (Y-Δ)

	Pump	Motor					Motor lead 2), flat	
	Discharge head Q = 0 m^3/h	Rated power	Max. temperature of the fluid pumped v ≥ 0.2 m/s (0.0 m/s)	Rated current	Effi-ciency	Power factor	Number x cross-section of conductors (use under water, 400 V and ≤ +30 °C)	
UPA 150C - 30 / ...	H_0 m	P_N kW	t_{max} 1) °C	I_N A	η_M %	cos φ ---	d.o.l. mm^2	Y-Δ mm^2
1 + DN 100 - 1.1	10.6	1.1	30 (30)	3.1	73.5	0.71	4 x 1.5	-
2 + DN 100 - 2.2	21.5	2.2	30 (30)	6.2	75.0	0.75	4 x 1.5	-
3 + DN 100 - 3.0	32.0	3.0	30 (30)	8.0	76.0	0.76	4 x 1.5	-
4 + DN 100 - 3.7	43.0	3.7	30 (30)	9.2	77.5	0.80	4 x 1.5	-
5 + UMA 150D 5/21	56.0	4.5	41 (38)	12.0	76.5	0.74	4 x 2.5	3/4 x 2.5
5 + DN 100 - 5.5	55.0	5.5	30 (20)	13.0	76.5	0.80	4 x 1.5	-
6 + UMA 150D 5/21	67.0	5.5	37 (33)	13.6	75.5	0.80	4 x 2.5	3/4 x 2.5
6 + DN 100 - 5.5	66.0	5.5	30 (20)	13.0	76.5	0.80	4 x 1.5	-
7 + UMA 150D 7/21	78.0	6.5	37 (33)	16.0	77.5	0.79	4 x 2.5	3/4 x 2.5
7 + DN 100 - 7.5	76.0	7.5	30 (20)	18.4	74.0	0.79	4 x 1.5	-
8 + UMA 150D 7/21	88.0	7.0	33 (29)	16.8	77.0	0.81	4 x 2.5	3/4 x 2.5
9 + UMA 150D 9/21	100.0	8.0	35 (30)	19.0	78.5	0.80	4 x 2.5	3/4 x 2.5
10 + UMA 150D 9/21	110.0	9.0	31 (26)	20.5	78.0	0.82	4 x 2.5	3/4 x 2.5
11 + UMA 150D 9/21	120.0	9.3	28 (22)	21.0	77.5	0.83	4 x 2.5	3/4 x 2.5
12 + UMA 150D 13/21	134.0	11.0	35 (31)	25.5	80.5	0.78	4 x 2.5	3/4 x 2.5
13 + UMA 150D 13/21	144.0	11.5	33 (28)	26.5	80.5	0.79	4 x 2.5	3/4 x 2.5
14 + UMA 150D 13/21	154.0	12.5	31 (25)	28.0	80.5	0.80	4 x 2.5	3/4 x 2.5
15 + UMA 150D 13/21	165.0	13.0	29 (22)	29.0	80.0	0.81	4 x 2.5	3/4 x 2.5
16 + UMA 150D 15/21	176.0	14.5	33 (28)	31.5	82.0	0.82	4 x 4.0	3/4 x 2.5
17 + UMA 150D 15/21	186.0	15.0	31 (25)	32.5	81.5	0.83	4 x 4.0	3/4 x 2.5
18 + UMA 150D 18/21	200.0	16.0	32 (27)	36.5	82.5	0.78	4 x 4.0	3/4 x 2.5

1) also see page 36 2) 3/4 = 1 x 3-core + 1 x 4-core, 90° spacing.

Dimensions / Weights / Horizontal Installation 1)

	L_P ≈ mm		L_A ≈ mm		m_A ≈ kg		D_{max} ≈ mm			Installation 2)
	for motor		incl. motor		incl. motor		d.o.l.	d.o.l.	Y-Δ	
UPA 150C - 30 / ...	DN	UMA	DN	UMA	DN	UMA	DN	UMA	UMA	
1	389	--	690	--	18	--	139	--	--	v + h
2	485	--	840	--	23	--	139	--	--	v + h
3	581	--	1005	--	27	--	139	--	--	v + h
4	677	--	1235	--	36	--	139	--	--	v + h
5	773	805	1478	1505	44	63	139	146	148	v + h
6	869	901	1574	1600	46	65	139	146	148	v + h
7	965	997	1739	1715	51	68	139	146	148	v + h
8	--	1093	--	1810	--	70	--	146	148	v + h
9	--	1189	--	1940	--	74	--	146	148	v + h
10	--	1285	--	2035	--	76	--	146	148	v + h
11	--	1381	--	2130	--	77	--	146	148	v + h
12	--	1477	--	2305	--	86	--	146	148	v + h
13	--	1573	--	2400	--	88	--	146	148	v + h
14	--	1669	--	2500	--	89	--	146	148	v + h
15	--	1765	--	2595	--	91	--	146	148	v + h
16	--	1861	--	2735	--	96	--	147	148	v + h
17	--	1957	--	2830	--	98	--	147	148	v + h
18	--	2053	--	2970	--	104	--	147	148	v + h

1) Including check valve with threaded end and standard motor leads. 2) v = vertical / h = horizontal.

UPA 150C - 30 / ..., number of stages 1 - 18

The characteristic curves shown are for preliminary selection only. Exact selection data will be provided in our quotation.

Selection

The pressure losses H_v in the check valve are not considered in the pump characteristic curves.

Legend ...

H_v: Head losses in the check valve

η_p: Pump efficiency (not considering check valve)

NPSH: Net positive suction head required by the pump

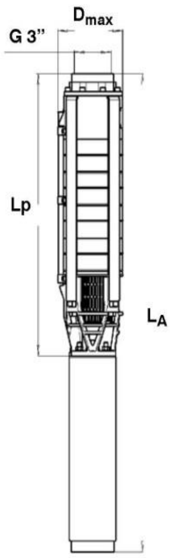
Pump End G 3"

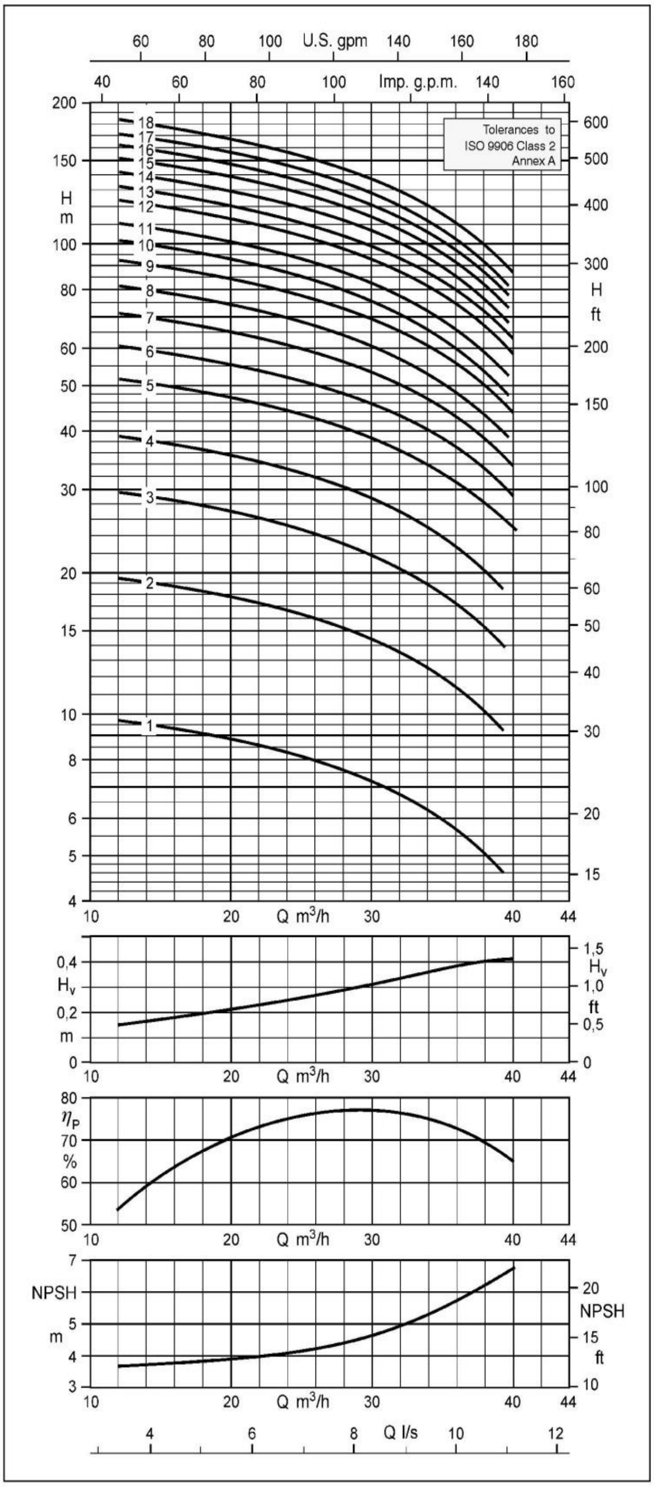
The information given below is based on the model with check valve and threaded end.

