An-Najah National University

Faculty of Graduate Studies

Technical and Financial Analysis of Using Variable Frequency Drive for Water Pumps Compared with Fixed Frequency

By

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Supervisor

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Dedication

I would like to dedicate my thesis work to

My father, mother, brother and sisters.

All friends and colleagues.

Every one works in this field.

Acknowledgment

A special thanks to my family. Words cannot express how grateful I am to my mother, and father for all of the sacrifices that you’ve made on my behalf. Your prayer for me was what sustained me thus far.

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الإقرار

أنا الموقعة أدناه مقدم الرسالة التي تحمل العنوان:

Technical and Financial Analysis of Using Variable Frequency Drive for Water Pumps Compared with Fixed Frequency

أقر بأن ما اشتملت عليه هذه الرسالة ، إنما هي نتاج جهدي الخاص ، باستثناء ما تمت الإشارة إليه حيثما ورد ، و أن هذه الرسالة ككل ، و أي جزء منها لم يقدم من قبل لنيل درجة علمية أو بحث علمي لدى أي مؤسسة تعليمية أو بحثية أخرى.

Declaration

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

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Technical and Financial Analysis of Using Variable Frequency Drive for Water Pumps Compared with Fixed Frequency

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Abstract

Variable speed drives in the water pumping systems are now a mature technology, can achieve significant gains for the user to reduce costs improve the efficiency and reliability, the right applications. However it is dear that higher costs and lower overall system efficiency are combined with the traditional control frequency system.

In this thesis, the performance of one water pumping system with a constant frequency (50 Hz) will be theoretically and practically analyzed and compared with another water pumping systems with variable frequency both system types are built on three artesian wells operating in Tulkarm area for irrigation of farms where one system operate with constant frequency (soft start) and remaining two systems with variable frequency inverter .

Chapter One

Introduction

1.1 Introduction to Ground Water Well Pumping System

A water system is needed to pump the water out of the well to the surface and deliver it under pressure to the place where you will be using it. A typical home water system , consists of a pump, a pitiless adapter or unit, and a pressure storage tank and control devices that allow the system to operate automatically.

A well is the most common way to obtain groundwater for household use. A well is basically a hole in the ground, held open by a pipe (or casing) that extends to an aquifer. A pump draws water from the aquifer for distribution through the plumbing system. The depth to which wells are constructed is determined by factors such as the depth of groundwater, the groundwater quality, and the geologic conditions at the well site [2].

1.2 Water in Palestine

The rain water is the main source of water in Palestine, but it fluctuates from year to year. So, the ground water will be the main source.

Groundwater is water located beneath the earth's surface through geological formations. On the other hand, the ground water is obtained through water pumps which lift the water by a mechanical action by using different methods.

Most of the West Bank’s natural water resources lie beneath its soil in three shared aquifers sometimes collectively known as the “Mountain Aquifer”. All three of these aquifers derive most of their recharge from rainfall and snowmelt on the Palestinian side of the Green Line. Two of the three aquifers (the Western and North-Eastern) also underlie Israeli territory, with a flow that follows the surface topography, from the West Bank towards Israel. The third aquifer – the Eastern – lies almost completely within the West Bank and discharges towards the Dead Sea. An overall view of Israel's and West Bank and Gaza's shared and non-shared groundwater aquifers is provided in a map shown in figure (1.1).

All three aquifers share the same predominant geology, largely karstic limestone formations, and are hierologically characterized by great depth (average 250 metres) and relatively rapid flow [2].

The Western Aquifer, with an estimated renewable yield of about 335-450 MCM, flows from the western slopes of the Palestinian hills towards the coast. Water from this aquifer, typically of a very high quality, provides about one fifth of Israel's fresh water, pumped from numerous wells located just west of the Green Line. In the North-Eastern Aquifer, natural replenishment is estimated at between 130-200 MCM. The Eastern Aquifer, estimated recharge of 155-237 MCM, drains to the Jordan River and the Dead Sea. The aquifer lies almost completely within the West Bank and contains locally more saline waters [3].

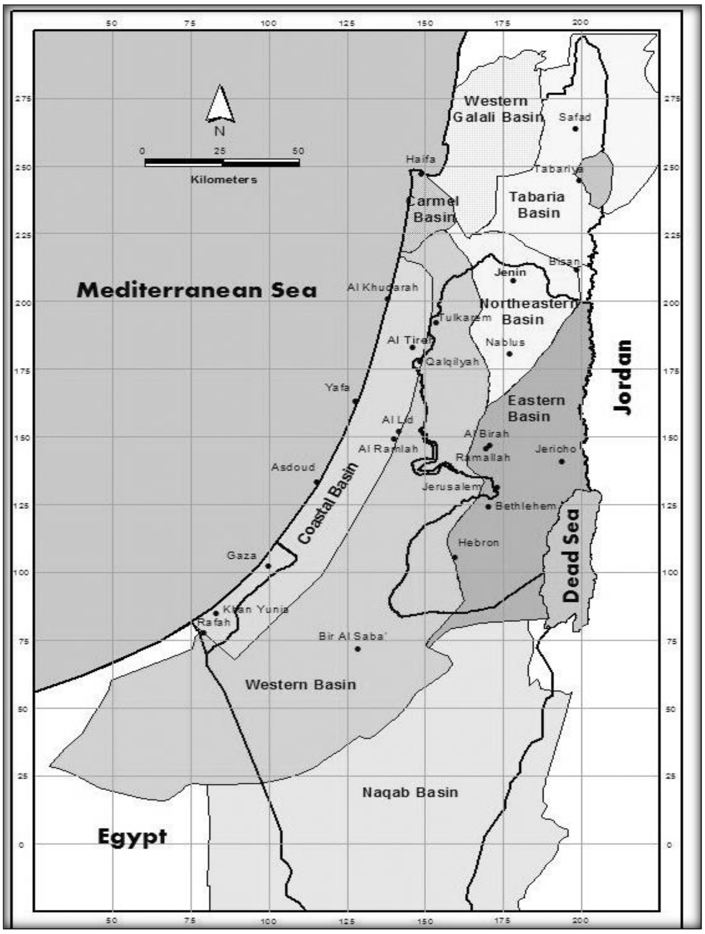


Figure 1.2): Map of shared and non-shared groundwater aquifers [4].

1.3 Pump

The focus of this thesis is to make financial analysis for energy efficiency for the ground water pumps controlled by a soft starter and others controlled by a variable frequency converter. Pumps are devices used to transfer liquids from low-pressure zones to high-pressure zones, or to move them from a low elevation into a higher elevation. There are many types of pumps used for many applications for ground water, wastewater application, circulation of water in closed systems e.g. heating, cooling and air conditioning systems. In this thesis I will introduce centrifugal pump that specially use to left water through ground water well. An increase in the fluid pressure from the pump inlet to its outlet is created when the pump is in operation. This pressure difference drives the fluid through the system or plant.

The centrifugal pump creates an increase in pressure by transferring mechanical energy from the motor to the fluid through the rotating impeller. The fluid flows from the inlet to the impeller center and out along its blades. The centrifugal force hereby increases the fluid velocity and consequently the kinetic energy is transformed into pressure. [5].

Pumps are used widely in industry to provide cooling and lubrication services, to transfer fluids for processing, and to provide the motive force in hydraulic systems. Pumping systems account for nearly 20% of the world's electrical energy demand and range from 25-50% of the energy usage in certain industrial plant operations. With raising energy costs, process plants are increasing their focus on the amount of energy consumed by rotating equipment. An improperly sized or poorly performing pump consumes unnecessary money [6].

1.4 Variable Frequency Drive (VFD)

VFD is a device using power electronics to vary the frequency of input power to the motor, thereby controlling motor speed.

There are many diverse reasons for using variable Frequency drives. Some applications, such as paper making machines, cannot run without them while others, such as centrifugal pumps can benefit from energy savings [7]**.**

In general, variable speed drives are used to:

- Match the speed of a drive to the process requirements.
- Match the torque of a drive to the process requirements.

- Save energy and improve efficiency [7].

The benefits of energy savings are not always fully appreciated by many users. These savings are particularly apparent with centrifugal pumps and fans, where load torque increases as the square of the speed and power consumption as the cube of the speed. Substantial cost savings can be achieved in some applications .

1.5 Motor

For industrial and mining applications, 3-phase AC induction motors are the prime movers for the vast majority of machines. These motors can be operated either directly from the mains or from adjustable frequency drives. In modern industrialized countries, more than half the total electrical energy used in those countries is converted to mechanical energy through AC induction motors. The applications for these motors cover almost every stage of manufacturing and processing. Applications also extend to commercial buildings and the domestic environment. They are used to drive pumps, fans, compressors, mixers, agitators, mills, conveyors, crushers, machine tools, cranes, etc [7].In the last decade, it has become increasingly common practice to use 3-phase squirrel cage AC induction motors with variable frequency converters for variable speed drive (VSD) applications, to clearly understand how the VSD system works, it is necessary to understand the principles of operation of this type of motor.

The thesis consists of eight chapters:

Chapter 1: Provides an introduction to the water sources in Palestine, the method for pumping ground water by using centrifugal pump and VFD for conserving energy.

Chapter 2: Shows all ground water wells in Palestine, and the quantity of water used in several fields for drinking, agriculture, and industry.

Chapter 3: Describes the water pumping system and the basic component in the system.

Chapter 4: Studies types of pumps used for water application and to choose more suitable pumps based on mechanical and electrical characteristic.

Chapter 5: Studies the characteristic of induction motor and the possibility to conserve energy by using VFD.

Chapter 6: Presents practical water pumping system and its control method.

Chapter 7: Financial analysis for using variable frequency convertor drive VFD as a driver for a pump with other pumps using a soft starter as a driver.

Chapter 8: Presents the main conclusion of this thesis and recommendation for future work.

Chapter Two

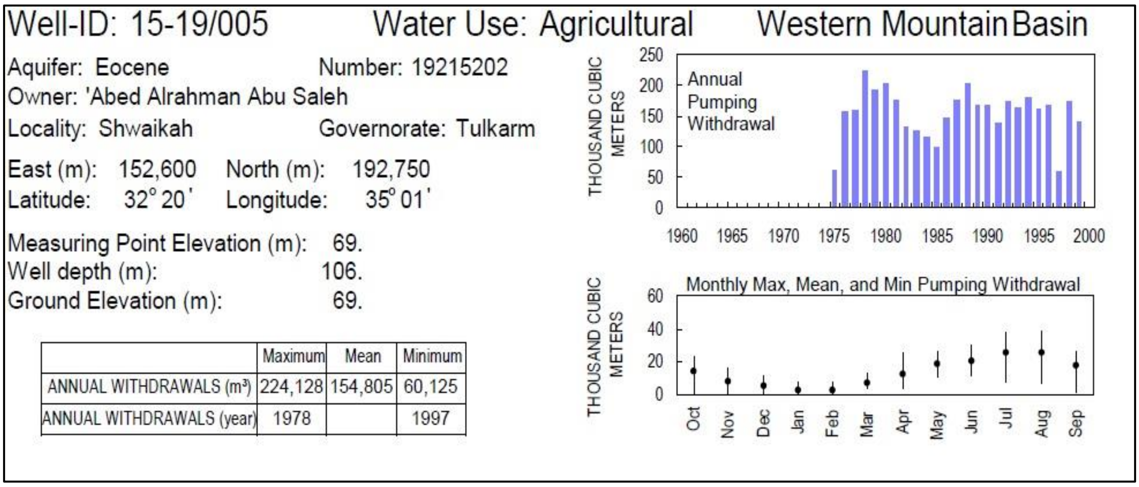
Ground Water Wells in Palestine

2.1 Introduction to Ground Water Wells

A water well is a hole, shaft, or excavation used for the purpose of extracting ground water from the subsurface. Water may flow to the surface naturally after excavation of the hole or shaft. Such a well is known as a flowing ground water well. More commonly, water must be pumped out of the well.

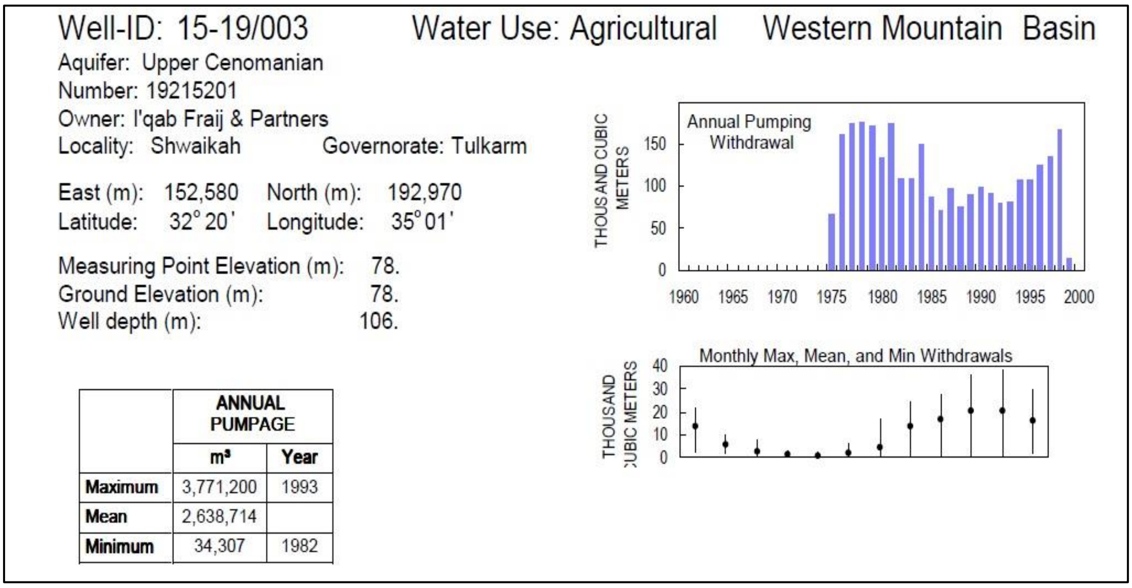
Most wells are vertical shafts, but they may also be horizontal or at an inclined angle. Horizontal wells are commonly used in *bank filtration,* where surface water is extracted via recharge through river bed sediments into horizontal wells located underneath or next to a stream. Some wells are used for purposes other than obtaining ground water oil and gas wells are examples of this [8].

This thesis focuses on vertical water-production wells commonly used to supply water for domestic, municipal, and agricultural uses. Three vertical wells conducted to practical test Agricultural irrigation company well and Mr. Waleed Ribhi that use VFD drive ,the other one Mr. Abu Saleh ground water well that use soft starter to drive the pump motor. Mr. Waleed Ribhi well neglected from analysis due to problem in mechanical structure that caused water leakage in his network resulting high cost for pumped water that will be shown in chapter six.



	Maximum	Mean	Minimum
ANNUAL WITHDRAWALS (m³)	224,128	154,805	60,125
ANNUAL WITHDRAWALS (year)	1978		1997

Figure(2.1): Abu Salah Well information [9].



	ANNUAL PUMPAGE	
	m³	Year
Maximum	3,771,200	1993
Mean	2,638,714	
Minimum	34,307	1982

Figure (2.2): Agricultural Irrigation Company Well information [9].

2.2 Palestinian Water Resources

The existing Palestinian water resources in the West Bank are primarily derived from four aquifer basins Eastern, Northeastern and Western Table (2.1) show the Palestinian Aquifer Recharge rates from this aquifer as well as a series of springs that emanate from the groundwater. Other sources of water are the Jordan River and wadi runoffs.

Table (2.1): Palestinian Aquifer Recharge rates [10].

Aquifer Basin	Recharge Rates (Mcm/yr)
Eastern	100-172
Northeastern	130-200
Western	335-450
Gaza Coastal	55-65
Total	620-887

2.3 Usage of Ground Water

The quantity of the ground water used in Palestine for municipal ,industry and irrigation Table(2.2) show Estimated Municipal and Industrial (Mcm/yr) total water use in Palestine , Table(2.3) Estimated Total Water Supply (Mcm/yr) for Irrigation in Palestine [11].

Table (2.2): Estimated Municipal and Industrial (Mcm/yr) total water use in Palestine [11].

Region	Wells	Springs	Total
West Bank	55*	4	59
Gaza Strip	53**	-	53
Total	108	4	112

* 22 Mcm/yr are purchased from Israeli sources

** 48 Mcm/yr are abstracted from wells in the Gaza aquifer and 5 Mcm/yr are supplied from the Mekorot Israeli water company.

Table (2. 3): Estimated Total Water Supply (Mcm/yr) for Irrigation in Palestine [11].

Region	Wells	Brackish wells	Springs	Total
West Bank	40	0	49	89
Gaza Strip	43	42	0	85
Total	83	42	49	174

2.4 The Control of Occupation on the Ground Water in Palestine:

Israeli occupation systematically escalates its aggression against the Palestinian population and their property across the occupied Palestinian territories; where these attacks targeted on the sources and the elements of life and equated development, especially water which is the main ingredient for the survival of every human life [12].

Water resources in Palestine consist of groundwater resources, groundwater system in the West Bank, and the coastal aquifer, in addition to the Jordan River system. Israel controls nearly all Palestinian water resources and use about 89 percent of the water available, leaving only 11% for the Palestinians. Over the last decade, the Palestinians were able to pump water from the aquifer in the West Bank but they were prohibited. This decreased the total amount of 138 million cubic meters in 1999 to 93 million cubic meters in 2009. The result was that the level of ground water has been reduced beneath the surface of the sea and the salty water had begun to enter the aquifer [12].