The changes in the main dimensions resulting from different threaded or flanged ends are specified in the table below.

	Overall length (mm)	D_{max} (mm)
G 3"	48	see page 44
G 4"	93	
DN 65	77	185
DN 80	77	200

Threaded end to DIN ISO 228, Part 1.
Flanged end to DIN 2501, Part 1





UPA 150C - 30 for Well Diameters of 150 mm (6 inches) and above

Pumps with submersible motors for ... - Type of current / voltage .... **three-phase** (3 ~) / **400 V**
- Starting .... **d.o.l.** (D) or **star-delta** (Y-Δ)

	Pump	Motor					Motor lead 2), flat	
	Discharge head Q = 0 m^3/h	Rated power	Max. temperature of the fluid pumped v ≥ 0.2 m/s (0.0 m/s)	Rated current	Efficiency	Power factor	Number x cross-section of conductors (use under water, 400 V and ≤ +30 °C)	
UPA 150C - 30 / ...	H_0 m	P_N kW	t_{max} 1) °C	I_N A	η_M %	cos φ ---	d.o.l. mm^2	Y-Δ mm^2
19 + UMA 150D 18/21	210.0	17.0	30 (24)	38.0	82.0	0.79	4 x 4.0	3/4 x 2.5
20 + UMA 150D 18/21	220.0	18.0	29 (22)	39.5	82.0	0.81	4 x 4.0	3/4 x 2.5
21 + UMA 150D 18/21	230.0	18.5	27 (20)	40.5	81.5	0.81	4 x 4.0	3/4 x 2.5
22 + UMA 150D 22/21	244.0	20.0	33 (28)	44.0	83.5	0.79	4 x 4.0	3/4 x 2.5
23 + UMA 150D 22/21	254.0	21.0	32 (26)	46.0	83.5	0.80	4 x 4.0	3/4 x 2.5
24 + UMA 150D 22/21	265.0	22.0	31 (25)	47.5	83.5	0.81	4 x 4.0	3/4 x 2.5
25 + UMA 150D 22/21	275.0	22.0	29 (23)	47.5	83.5	0.81	4 x 4.0	3/4 x 2.5
26 + UMA 150D 26/21	289.0	24.0	36 (31)	52.0	85.0	0.80	4 x 6.0	3/4 x 4.0
27 + UMA 150D 26/21	299.0	24.0	35 (30)	52.0	85.0	0.80	4 x 6.0	3/4 x 4.0
28 + UMA 150D 26/21	309.0	25.0	34 (28)	53.0	85.0	0.81	4 x 6.0	3/4 x 4.0
29 + UMA 150D 26/21	320.0	26.0	32 (27)	55.0	84.5	0.82	4 x 6.0	3/4 x 4.0
30 + UMA 150D 26/21	330.0	26.0	31 (26)	55.0	84.5	0.82	4 x 6.0	3/4 x 4.0
31 + UMA 150D 30/21	345.0	28.0	34 (28)	61.0	84.5	0.79	4 x 6.0	3/4 x 4.0
32 + UMA 150D 30/21	355.0	29.0	33 (27)	63.0	84.5	0.80	4 x 6.0	3/4 x 4.0
33 + UMA 150D 30/21	365.0	30.0	32 (26)	65.0	84.5	0.80	4 x 6.0	3/4 x 4.0
34 + UMA 150D 30/21	376.0	30.0	31 (25)	65.0	84.5	0.80	4 x 6.0	3/4 x 4.0
35 + UMA 150D 37/22	389.0	32.0	46 (41)	71.0	84.0	0.78	3/4 x 4.0 3)	3/4 x 4.0

1) also see page 36 2) 3/4 = 1 x 3-core + 1 x 4-core, 90° spacing 3) Parallel cable

Dimensions / Weights / Horizontal Installation 1)

	L_P ≈ mm	L_A ≈ mm	m_A ≈ kg	D_{max} ≈ mm		Installation 2)
	for motor	incl. motor	incl. motor	d.o.l.	Y-Δ	
UPA 150C - 30 / ...	UMA	UMA	UMA	UMA	UMA	
19	2149	3070	105	147	148	v 3)
20	2245	3165	107	147	148	v 3)
21	2341	3260	108	147	148	v 3)
22	2437	3445	118	147	148	v 3)
23	2533	3540	119	147	148	v 3)
24	2629	3640	121	147	148	v 3)
25	2725	3735	123	147	148	v 3)
26	2821	3935	133	149	149	v 3)
27	2917	4030	135	149	149	v 3)
28	3013	4125	136	149	149	v 3)
29	3109	4225	138	149	149	v 3)
30	3205	4320	140	149	149	v 3)
31	3301	4515	150	149	149	v 3)
32	3397	4610	152	149	149	v 3)
33	3493	4705	153	149	149	v 3)
34	3589	4805	155	149	149	v 3)

1) Including check valve with threaded end and standard motor leads. 2) v = vertical / h = horizontal. 3) Horizontal installation on request

UPA 150C - 30 / ..., number of stages 19 - 35

The characteristic curves shown are for preliminary selection only. Exact selection data will be provided in our quotation.

Selection

The pressure losses H_v in the check valve are not considered in the pump characteristic curves.

Legend ...

H_v : Head losses in the check valve

η_p: Pump efficiency (not considering check valve)

NPSH: Net positive suction head required by the pump

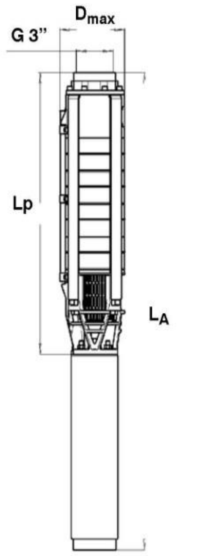
Pump End G 3"