The Israelis use ALL of these quantities for the following purposes:

1. About 33% for drinking.
2. Irrigation purposes by rate more than Palestinian water pumping ratio [11].

In addition, Israel's ambitions appeared in control and theft of water from water basins and prevent the Palestinians to use it, including through the establishment of the wall that matches the path with the path of aquifers, confiscate water wells and prevent digging artesian wells.

The occupation do not take into account the growing needs of water per year, resulting from increasing natural population, expansion of cultivated areas and other agricultural businesses. This situation led to increasing water problems, needs of agricultural, industrial and household increasing but the available quantities are limited. On the other hand, Gaza suffers from high water salinity and pollution, as a result of the lack of groundwater recharge and increasing used quantities to cover water needs.

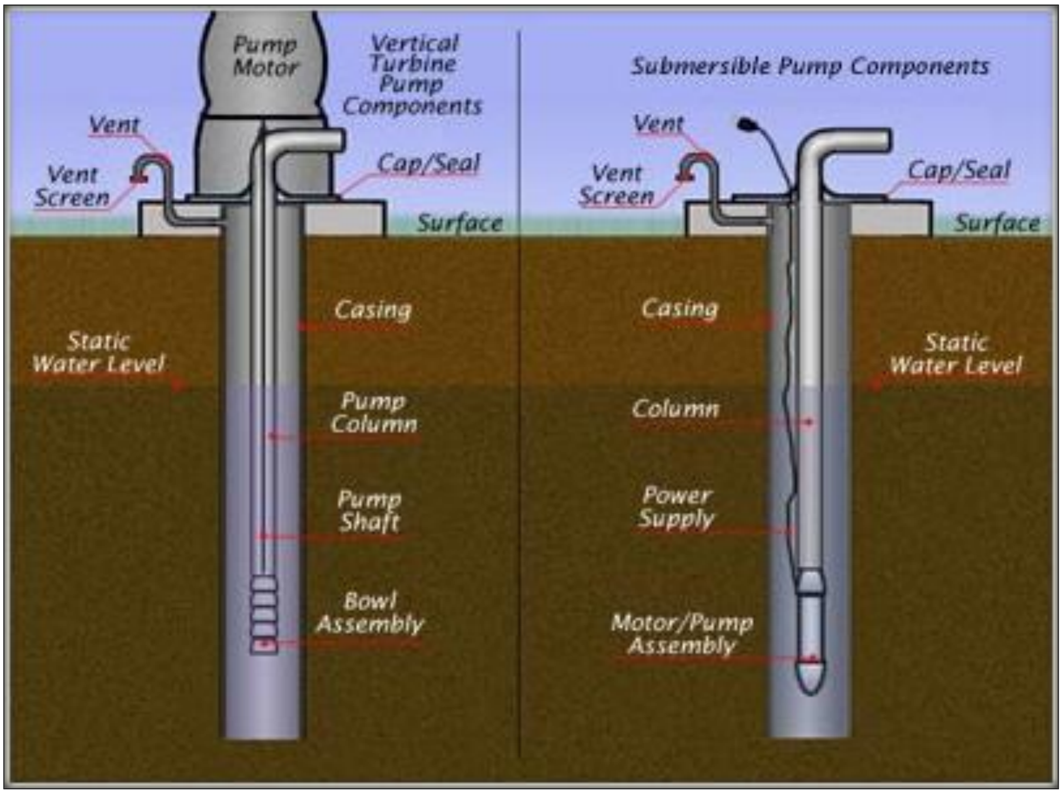
Chapter Three
Water Pumping System

3.1 Introduction to Water Pumping System

Pumps are devices used to transfer liquids from low-pressure zones to high-pressure zones, or to move it from a low elevation into a higher elevation. Pumps are also used to accelerate liquids through pipes. illustrated that without using a pump in this system, the liquid would move in the opposite direction because of the difference of pressure [15].

The Pumping system components is motor- pump, control system, discharge assembly and storage tank.

Two common well construction methods as shown in figure 3.1): On the left is an example of a **vertical turbine** type pump installation and on the right is an example of a **submersible** type pump installation [1].



Figure(3.1): Type of pumps used in ground water well.

3.2 Types of Pumps

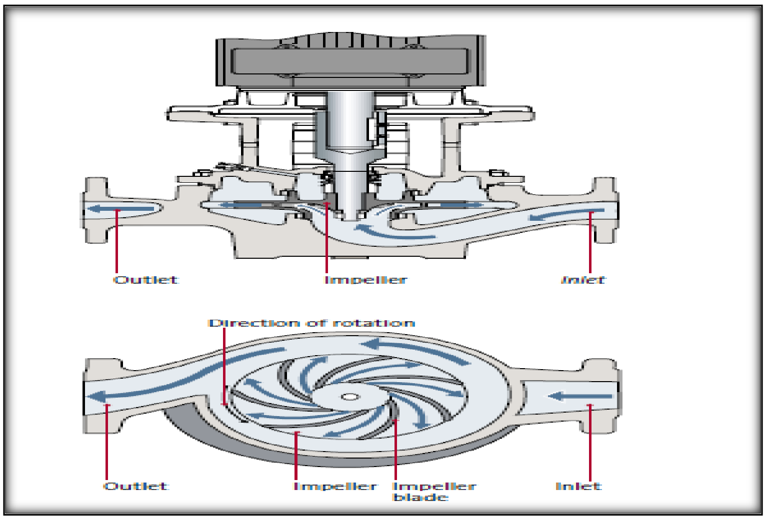
Pumps come in a variety of sizes for a wide range of applications. They can be classified according to their basic operating principle as dynamic or displacement pumps. Dynamic pumps can be sub-classified as centrifugal and special effect pumps. Displacement pumps can be sub-classified as rotary or reciprocating pumps [13].

In general, any liquid can be handled by any of the pump designs. Where different pump designs could be used depending on Performance evaluation, efficient system operation, flow control strategies and energy conservation opportunities.

The centrifugal pump is generally the most economical then followed by rotary pump and reciprocating pumps from economical performance. Although, positive displacement pumps are generally more efficient than centrifugal pumps, the benefit of higher efficiency tends to be offset by increased maintenance costs [14].

3.2.1 Centrifugal Pumps

A centrifugal pump is a very simple design as shown in figure (3.2). The two main parts of the pump are the impeller and the diffuser. Impeller, which is the only moving part, is attached to a shaft and driven by a motor. Impellers are generally made of bronze, polycarbonate, cast iron, stainless steel as well as other materials. The diffuser (also called as volute) Houses the impeller and captures and directs the water off the impeller [5].



Figure(3.2): Hydraulic components of centrifugal pump [5].

Water enters the center (eye) of the impeller and exits the impeller with the help of centrifugal force. As water leaves the eye of the impeller a low-pressure area is created, causing more water to flow into the eye. Atmospheric pressure and centrifugal force cause this to happen. Velocity is developed as the water flows through the impeller spinning at high speed. The water velocity is collected by the diffuser and converted to pressure by specially designed passageways that direct the flow to the discharge of the pump, or to the next impeller that the pump should have a multi-stage configuration [5].

The pressure (head) that a pump will develop is indirect relationship to the impeller diameter, the number of impellers, the size of impeller eye and shaft speed. Capacity is determined by the exit water width of the impeller. The head and capacity are the main factors, which affect the horsepower size of the motor to be used. The more quantity of water to be pumped, the more energy is required.

A centrifugal pump is not positive acting; it will not always pump the same volume. Also, when it pumps against increasing pressure, the less it will pump. For these reasons it is important to select a centrifugal pump that is designed to do a particular job.

3.2.2 Positive Displacement Water Pumps:

Positive displacement designs deliver a fixed amount of flow through the mechanical contraction and expansion of a flexible diaphragm. Liquid flows into the pump as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity collapses. The volume is constant through each cycle of operation.