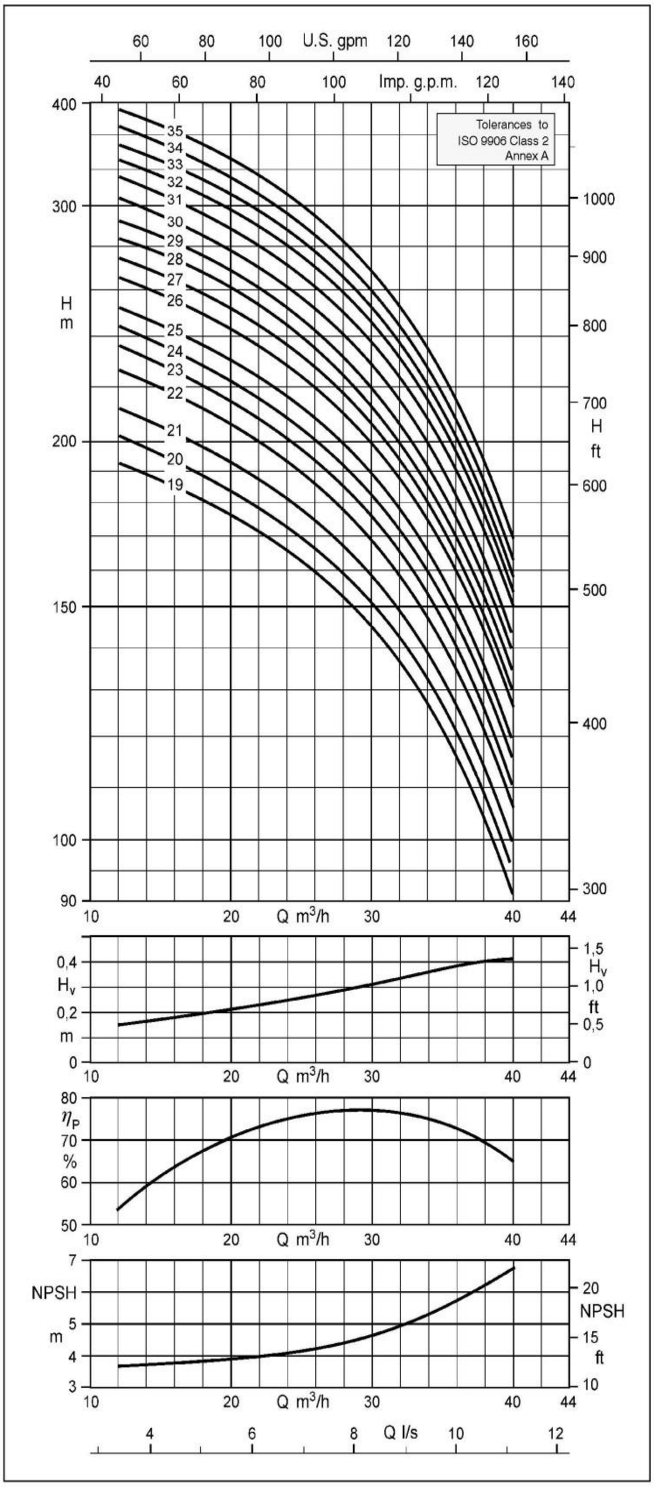
The information given below is based on the model with check valve and threaded end.

The changes in the main dimensions resulting from different threaded or flanged ends are specified in the table below.

	Overall length (mm)	D_{max} (mm)
G 3"	48	see page 46
G 4"	93	
DN 65	77	185
DN 80	77	200

Threaded end to DIN ISO 228, Part 1. Flanged end to DIN 2501, Part 1





UPA 150C - 48 for Well Diameters of 150 mm (6 inches) and above

Pumps with submersible motors for ... - Type of current / voltage .... **three-phase** (3 ~) / **400 V**
- Starting .... **d.o.l.** (D) or **star-delta** (Y-Δ)

	Pump	Motor					Motor lead [2], flat	
	Discharge head $Q = 0\ m^3/h$	Rated power	Max. temperature of the fluid pumped $v \geq 0.2$ m/s (0.0 m/s)	Rated current	Efficiency	Power factor	Number x cross-section of conductors (use under water, 400 V and ≤ +30 °C)	
UPA 150C - 48 / ...	H_0 m	P_N kW	t_{max} [1] °C	I_N A	η_M %	cos φ ---	d.o.l. mm²	Y-Δ mm²
1 + DN 100 - 2.2	13.2	2.2	30 (30)	6.2	75.0	0.75	4 x 1.5	-
2 + DN 100 - 3.0	26.5	3.0	30 (30)	8.0	76.0	0.76	4 x 1.5	-
3 + UMA 150D 5/21	42.0	5.0	40 (36)	12.7	76.0	0.78	4 x 2.5	3/4 x 2.5
3 + DN 100 - 5.5	41.0	5.5	30 (20)	13.0	76.5	0.80	4 x 1.5	-
4 + UMA 150D 7/21	55.0	6.5	37 (32)	16.0	77.5	0.79	4 x 2.5	3/4 x 2.5
4 + DN 100 - 7.5	54.0	7.5	30 (20)	18.4	74.0	0.79	4 x 1.5	-
5 + UMA 150D 9/21	69.0	8.0	35 (30)	19.0	78.5	0.80	4 x 2.5	3/4 x 2.5
6 + UMA 150D 9/21	81.0	9.3	29 (23)	21.0	77.5	0.83	4 x 2.5	3/4 x 2.5
7 + UMA 150D 13/21	97.0	11.5	34 (29)	26.5	80.5	0.79	4 x 2.5	3/4 x 2.5
8 + UMA 150D 13/21	109.0	12.5	30 (25)	28.0	80.5	0.80	4 x 2.5	3/4 x 2.5
9 + UMA 150D 15/21	123.0	14.5	33 (28)	31.5	82.0	0.82	4 x 4.0	3/4 x 2.5
10 + UMA 150D 18/21	138.0	16.0	32 (27)	36.5	82.5	0.78	4 x 4.0	3/4 x 2.5
11 + UMA 150D 18/21	151.0	17.5	29 (23)	39.0	82.0	0.80	4 x 4.0	3/4 x 2.5
12 + UMA 150D 18/21	163.0	18.5	26 (19)	40.5	81.5	0.81	4 x 4.0	3/4 x 2.5
13 + UMA 150D 22/21	179.0	21.0	32 (26)	46.0	83.5	0.80	4 x 4.0	3/4 x 2.5
14 + UMA 150D 22/21	191.0	22.0	29 (23)	47.5	83.5	0.81	4 x 4.0	3/4 x 2.5

[1] also see page 36   [2] 3/4 = 1 x 3-core + 1 x 4-core, 90° spacing.

Dimensions / Weights / Horizontal Installation [1]

	$L_P \approx$ mm		$L_A \approx$ mm		$m_A \approx$ kg		$D_{max} \approx$ mm			Installation [2]
	for motor		incl. motor		incl. motor		d.o.l.	d.o.l.	Y-Δ	
UPA 150C - 48 / ...	DN	UMA	DN	UMA	DN	UMA	DN	UMA	UMA	
1	406	--	765	--	23.0	--	139	--	--	v + h
2	519	--	945	--	29.1	--	139	--	--	v + h
3	632	664	1337	1365	43.0	63.3	139	143	146	v + h
4	745	777	1519	1500	49.2	67.6	139	143	146	v + h
5	--	890	--	1640	--	72.9	--	143	146	v + h
6	--	1003	--	1755	--	75.1	--	143	146	v + h
7	--	1116	--	1945	--	84.4	--	143	146	v + h
8	--	1229	--	2060	--	86.7	--	143	146	v + h
9	--	1342	--	2220	--	92.9	--	145	146	v + h
10	--	1455	--	2375	--	99.2	--	145	146	v + h
11	--	1568	--	2490	--	101.5	--	145	146	v + h
12	--	1681	--	2600	--	103.7	--	145	146	v + h
13	--	1794	--	2805	--	114.0	--	145	146	v + h
14	--	1907	--	2920	--	116.3	--	145	146	v + h

[1] Including check valve with threaded end and standard motor leads.   [2] v = vertical / h = horizontal.

UPA 150C - 48 / ..., number of stages 1 - 14

The characteristic curves shown are for preliminary selection only. Exact selection data will be provided in our quotation.

Selection

The pressure losses H_v in the check valve are not considered in the pump characteristic curves.

Legend ...

H_v: Head losses in the check valve

η_p: Pump efficiency (not considering check valve)

NPSH: Net positive suction head required by the pump

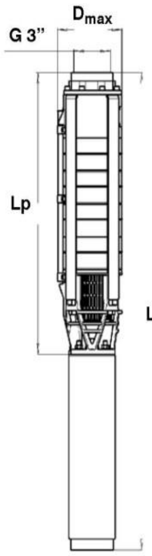
Pump End G 3"

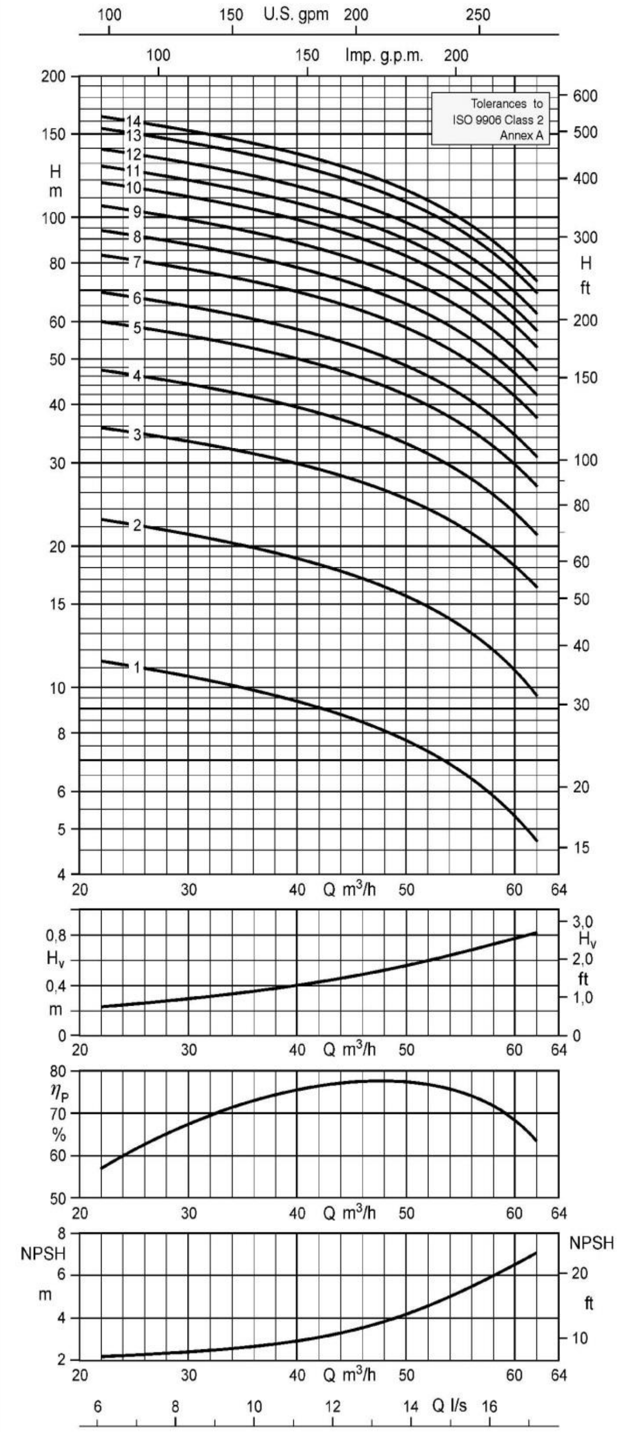
The information given below is based on the model with check valve and threaded end.

The changes in the main dimensions resulting from different threaded or flanged ends are specified in the table below.

	Overall length (mm)	D_{max} (mm)
G 3"	48	see page 48
G 4"	93	
DN 80	77	200

Threaded end to DIN ISO 228, Part 1.
Flanged end to DIN 2501, Part 1





UPA 150C - 48 for Well Diameters of 150 mm (6 inches) and above

Pumps with submersible motors for ... - Type of current / voltage .... **three-phase** (3 ~) / **400 V**
- Starting .... **d.o.l.** (D) or **star-delta** (Y-Δ)

	Pump	Motor					Motor lead 2), flat	
	Discharge head Q = 0 m³/h	Rated power	Max. temperature of the fluid pumped v ≥ 0.2 m/s (0.0 m/s)	Rated current	Effi-ciency	Power factor	Number x cross-section of conductors (use under water, 400 V and ≤ +30 °C)	
UPA 150C - 48 / ...	H_0 m	P_N kW	t_{max} 1) °C	I_N A	η_M %	cos φ ---	d.o.l. mm²	Y-Δ mm²
15 + UMA 150D 26/21	207.0	24.0	35 (30)	52.0	85.0	0.80	4 x 6.0	3/4 x 4.0
16 + UMA 150D 26/21	219.0	26.0	33 (28)	55.0	84.5	0.82	4 x 6.0	3/4 x 4.0
17 + UMA 150D 26/21	232.0	26.0	31 (25)	55.0	84.5	0.82	4 x 6.0	3/4 x 4.0
18 + UMA 150D 30/21	248.0	29.0	33 (27)	63.0	84.5	0.80	4 x 6.0	3/4 x 4.0
19 + UMA 150D 30/21	261.0	30.0	31 (25)	65.0	84.5	0.80	4 x 6.0	3/4 x 4.0
20 + UMA 150D 37/22	276.0	32.0	45 (40)	71.0	84.0	0.78	3/4 x 4.0 3)	3/4 x 4.0
21 + UMA 150D 37/22	289.0	33.0	44 (38)	72.0	84.0	0.79	3/4 x 4.0 3)	3/4 x 4.0
22 + UMA 150D 37/22	301.0	35.0	42 (36)	76.0	84.0	0.80	3/4 x 4.0 3)	3/4 x 4.0
23 + UMA 150D 37/22	314.0	36.0	41 (35)	77.0	83.5	0.81	3/4 x 4.0 3)	3/4 x 4.0
24 + UMA 150D 37/22	327.0	37.0	39 (33)	79.0	83.5	0.82	3/4 x 4.0 3)	3/4 x 4.0

1) also see page 36 2) 3/4 = 1 x 3-core + 1 x 4-core, 90° spacing 3) Parallel cable

Dimensions / Weights / Horizontal Installation 1)

	L_P ≈ mm	L_A ≈ mm	m_A ≈ kg	D_{max} ≈ mm		Installation 2)
	for motor	incl. motor	incl. motor	d.o.l.	Y-Δ	
UPA 150C - 48 / ...	UMA	UMA	UMA	UMA	UMA	
15	2020	3135	128.0	146	147	v 3)
16	2133	3250	130.0	146	147	v 3)
17	2246	3360	132.0	146	147	v 3)
18	2359	3575	143.0	146	147	v 3)
19	2472	3690	146.0	146	147	v 3)
20	2585	3880	155.0	145	147	v 3)
21	2698	3995	157.0	145	147	v 3)
22	2811	4105	159.0	145	147	v 3)
23	2924	4220	162.0	145	147	v 3)
24	3037	4335	164.0	145	147	v 3)

1) Including check valve with threaded end and standard motor leads. 2) v = vertical / h = horizontal. 3) Horizontal installation on request

UPA 150C - 48 / ..., number of stages 15 - 24

The characteristic curves shown are for preliminary selection only. Exact selection data will be provided in our quotation.

Selection

The pressure losses H_V in the check valve are not considered in the pump characteristic curves.

Legend ...