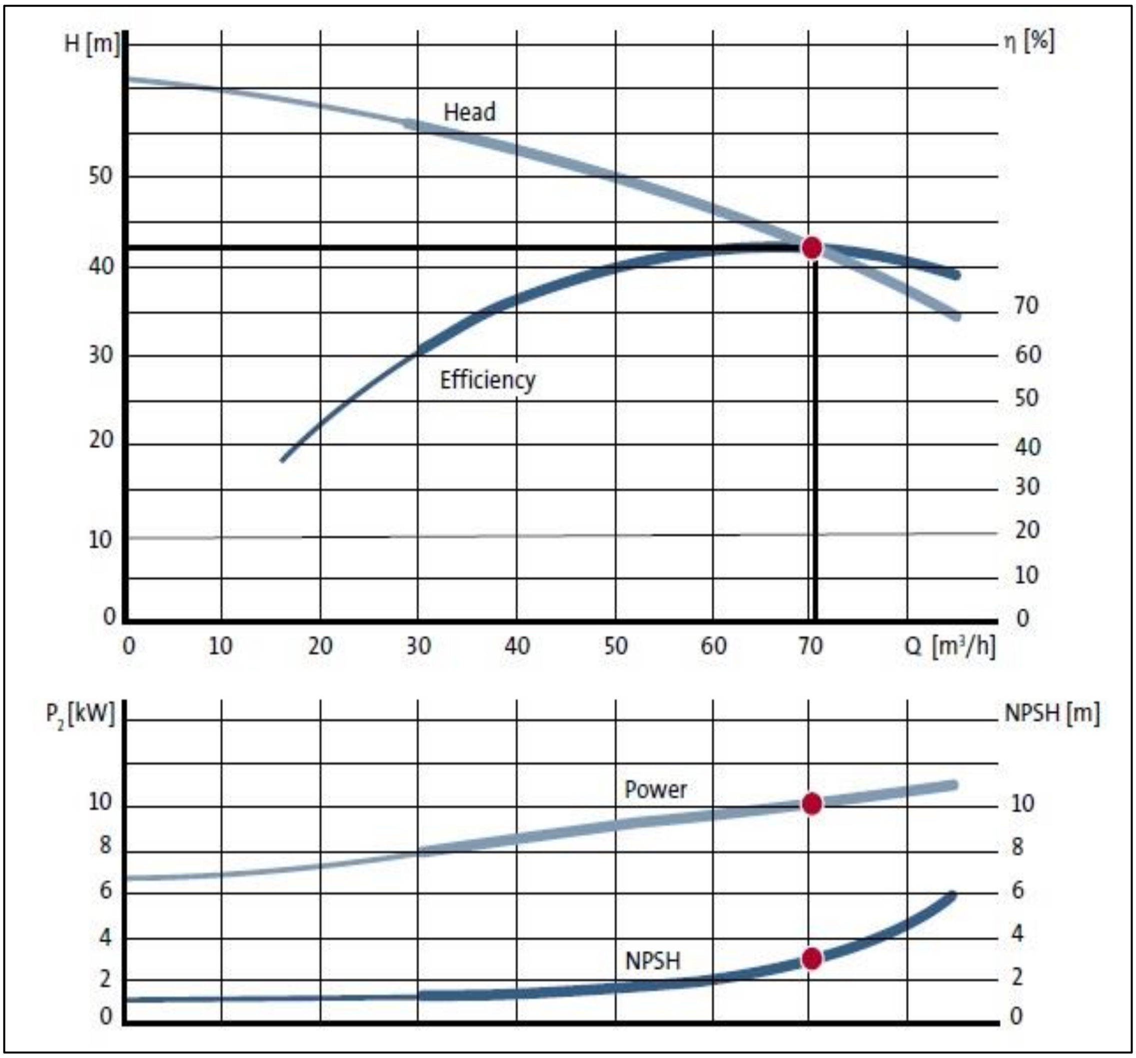
Positive displacement water pumps advantages and disadvantages:

Positive displacement water pumps or rotary pumps are very efficient, due to the fact that they remove air from the lines, thus eliminating the need to bleed the air from the lines. In addition these pumps are great when dealing with high viscosity liquids.

On the other hand, these pumps require that the clearance between the rotating pump and the outer edge must be very close. This causes that the rotation occurs at very slow speeds; otherwise if the pump is operated at higher speed, the liquids might erode and will eventually reduce the efficiency of the water pump [15].

3.2.3 Typical Performance Curve of Centrifugal Pump

The standard convention of centrifugal pump is to draw the pump performance curves showing Flow on the horizontal axis and Head generated on the vertical axis. Efficiency, Power & NPSH" is a term describing conditions related to cavitations, " are conventionally shown on the vertical axis, plotted against Flow, as illustrated in figure (3.3) [5].



Figure(3.3): Typical performance curves for a centrifugal pump [5].

3.2.3.1 Head Calculation

A pump curve (HQ curve) shows the head (H) as a function of the flow (Q). The flow (Q) is the rate of fluid going through the pump. The flow is generally stated in cubic meter per hour [m3/h] but at insertion into formulas cubic meter per Second [m3/s] is used.

In most cases the differential pressure across the pump is measured and the head H is calculated by the following formula:

$$H = \frac{\Delta P_{tot}}{\rho . g} \tag{3.1}$$

H: head of pump [m]

ΔP_{tot}: Total pressure difference across the pump [Pa]

ρ: Density of liquid, for water ρ= 1000 kg/m^3

g : Standard gravity acceleration, 9.80665 m/s^2

3.2.3.2 Power Consumption

The power curves shown in (3.4) show the energy transfer rate as a function of flow, the power is given in Watt [W]. Distinction is made between three kinds of power:

- Supplied power from external electricity source to the motor and controller (P_1)
- Shaft power transferred from the motor to the shaft (P_2)
- Hydraulic power transferred from the impeller to the fluid ($P_{\mathbf{hyd}}$).

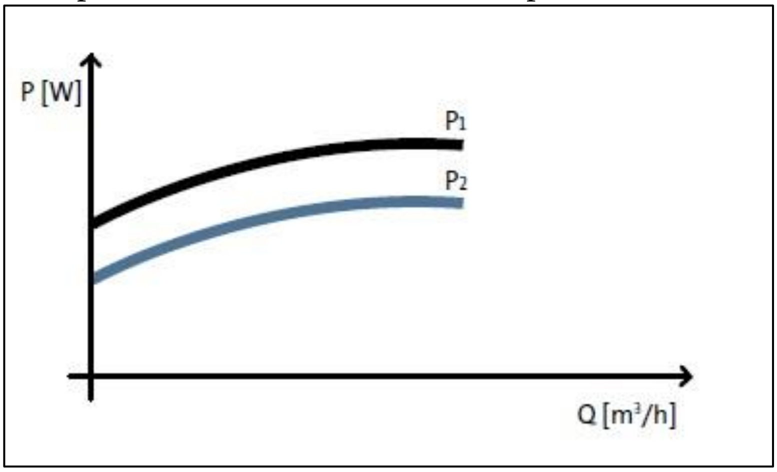


Figure (3.4): P1 and P2 power curves.

The total efficiency (η_{tot}) is the ratio between hydraulic power and supplied power. figure (3.2.3) shows the efficiency curves for the pump (η_{hyd}) and for a complete pump unit with motor and controller (η_{tot}).

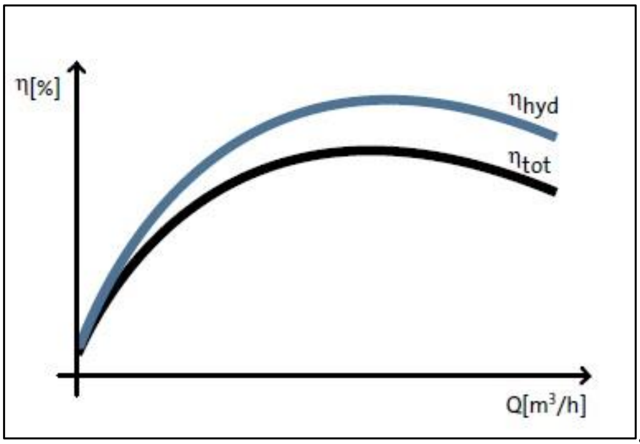


Figure (3.2.3): Efficiency curves for the pump (ηhyd) and complete pump unit with motor and controller ($\eta\ tot$).

3.2.3.3 Efficiency Calculation Of Centrifugal Pump

The hydraulic efficiency refers to P2, whereas the total efficiency refers to P1:

$$\eta_{\mathbf{hyd}} = \frac{P_{hyd}}{P_2}\ .[100\ \%] \tag{3.2}$$

$$\eta_{\mathbf{hyd}} = \frac{P_{hyd}}{P_1}\ .[100\ \%] \tag{3.3}$$

$P1 < P2 < \mathrm{P}_{\mathbf{hyd}}$

The efficiency is always below 100% since the supplied power is always larger than the hydraulic power due to losses in controller, motor and pump components. The total efficiency for the entire pump unit (controller, motor and hydraulics) is the product of the individual efficiencies [17]:

$$\eta_{\mathbf{tot}} = \eta_{\mathbf{hyd}} . \eta_{\mathbf{motor}} . \eta_{\mathbf{controller}} . [100\ \%] \tag{3.4}$$

3.2.3.4 NPSH Definition

NPSH is a term describing conditions related to cavitations, which is undesired and harmful. Cavitations are the creation of vapor bubbles in areas where the pressure locally drops to the fluid vapor pressure. The extent of cavitations depends on how low the pressure is in the pump. Cavitations generally lowers the head and causes noise and vibration.