H_V: Head losses in the check valve

η_p: Pump efficiency (not considering check valve)

NPSH: Net positive suction head required by the pump

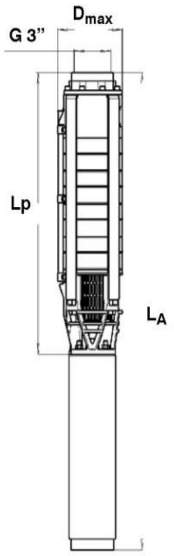
Pump End G 3"

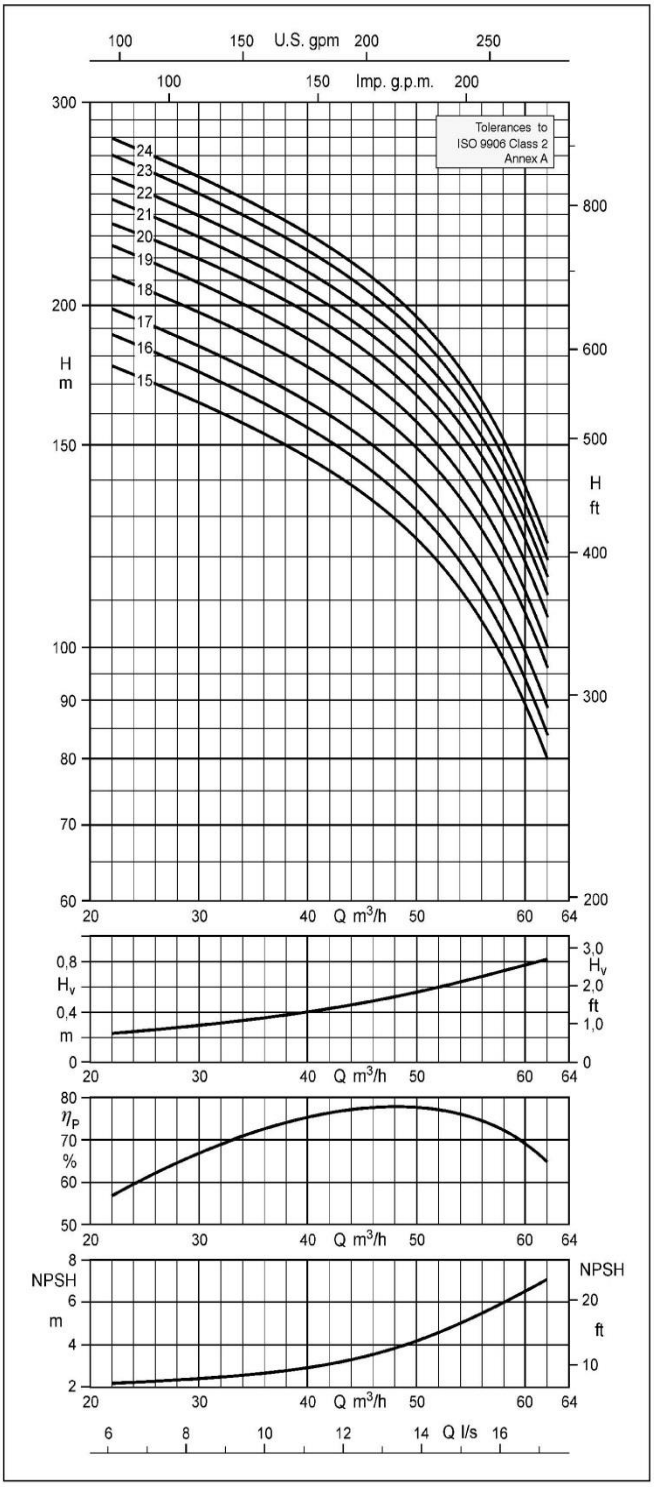
The information given below is based on the model with check valve and threaded end.

The changes in the main dimensions resulting from different threaded or flanged ends are specified in the table below.

	Overall length (mm)	D_{max} (mm)
G 3"	48	see page 50
G 4"	93	
DN 80	77	200

Threaded end to DIN ISO 228, Part 1.
Flanged end to DIN 2501, Part 1





UPA 150C - 60 for Well Diameters of 150 mm (6 inches) and above

Pumps with submersible motors for ... - Type of current / voltage .... **three-phase** (3 ~) / **400 V**
- Starting .... **d.o.l.** (D) or **star-delta** (Y-Δ)

	Pump	Motor					Motor lead [2], flat	
	Discharge head $Q = 0\ m^3/h$	Rated power	Max. temperature of the fluid pumped $v \geq 0.2$ m/s (0.0 m/s)	Rated current	Efficiency	Power factor	Number x cross-section of conductors (use under water, 400 V and ≤ +30 °C)	
UPA 150C - 60 / ...	H_0 m	P_N kW	t_{max} [1] °C	I_N A	η_M %	cos φ ---	d.o.l. mm^2	Y-Δ mm^2
1 + DN 100 - 2.2	13.4	2.2	30 (30)	6.2	75.0	0.75	4 x 1.5	-
2 + DN 100 - 3.7	27.0	3.7	30 (30)	9.2	77.5	0.80	4 x 1.5	-
3 + UMA 150D 7/21	42.0	6.0	39 (35)	15.1	77.5	0.77	4 x 2.5	3/4 x 2.5
3 + DN 100 - 7.5	41.0	7.5	30 (20)	18.4	74.0	0.79	4 x 1.5	-
4 + UMA 150D 7/21	55.0	7.5	31 (26)	17.8	76.5	0.82	4 x 2.5	3/4 x 2.5
4 +DN 100 - 7.5	53.0	7.5	30 (20)	18.4	74.0	0.79	4 x 1.5	-
5 + UMA 150D 9/21	69.0	9.3	29 (23)	21.0	77.5	0.83	4 x 2.5	3/4 x 2.5
6 + UMA 150D 13/21	84.0	11.5	33 (28)	26.5	80.5	0.79	4 x 2.5	3/4 x 2.5
7 + UMA 150D 13/21	97.0	13.0	28 (22)	29.0	80.0	0.81	4 x 2.5	3/4 x 2.5
8 + UMA 150D 15/21	111.0	15.0	31 (25)	32.5	81.5	0.83	4 x 4.0	3/4 x 2.5
9 + UMA 150D 18/21	125.0	17.5	30 (24)	39.0	82.0	0.80	4 x 4.0	3/4 x 2.5
10 + UMA 150D 22/21	140.0	20.0	34 (29)	44.0	83.5	0.79	4 x 4.0	3/4 x 2.5
11 + UMA 150D 22/21	153.0	21.0	31 (25)	46.0	83.5	0.80	4 x 4.0	3/4 x 2.5
12 + UMA 150D 26/21	168.0	23.0	36 (31)	49.5	85.0	0.79	4 x 6.0	3/4 x 4.0
13 + UMA 150D 26/21	181.0	25.0	34 (28)	53.0	85.0	0.81	4 x 6.0	3/4 x 4.0

[1] also see page 36 [2] 3/4 = 1 x 3-core + 1 x 4-core, 90° spacing.

Dimensions / Weights / Horizontal Installation [1]

	L_P ≈ mm		L_A ≈ mm		m_A ≈ kg		D_{max} ≈ mm			Installation [2]
	for motor		incl. motor		incl. motor		d.o.l.	d.o.l.	Y-Δ	
UPA 150C - 60 / ...	DN	UMA	DN	UMA	DN	UMA	DN	UMA	UMA	
1	406	--	765	--	22.9	--	139	--	--	v + h
2	519	--	1075	--	36.5	--	139	--	--	v + h
3	632	664	1406	1385	46.8	65.2	139	143	146	v + h
4	745	777	1519	1495	49.1	67.5	139	143	146	v + h
5	--	890	--	1640	--	72.8	--	143	146	v + h
6	--	1003	--	1830	--	82.0	--	143	146	v + h
7	--	1116	--	1945	--	84.3	--	143	146	v + h
8	--	1229	--	2105	--	90.6	--	145	146	v + h
9	--	1342	--	2260	--	96.8	--	145	146	v + h
10	--	1455	--	2465	--	107.1	--	145	146	v + h
11	--	1568	--	2575	--	109.4	--	145	146	v + h
12	--	1681	--	2795	--	120.6	--	146	147	v + h
13	--	1794	--	2910	--	122.9	--	146	147	v + h

[1] Including check valve with threaded end and standard motor leads. [2] v = vertical / h = horizontal.

UPA 150C - 60 / ..., number of stages 1 - 13

The characteristic curves shown are for preliminary selection only. Exact selection data will be provided in our quotation.

Selection

The pressure losses H_v in the check valve are not considered in the pump characteristic curves.

Legend ...

H_v : Head losses in the check valve

η_p: Pump efficiency (not considering check valve)

NPSH: Net positive suction head required by the pump

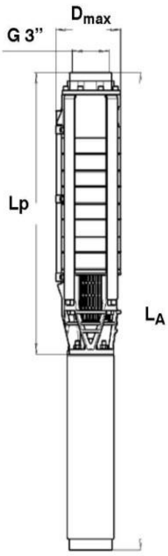
Pump End G 3"

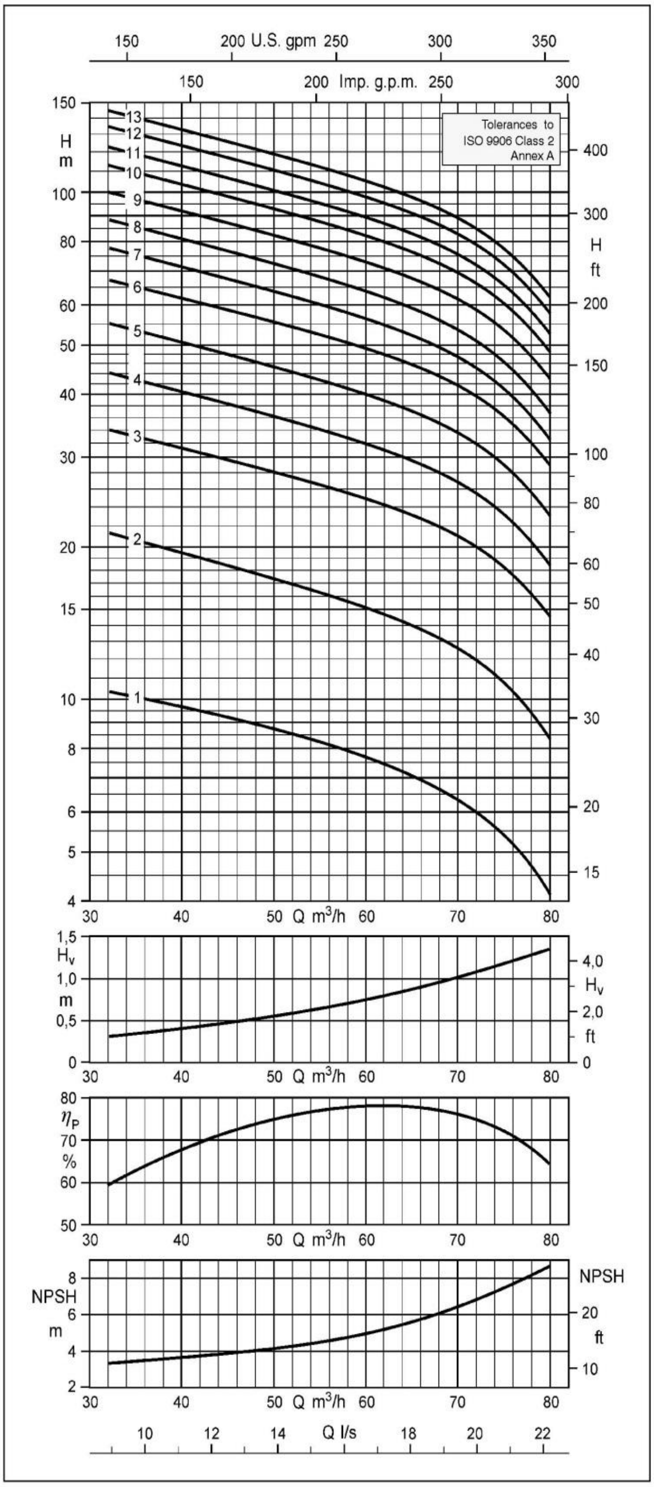
The information given below is based on the model with check valve and threaded end.

The changes in the main dimensions resulting from different threaded or flanged ends are specified in the table below.

	Overall length (mm)	D_{max} (mm)
G 3"	48	see page 52
G 4"	93	

Threaded end to DIN ISO 228, Part 1.
Flanged end to DIN 2501, Part 1





UPA 150C - 60 for Well Diameters of 150 mm (6 inches) and above

Pumps with submersible motors for ... - Type of current / voltage .... **three-phase** (3 ~) / **400 V**
- Starting .... **d.o.l.** (D) or **star-delta** (Y-Δ)

	Pump	Motor					Motor lead 2), flat	
	Discharge head Q = 0 m³/h	Rated power	Max. temperature of the fluid pumped v ≥ 0.2 m/s (0.0 m/s)	Rated current	Efficiency	Power factor	Number x cross-section of conductors (use under water, 400 V and ≤ +30 °C)	
UPA 150C - 60 / ...	H_0 m	P_N kW	t_{max} 1) °C	I_N A	η_M %	cos φ ---	d.o.l. mm²	Y-Δ mm²
14 + UMA 150D 26/21	194.0	26.0	31 (25)	55.0	84.5	0.82	4 x 6.0	3/4 x 4.0
15 + UMA 150D 30/21	210.0	29.0	32 (27)	63.0	84.5	0.80	4 x 6.0	3/4 x 4.0
16 + UMA 150D 30/21	223.0	30.0	30 (24)	65.0	84.5	0.80	4 x 6.0	3/4 x 4.0
17 + UMA 150D 37/22	237.0	33.0	44 (39)	72.0	84.0	0.79	3/4 x 4.0 3)	3/4 x 4.0
18 + UMA 150D 37/22	251.0	35.0	43 (37)	76.0	84.0	0.80	3/4 x 4.0 3)	3/4 x 4.0
19 + UMA 150D 37/22	264.0	36.0	41 (35)	77.0	83.5	0.81	3/4 x 4.0 3)	3/4 x 4.0
20 + UMA 150D 37/22	277.0	37.0	39 (32)	79.0	83.5	0.82	3/4 x 4.0 3)	3/4 x 4.0

1) also see page 36 2) 3/4 = 1 x 3-core + 1 x 4-core, 90° spacing. 3) Parallel cable

Dimensions / Weights / Horizontal Installation 1)

	L_P ≈ mm	L_A ≈ mm	m_A ≈ kg	D_{max} ≈ mm		Installation 2)
	for motor	incl. motor	incl. motor	d.o.l.	Y-Δ	
UPA 150C - 60 / ...	UMA	UMA	UMA	UMA	UMA	
14	1907	3020	125.0	146	147	v 3)
15	2020	3235	136.0	146	147	v 3)
16	2133	3345	139.0	146	147	v 3)
17	2246	3540	148.0	145	147	v 3)
18	2359	3655	150.0	145	147	v 3)
19	2472	3765	153.0	145	147	v 3)
20	2585	3880	155.0	145	147	v 3)

1) Including check valve with threaded end and standard motor leads. 2) v = vertical / h = horizontal. 3) Horizontal installation on request

UPA 200 – 11 for Well Diameters of 200 mm (8 inches) and above

Pumps with submersible motors for .... **three-phase current** (3~) / **400 V / d.o.l.** (D) or **star-delta** (Y-Δ) **starting**