Cavitations first occur at the point in the pump where the pressure is lowest, which is most often at the blade edge at the impeller inlet, as shown in figure (3.6)

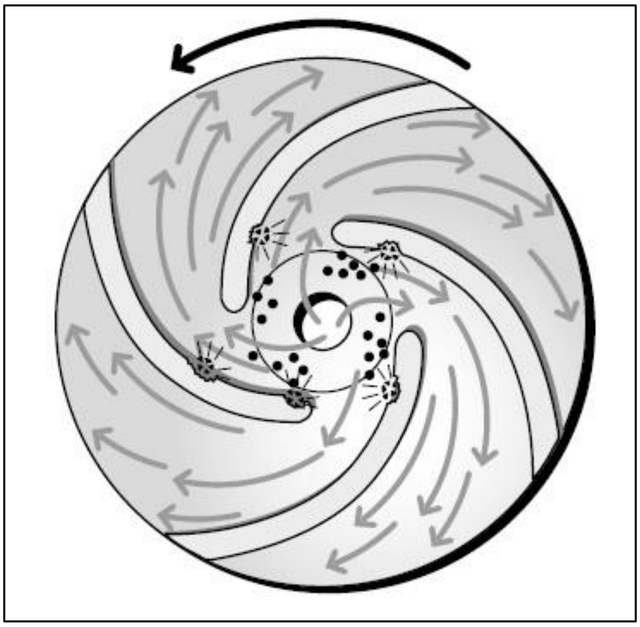


Figure (3.2.3): Cavitations on impeller.

$$NPSH = \frac{P_{abs,tot,in} - P_{vapor}}{\rho . g} \; [m \qquad (3.5)$$

P_{vapor} : The vapor pressure of the fluid at the present temperature [Pa].

$P_{abs,\,tot,\,in}$: The absolute pressure at the inlet flange [Pa].

3.3 Pump Affinity Relationships

The pump affinity laws allow the prediction of centrifugal pump performance give changes to the speed of the pump or the diameter of impeller. This article presents the pump affinity laws for reference.

The pump affinity laws can be used to predict the performance of a centrifugal pump as two variables change, the pump shaft rotational speed and the pump impeller diameter. They are useful particularly for the modification of existing pumps to meet a new service. These relationships are approximate and rely on the assumption that the pump efficiency is equal at both speeds/diameters. The prediction of performance based on impeller diameter changes also relies on the assumption that the impellers are geometrically similar. In all experiments in this thesis the impeller diameter constant, but the change just happened in speed of pump

The effect on pump performance for a given change in pump shaft rotational speed can be estimated from the relationships shown in table (3.1):

Table (3.1): pump performance for a given change in pump shaft rotational speed

Property	Relationship
Flow Rate	$Q_2/Q_1=(N_2/N_1)$
Head	$h_2/h_1=(N_2/N_1)^2$
Power	$P_2/P_1=(N_2N_1)^3$

Where:

Q: Volumetric flow rate**.**

N: Pump shaft rotational speed.

h :Pump head.

P :Hydraulic out power .

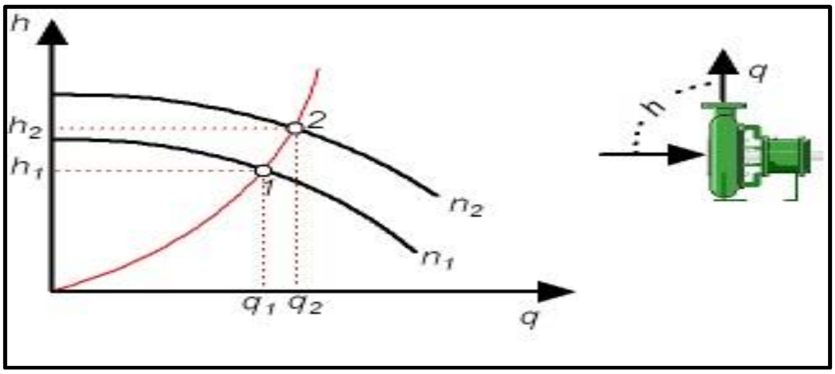


Figure (3.7): change in pump characteristic through changing the wheel velocity.

3.4 Component of Pumping Systems

The component of pumping system shown in figure

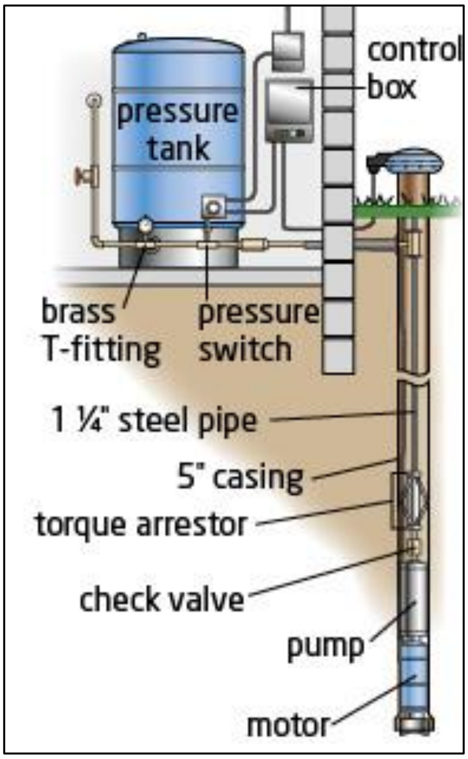


Figure (3.8): Pumping System**.**

3.4.1 Pump

A pump’s main function is to bring water from a well or lake to an irrigation system. Pumps can be used to increase water pressure when the provided pressure isn't high enough. Pumps are generally used in systems that have elevation extremes and systems that are located in areas that provide water at low pressures [18].

3.4.2 Motor

A pump draws and expels water using its intake and discharge line. A shaft connects the motor to the pump blades or impellor. The motor turns the impellor creating a vacuum or low pressure zone. A vacuum is achieved when there is zero pressure. Most pumps don't create a true vacuum, but create a zone with pressure that is lower than air pressure.

3.4.3 Control Box

The control panel includes internal plug-in type Run and Stop Relays to control the operation of the pump. An adjustable Timing Relay monitors the operation of the system and automatically shuts down the pump if the pump does not build pressure or the valve fails to open. Transformer is used to provide safe indication. The RUN, OPEN, and CLOSE lights indicate valve and pump operation. The STOP light indicates that an alarm condition exists and the pump is locked out. Once the alarm condition is resolved, the RESET button is pressed to activate the system. An EMERGENCY STOP button provided to stop the pump at the valve location. When the button is pressed, the valve closes at the normal rate, and automatically shuts off the pump when the closed limit switch is tripped [19].

3.4.4 Pressure Tank

The functions of a pressure tank are to protect and prolong the life of the pump by preventing rapid cycling of the pump motor, provide water under pressure for delivery between pump cycles; and provide additional water storage under pressure to assist the pump in meeting the total demands of a system if the pump or well is incapable of supplying the required capacity [20].

Chapter Four

Practical Experiments on Pump Systems

4.1 Types of Tested Water Pumps

Two vertical wells conducted to practical test the first one Agricultural irrigation company well that use VFD drive ,the second one Mr. Abu Saleh ground water well that use soft starter to drive the pump motor.

4.1.1 Abu Saleh groundwater well pump

The pump of the well is a vertical turbine manufactured by National Pump Company has a serial number " CVJ8XH4P6CY" table (4.1) show all technical data for pump.

Table (4.1): Abu Saleh vertical pump, technical data [21] .

Property	Design value	Property	Design value
Flow rate (Q)	120 m^3 /h	pressure	3262 kpa g
Head (H)	120 m	Sphere size	15mm
Speed	1475 rpm	Eye area	8264 mm^2
Synch speed	1500 rpm	Power of motor	55 kW
Diameter	6.6 in	Atm pressure	101.4 kPa
Specific speed	nq: 87 ,S : 122	Vapor pressure	1.773 kPa
Temperature limit	82.2^0	Density of fluid	997.2 kg/m^3

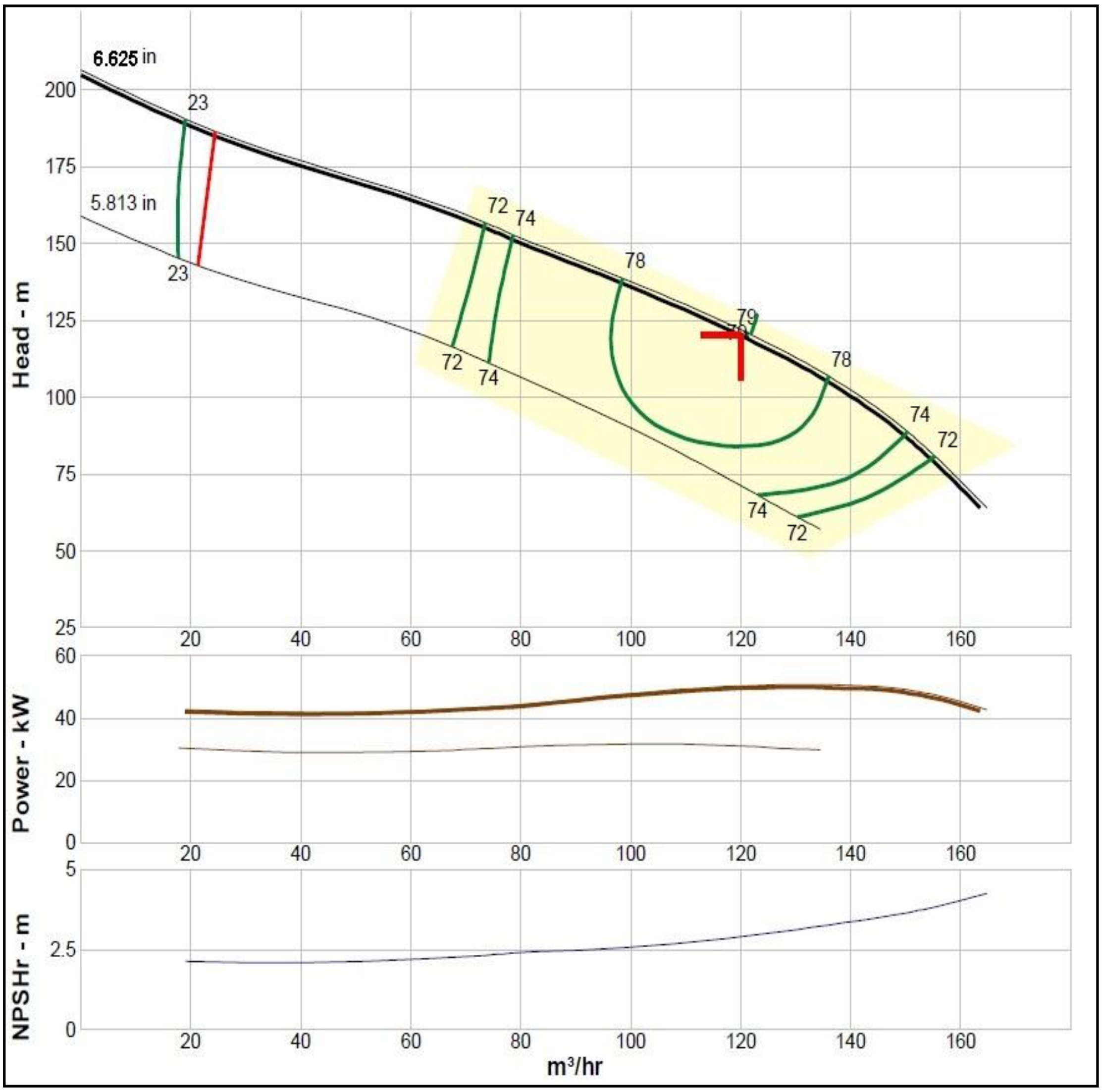


Figure (4.1): Design Curve of Abu Saleh well pumps [21].

From the previous figure at maximum flow 120 m^3 /h and maximum head 120 m, we can calculate Efficiency from curve about 79% , Power 49.5 kW ,NPSH r 2.92 m .

Table (4.2) : Performance evaluation of Abu Saleh well pump test by manufacturer [21].

Flow (m^3 /h)	Speed (rpm)	Head (m)	Efficiency (%)	Power(kW)	NPSH
144	1475	94.7	76	48.8	3.49
120	1475	120	79	49.5	2.92
96	1475	139	78	46.6	2.54
72	1475	156	71	43	2.32
48	1475	171	49	42.6	2.23

Sample of calculation :

$$\eta = \frac{\text{Phyd}}{Pin} \times 100\ \% \qquad (4.1)$$

$$P_{hyd} = 2.75 \times \text{Q} \times \text{H} \qquad (4.2)$$

$$\eta = \frac{2.725 \times \text{Q} \times \text{H}}{Pin} \times 100\% \qquad (4.3)$$

At flow rate = 120 m^3 /h ,head= 120 m :

$$\eta = \frac{2.725 \times 120 \times 120}{49500} \times 100\% = 79.27\%$$

$$2.275 = \frac{\rho \times g}{3.6 \times 10^3} = \frac{1000 \times 9.81}{3.6 \times 10^3} \qquad (4.4)$$

η : Efficiency of pump

P_{hyd} :Hydraulic power(Watt)

P_{in} :Input power of the pump (Watt)

ρ : density of fluid , for water 1000(kg/m^3)

g :gravity (9.81 m/s^2)

3.6×10^3 : convert power to w , hour = 60 s $\times$ 60 m= 3.6×10^3

4.1.2 Agricultural irrigation company Ground Water Well Pump

The pump of the well is a vertical turbine manufactured by National Pump Company has a serial number " CVE12M4P6CY" , with 9 stage's Table (4.2) show all technical data for pump.

Table (4.3) : Agricultural irrigation company vertical pump ,technical data [21].

Property	Design value	Property	Design value
Flow rate (Q)	213 m^3/h	pressure	2600 kpa g
Head (H)	128 m	Sphere size	16mm
Speed	1450 rpm	Eye area	9077 mm^2
Synch speed	1500 rpm	Power of motor	111 kW
Diameter	9.75 in	Atm pressure	101.4 kPa
Specific speed	nq:49 S : 46	Vapor pressure	2.339 kPa
Temperature limit	82.2^0	Density of fluid	997.2 kg/m^3

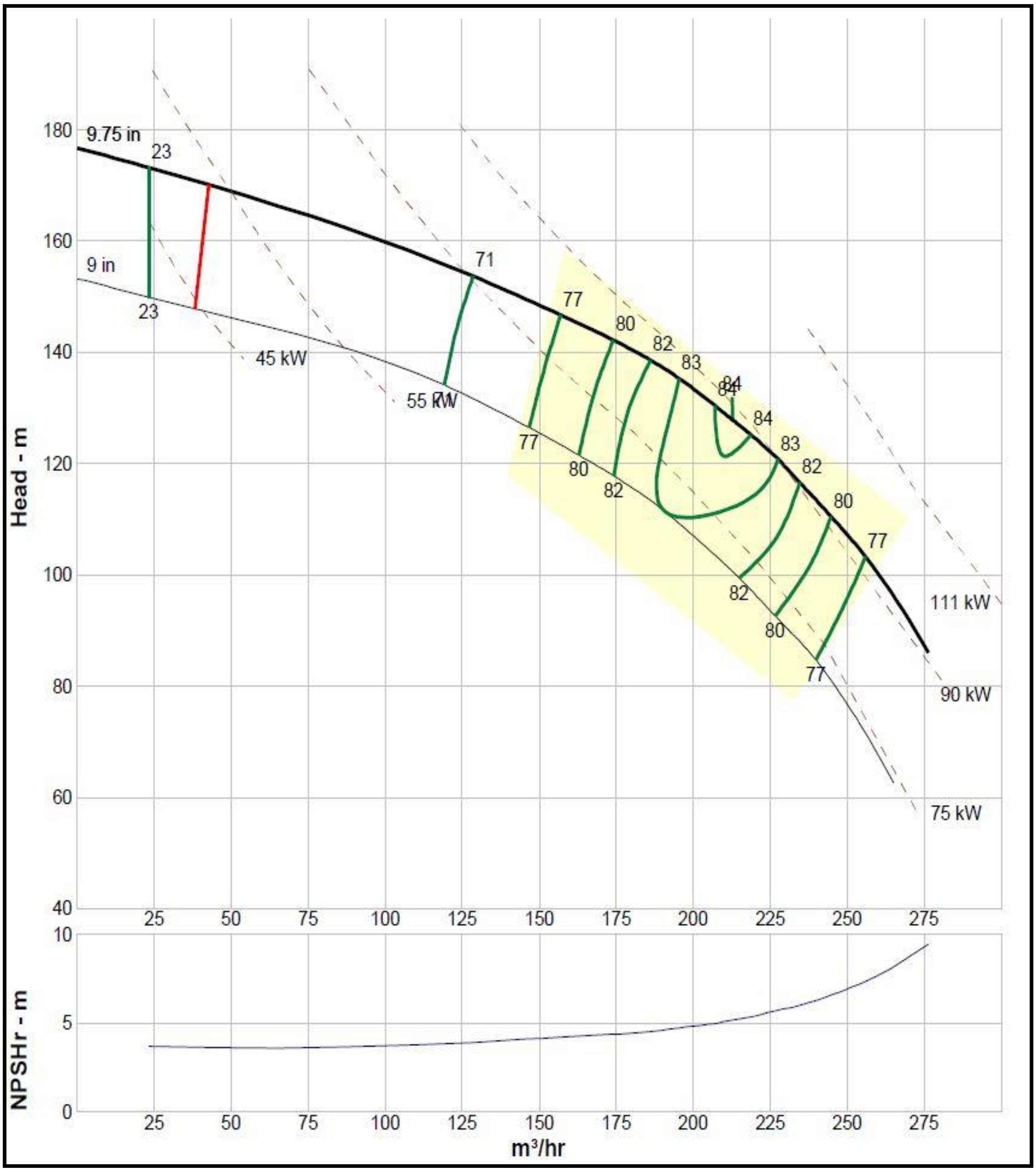


Figure (4.2) : Design curve of Agricultural Irrigation Company pump [21].