Pump + motor	**Pump**	**Motor**					**Motor lead** [2], flat	
	Discharge head Q = 0 m³/h	Rated power	Max. temperature of the fluid pumped v ≥ 0.2 m/s (= 0 m/s)	Rated current	Effi-ciency	Power factor	Number x cross-section of conductors (use under water, 400 V and ≤+30 °C)	
UPA 200 – 11/ ... + ..	H_0 m	P_N kW	t_{max} [1] °C	I_N A	η_M %	cos φ --	**D.o.l.** mm²	**Y-Δ** mm²
1e + UMA 150D 5/21	19	2.5	45 (42)	9.5	70.2	0.57	4 x 2.5	3/4 x 2.5
1d + UMA 150D 5/21	20	2.5	45 (42)	9.5	70.2	0.57	4 x 2.5	3/4 x 2.5
1 + UMA 150D 5/21	23	3.5	45 (42)	10.6	75.2	0.67	4 x 2.5	3/4 x 2.5
2e + UMA 150D 5/21	36	4.5	42 (39)	12.0	76.4	0.74	4 x 2.5	3/4 x 2.5
2c + UMA 150D 5/21	41	5.5	39 (35)	13.6	75.7	0.80	4 x 2.5	3/4 x 2.5
2 + UMA 150D 7/21	45	6.0	38 (34)	15.1	77.6	0.77	4 x 2.5	3/4 x 2.5
3d + UMA 150D 7/21	59	7.0	35 (30)	16.8	76.9	0.81	4 x 2.5	3/4 x 2.5
3 + UMA 150D 9/21	66	9.0	32 (27)	20.5	77.9	0.82	4 x 2.5	3/4 x 2.5
4c + UMA 150D 13/21	83	10.0	37 (33)	24.0	80.8	0.75	4 x 2.5	3/4 x 2.5
4 + UMA 150D 13/21	89	12.0	33 (28)	27.0	80.5	0.80	4 x 2.5	3/4 x 2.5
5b + UMA 150D 13/21	103	12.5	31 (35)	28.0	80.4	0.80	4 x 2.5	3/4 x 2.5
5 + UMA 150D 15/21	110	14.5	32 (37)	31.5	81.9	0.82	4 x 4.0	3/4 x 2.5
6b + UMA 150D 15/21	123	15.0	31 (35)	32.5	81.7	0.83	4 x 4.0	3/4 x 2.5
6 + UMA 150D 18/21	133	17.5	29 (23)	39.0	82.0	0.80	4 x 4.0	3/4 x 2.5
7 + UMA 150D 22/21	155	21.0	32 (27)	46.0	83.5	0.80	4 x 4.0	3/4 x 2.5
8 + UMA 150D 26/21	178	24.0	35 (31)	52.0	84.9	0.80	4 x 6.0	3/4 x 4.0
9 + UMA 150D 26/21	199	26.0	32 (26)	55.0	84.6	0.82	4 x 6.0	3/4 x 4.0
10 + UMA 150D 30/21	222	29.0	32 (26)	63.0	84.6	0.80	4 x 6.0	3/4 x 4.0
11 + UMA 150D 37/22	245	32.0	45 (40)	71.0	84.2	0.78	3/4 x 4.0 [4]	3/4 x 4.0
12 + UMA 150D 37/22	266	35.0	42 (36)	76.0	83.9	0.80	3/4 x 4.0 [4]	3/4 x 4.0
13 + UMA 150D 37/22	286	37.0	39 (33)	79.0	83.6	0.82	3/4 x 4.0 [4]	3/4 x 4.0
14 + UMA 200D 45/21	315	42.0	30 (25)	85.0	86.1	0.83	3/4 x 6.0 [3]	3/4 x 6.0

[1] Also see pages 3 and 60. [2] 3/4 = 1 x 3-core + 1 x 4-core, 90° spacing. [3] Delta wiring in the cable connector or control cabinet.
[4] cable parallel

Dimensions / Weights / Horizontal Installation [1]

Pump unit	L_P	L_A ≈ mm		m_A ≈ kg		D_{max} ≈ mm		Installation [2]	A ≈ mm
UPA 200 - 11/ ..	mm	**G** (Standard)	**B** (Special)	**G** (Standard)	**B** (Special)	D.o.l.	Y-Δ		
1e	515	1215	1225	66	69	192	195	v + h	645
1d	515	1215	1225	66	69	192	195	v + h	645
1	515	1215	1225	66	69	192	195	v + h	645
2e	580	1280	1290	70	74	192	195	v + h	710
2c	580	1280	1290	70	74	192	195	v + h	710
2	580	1300	1310	72	76	192	195	v + h	720
3d	645	1365	1375	75	79	192	195	v + h	785
3	645	1395	1405	78	82	192	195	v + h	800
4c	710	1540	1550	88	93	192	195	v + h	905
4	710	1540	1550	88	93	192	195	v + h	905
5b	775	1605	1615	92	97	192	195	v + h	970
5	775	1650	1660	96	101	193	195	v + h	990
6b	840	1715	1725	99	105	193	195	v + h	1055
6	840	1760	1770	103	109	193	195	v + h	1080
7	905	1915	1925	114	120	193	195	v + h	1190
8	970	2085	2095	127	134	194	196	v + h	1305
9	1035	2150	2160	130	137	194	196	v + h	1370
10	1100	2315	2325	142	150	194	196	v + h	1485
11	1165	2460	2470	152	160	196	196	v [3]	-
12	1230	2525	2535	156	165	196	196	v [3]	-
13	1295	2590	2600	159	168	196	196	v [3]	-
14	1360	2590	2590	220	230	199	199	v + h	1755

[1] Including check valve with threaded end and standard motor leads. [2] v = vertical and h = horizontal. [3] Horizontal installation on request.

UPA 200 - 11 / ..

The characteristic curves shown are for preliminary selection only. Exact selection data will be provided in our quotation.

Selection

The pressure losses H_v in the check valve are not considered in the pump characteristic curves.
For more details and a selection example refer to page 8.

Legend ...

H_v : Head losses in the check valve

η_p: Pump efficiency (not considering check valve)

NPSH: Net positive suction head required by the pump

Pump End G 3" / DN 80

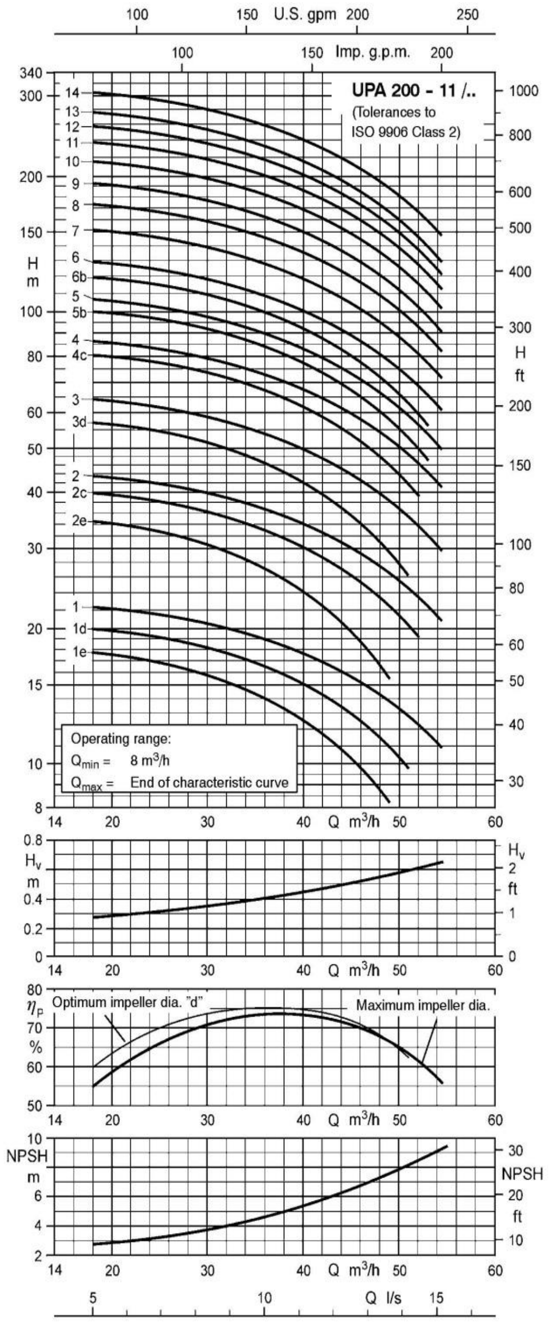
The information is based on the model "with check valve / connection branch and threaded end".
The changes in the main dimensions of the "flanged end" model are specified in the table below.

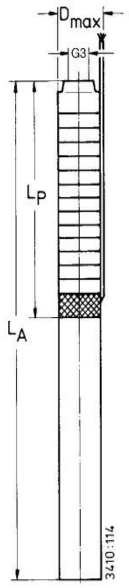
Check valve / connection branch with:

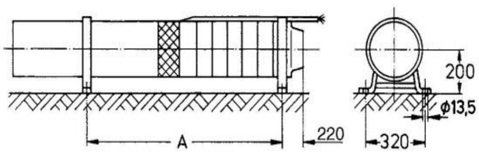
Threaded end G 3"	Flanged end DN 80	
Length mm	Length mm	Outside diameter mm
200	200 (PN 10/16) 200 (PN 25/40)	200 200

Threaded end to DIN ISO 228, Part 1

Flange mating dimensions to DIN 2501, Part 1







APPENDIX –C

8% TABLE 13 Discrete Cash Flow: Compound Interest Factors 8%

	Single Payments		Uniform Series Payments				Arithmetic Gradients	
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 Uniform Series A/G
1	1.0800	0.9259	1.00000	1.0000	1.08000	0.9259		
2	1.1664	0.8573	0.48077	2.0800	0.56077	1.7833	0.8573	0.4808
3	1.2597	0.7938	0.30803	3.2464	0.38803	2.5771	2.4450	0.9487
4	1.3605	0.7350	0.22192	4.5061	0.30192	3.3121	4.6501	1.4040
5	1.4693	0.6806	0.17046	5.8666	0.25046	3.9927	7.3724	1.8465
6	1.5869	0.6302	0.13632	7.3359	0.21632	4.6229	10.5233	2.2763
7	1.7138	0.5835	0.11207	8.9228	0.19207	5.2064	14.0242	2.6937
8	1.8509	0.5403	0.09401	10.6366	0.17401	5.7466	17.8061	3.0985
9	1.9990	0.5002	0.08008	12.4876	0.16008	6.2469	21.8081	3.4910
10	2.1589	0.4632	0.06903	14.4866	0.14903	6.7101	25.9768	3.8713
11	2.3316	0.4289	0.06008	16.6455	0.14008	7.1390	30.2657	4.2395
12	2.5182	0.3971	0.05270	18.9771	0.13270	7.5361	34.6339	4.5957
13	2.7196	0.3677	0.04652	21.4953	0.12652	7.9038	39.0463	4.9402
14	2.9372	0.3405	0.04130	24.2149	0.12130	8.2442	43.4723	5.2731
15	3.1722	0.3152	0.03683	27.1521	0.11683	8.5595	47.8857	5.5945
16	3.4259	0.2919	0.03298	30.3243	0.11298	8.8514	52.2640	5.9046
17	3.7000	0.2703	0.02963	33.7502	0.10963	9.1216	56.5883	6.2037
18	3.9960	0.2502	0.02670	37.4502	0.10670	9.3719	60.8426	6.4920
19	4.3157	0.2317	0.02413	41.4463	0.10413	9.6036	65.0134	6.7697
20	4.6610	0.2145	0.02185	45.7620	0.10185	9.8181	69.0898	7.0369
21	5.0338	0.1987	0.01983	50.4229	0.09983	10.0168	73.0629	7.2940
22	5.4365	0.1839	0.01803	55.4568	0.09803	10.2007	76.9257	7.5412
23	5.8715	0.1703	0.01642	60.8933	0.09642	10.3711	80.6726	7.7786
24	6.3412	0.1577	0.01498	66.7648	0.09498	10.5288	84.2997	8.0066
25	6.8485	0.1460	0.01368	73.1059	0.09368	10.6748	87.8041	8.2254
26	7.3964	0.1352	0.01251	79.9544	0.09251	10.8100	91.1842	8.4352
27	7.9881	0.1252	0.01145	87.3508	0.09145	10.9352	94.4390	8.6363
28	8.6271	0.1159	0.01049	95.3388	0.09049	11.0511	97.5587	8.8289
29	9.3173	0.1073	0.00962	103.9659	0.08962	11.1584	100.5738	9.0133
30	10.0627	0.0994	0.00883	113.2832	0.08883	11.2578	103.4558	9.1897
31	10.8677	0.0920	0.00811	123.3459	0.08811	11.3498	106.2163	9.3584
32	11.7371	0.0852	0.00745	134.2135	0.08745	11.4350	108.8575	9.5197
33	12.6760	0.0789	0.00685	145.9506	0.08685	11.5139	111.3819	9.6737
34	13.6901	0.0730	0.00630	158.6267	0.08630	11.5869	113.7924	9.8208
35	14.7853	0.0676	0.00580	172.3168	0.08580	11.6546	116.0920	9.9611
40	21.7245	0.0460	0.00386	259.0565	0.08386	11.9246	126.0422	10.5699
45	31.9204	0.0313	0.00259	386.5056	0.08259	12.1084	133.7331	11.0447
50	46.9016	0.0213	0.00174	573.7702	0.08174	12.2335	139.5928	11.4107
55	68.9139	0.0145	0.00118	848.9232	0.08118	12.3186	144.0065	11.6902
60	101.2571	0.0099	0.00080	1253.21	0.08080	12.3766	147.3000	11.9015
65	148.7798	0.0067	0.00054	1847.25	0.08054	12.4160	149.7387	12.0602
70	218.6064	0.0046	0.00037	2720.08	0.08037	12.4428	151.5326	12.1783
75	321.2045	0.0031	0.00025	4002.56	0.08025	12.4611	152.8448	12.2658
80	471.9548	0.0021	0.00017	5886.94	0.08017	12.4735	153.8001	12.3301
85	693.4565	0.0014	0.00012	8655.71	0.08012	12.4820	154.4925	12.3772
90	1018.92	0.0010	0.00008	12724	0.08008	12.4877	154.9925	12.4116
95	1497.12	0.0007	0.00005	18702	0.08005	12.4917	155.3524	12.4365
96	1616.89	0.0006	0.00005	20199	0.08005	12.4923	155.4112	12.4406
98	1885.94	0.0005	0.00004	23562	0.08004	12.4934	155.5176	12.4480
100	2199.76	0.0005	0.00004	27485	0.08004	12.4943	155.6107	12.4545

جامعة النجاح الوطنية

كليةالدراسات العليا

كفاءة وجدوى استعمال كل من الشبكات الكهربائية ومحرك الديزل والخلايا الشمسية عن طريق تحكم آلي لتتبع منحنى الإشعاع الشمسي في ضخ المياه

إعداد

حنان محمد محمودعلي

إشراف

أ.د.مروان محمود

قدمت هذه الاطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة الطاقة النظيفة واستراتيجية الترشيد بكلية الدراسات العليا في جامعة النجاح الوطنية نابلس فلسطين

2013

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إشراف

أ.د. مروان محمود

الملخص

يعرض هذا البحث مقارنة بين اربع آليات لتشغيل نظام مضخات المياه، هذه الآليات تشمل الخلايا الشمسية، مولد الديزل، محرك الديزل والشبكة الكهربائية. بناء على هذا البحث تبين أن الخلايا الشمسية مجديةأكثر من مولد الديزل حيث أن تكلفة المتر المكعب من المياه باستخدام مولد الديزل أعلى بحوالي 80% من تكلفته باستخدام الخلايا الشمسية.

عند مقارنة الخلايا الشمسية مع محرك الديزل أيضا حصلناعلى نتيجة مشابهة لما سبق، حيث تبين أيضاً أن محرك اليزل أقل جدوى من الخلايا الشمسية. تلا ذلك مقارنة الخلايا الشمسية بالشبكة الكهربائية، وظهر من التحليلات أن تكلفة المتر المكعب من الماء في كلتي التقنيتين متقاربة جدا إلا أن الشبكة الكهربائيةأكثر جدوى.

أخيرا تم تطبيق ربط الأحمال باستخدام نظامين من الخلايا الشمسية بالإعتماد على المنحنى اليومي للإشعاع الشمسي وتبين أن تكلفة المتر المكعب من المياه قدانخفضت بحوالي 9% مع استخدام نظام واحد من الخلايا.