From the previous figure at maximum flow 213 m^3 /h and maximum head 128 m , we can calculate Efficiency from curve about 84% , Power 88kW ,NPSH r 5.19m.

Table (4.4) : Performance evaluation of irrigation company pump [21].

Flow (m^3 /h)	Speed (rpm)	Head (m)	Efficiency (%)	Power (kW)	NPSH
265	1475	95.5	74.3	92.2	8.3
221	1475	124	83.7	89	5.47
177	1475	141	80.5	84.5	42.24
133	1475	153	72	76.5	3.97
88.4	1475	161	52.7	65	3.84

Sample of calculation :

$$\eta = \frac{\text{Phyd}}{Pin} \times 100\ \%$$

$P_{hyd} = 2.75 \times \text{Q} \times \text{H}$

$$\eta = \frac{2.725 \times \text{Q} \times \text{H}}{Pin} \times 100\%$$

At flow rate = 221 m^3 /h ,head= 124 m :

$$\eta = \frac{2.725 \times 221 \times 124}{89000} \times 100\% = 83.96\%$$

$$2.275 = \frac{\rho \times g}{3.6 \times 10^3} = \frac{1000 \times 9.81}{3.6 \times 10^3}$$

4.1.3 Waleed Ribhi groundwater well pump

The pump of well is vertical turbine manufactured by National Pump Company has a serial number " CVJ8XH4P6CY" table (4.5) show all technical data for pump.

Table (4.5) :Waleed Ribhi vertical pump ,technical data [21].

Property	Design value	Property	Design value
Flow rate (Q)	120 m^3 /h	pressure	3262 kpa g
Head (H)	120 m	Sphere size	15mm
Speed	1475 rpm	Eye area	8264 mm^2
Synch speed	1500 rpm	Power of motor	55 kW
Diameter	6.6 in	Atm pressure	101.4 kPa
Specific speed	nq: 87 ,S : 122	Vapor pressure	1.773 kPa
Temperature limit	82.2^0	Density of fluid	997.2 kg/m³

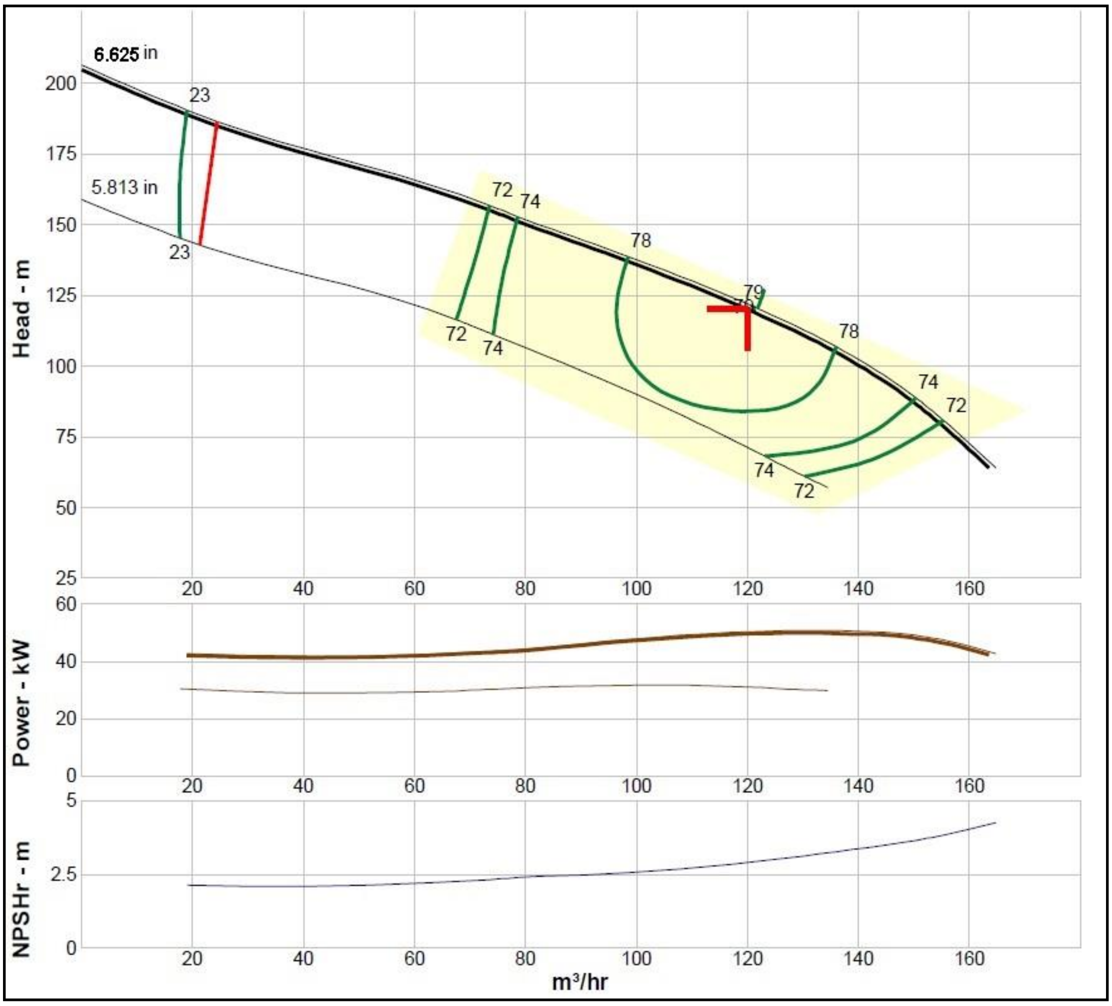


Figure (4.3) : Design Curve of Waleed Ribhi well pump [21].

From the previous figure at maximum flow 120 m^3 /h and maximum head 120 m , we can calculate Efficiency from curve about 79% , Power 49.5 kW ,NPSH r 2.92 m .

Table (4.6) : Performance evaluation of Waleed Ribhi well pump test by manufacturer [21].

Flow (m^3 /h)	Speed (rpm)	Head (m)	Efficiency (%)	Power(kW)	NPSH
144	1475	94.7	76	48.8	3.49
120	1475	120	79	49.5	2.92
96	1475	139	78	46.6	2.54
72	1475	156	71	43	2.32
48	1475	171	49	42.6	2.23

Sample of calculation :

$$\eta = \frac{\text{Phyd}}{Pin} \times 100\ \%$$

$P_{hyd} = 2.75 \times \text{Q} \times \text{H}$

$$\eta = \frac{2.725 \times \text{Q} \times \text{H}}{Pin} \times 100\%$$

At flow rate = 120 m^3 /h ,head= 120 m :

$$\eta = \frac{2.725 \times 120 \times 120}{49500} \times 100\% = 79.27\%$$

$$2.275 = \frac{\rho \times g}{3.6 \times 10^3} = \frac{1000 \times 9.81}{3.6 \times 10^3}$$

Chapter Five

Induction Motor

5.1 Characteristic of Induction Motors

Induction motors are the most used in industry since they are rugged, inexpensive, and are maintenance free. It is estimated that more than 50% of the world electric energy generated is consumed by electric machines. Improving efficiency in electric drives is important, mainly for economic saving and reduction of environmental pollution [23,24]. Induction motors have a high efficiency at rated speed and torque. However, at light loads, motor efficiency decreases dramatically due to an imbalance between the copper and the core losses. Hence, energy saving can be achieved by proper selection of the flux level in the motor [25,26].

The induction motor is classified into a single-phase motor and a three-phase motor according to the using power source. This motor always uses both auxiliary winding and condenser not only when starting but also during operation. Generally speaking, its starting torque is not so great, but its structure is simple and

reliable. In addition, its connection is simple. It is suitable to use in houses and on factories. For a single-phase induction motor, be sure that the condenser indicated in the name plate should comply with the capacity of the motor [27].

The three-phase induction motor has simpler connection, and higher efficiency and reliability than the single-phase motor, because it can be driven by a three-phase power source directly. The three-phase motor is popular as a general-purpose motor. The power source for a three-phase motor includes (220V 50/60Hz), (380V 50/60Hz), (440V50/60Hz). Refer to Figure (5.1) [27].

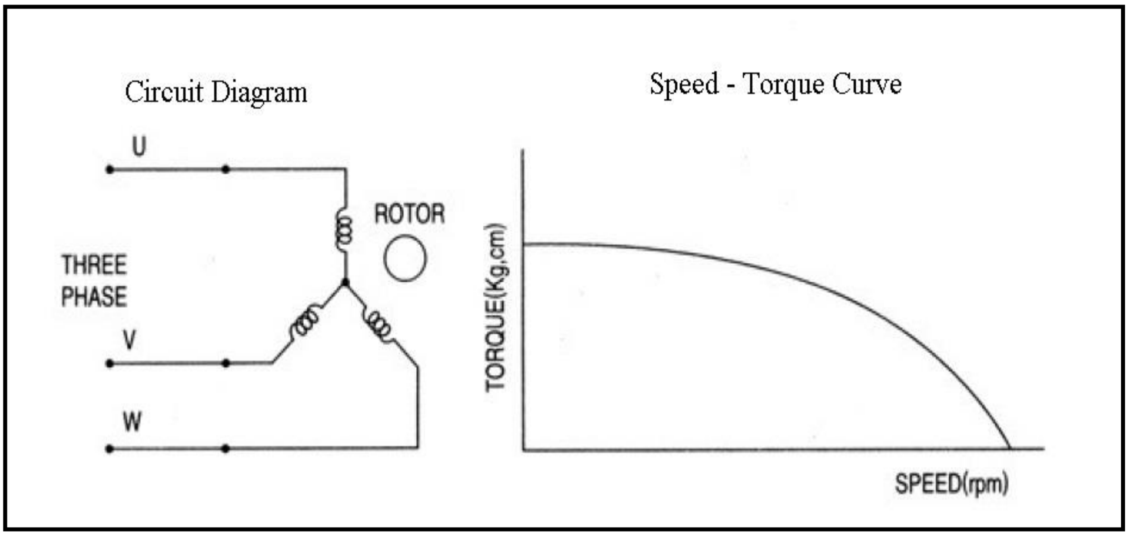


Figure (5.1) : Speed – Torque curve for induction motor [27].

Almost 90% of the three-phase AC Induction motors are of this type. Here, the rotor is of the squirrel cage type and it works as explained earlier. The power ratings range from one-third to several hundred horse-power in the three-phase motors. Motors of this type , rated one horsepower or larger, cost less and can start heavier loads than their single-phase counterparts [28].

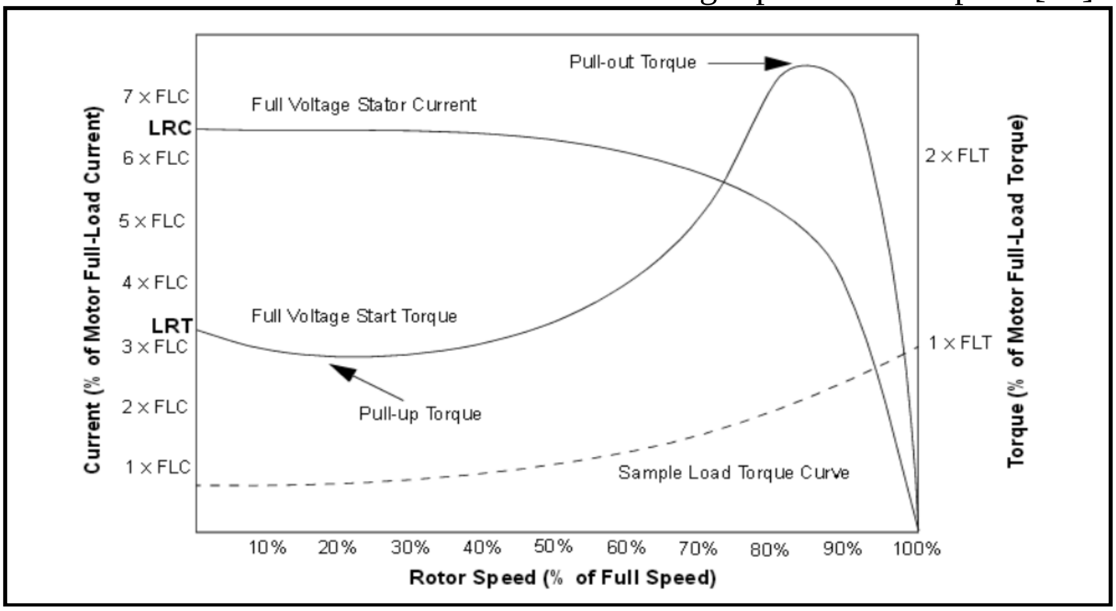


Figure (5.2) :Typical Torque-Speed curve of 3-PHASE AC Induction motor [28].

5.1.1 Starting Characteristic

Induction motors, at rest, appear just like a short circuited transformer and if connected to the full supply voltage, draw a very high current known as the “Locked Rotor Current.” They also produce torque which is known as the “Locked Rotor Torque”. The Locked Rotor Torque (LRT) and the Locked Rotor Current (LRC) are a function of the terminal voltage of the motor and the motor design. As the motor accelerates, both the torque and the current tend to alter with rotor speed if the voltage is maintained constant.

The starting current of a motor with a fixed voltage will drop very slowly as the motor accelerates and will only begin to fall significantly when the motor has reached at least 80% of the full speed. The actual curves for the induction motors can vary considerably between designs but the general trend is for a high current until the motor has almost reached full speed. The LRC of a motor can range from 500% of Full-Load Current (FLC) to as high as 1400% of FLC. Typically, good motors fall in the range of 550% to 750% of FLC.

The starting torque of an induction motor starting with a fixed voltage will drop a little to the minimum torque, known as the pull-up torque, as the motor accelerates and then rises to a maximum torque, known as the breakdown or pull-out torque, at almost full speed and then drop to zero at the synchronous speed. The curve of the start torque against the rotor speed is dependent on the terminal voltage and the rotor design.

The LRT of an induction motor can vary from as low as 60% of FLT to as high as 350% of FLT. The pull-up torque can be as low as 40% of FLT and the breakdown torque can be as high as 350% of FLT. Typically, LRTs for medium to large motors are in the order of 120% of FLT to 280% of FLT. The PF of the motor at start is typically 0.1-0.25, rising to a maximum as the motor accelerates and then falling again as the motor approaches full speed [28].

5.1.2 Running Characteristic

Once the motor is up to speed, it operates at a low slip, at a speed determined by the number of the stator poles. Typically, the full-load slip for the squirrel cage induction motor is less than 5%. The actual full-load slip of a particular motor is dependent on the motor design. The typical base speed of the four pole induction motor varies between 1420 and 1480 RPM at 50 Hz, while the synchronous speed is 1500 RPM at 50 Hz. The current drawn by the induction motor has two components: reactive component (magnetizing current) and active component (working current). The magnetizing current is independent of the load but is dependent on the design of the stator and the stator voltage. The actual magnetizing current of the induction motor can vary, from as low as 20% of FLC for the large two pole machine, to as high as 60% for the small eight pole machine. The working current of the motor is directly proportional to the load.

The tendency for the large machines and high-speed machines is to exhibit a low magnetizing current, while for the low-speed machines and small machines the tendency is to exhibit a high magnetizing current. A typical medium sized four pole machine has a magnetizing current of about 33% of FLC. A low magnetizing current indicates a low iron loss, while a high magnetizing current indicates an increase in iron loss and a resultant reduction in the operating efficiency. Typically, the operating efficiency of the induction motor is highest at 3/4 load and varies from less than 60% for small low-speed motors to greater than 92% for large high-speed motors. The operating PF and efficiencies are generally quoted on the motor data sheets.

5.1.3 Load Characteristic

In real applications, various kinds of loads exist with different torque-speed curves. For example, Constant Torque, Variable Speed Load (screw compressors, conveyors, feeders), Variable Torque, Variable Speed Load (fan, pump), Constant Power Load (traction drives), Constant Power, Constant Torque Load (coiler drive) and High Starting/Breakaway Torque followed by Constant Torque Load (extruders, screw pumps).The motor load system is said to be stable when the developed motor torque is equal to the load torque requirement. The motor will operate in a steady state at a fixed speed. The response of the motor to any disturbance gives us an idea about the stability of the motor load system. This concept helps us in quickly evaluating the selection of a motor for driving a particular load.

In most drives, the electrical time constant of the motor is negligible as compared to its mechanical time constant. Therefore, during transient operation, the motor can be assumed to be in an electrical equilibrium, implying that the steady state torque-speed curve is also applicable to the transient operation. As an example, figure (5.3) shows torque-speed curves of the motor with two different loads. The system can be termed as stable, when the operation will be restored after a small departure from it, due to a disturbance in the motor or load. For example, disturbance causes a reduction of $\Delta\omega_{m\mathrm{in}}$ speed. In the first case, at a new speed, the motor torque (T) is greater than the load torque (T_l). Consequently, the motor will accelerate and the operation will be restored to X. Similarly, an increase of $\Delta\omega_{min}$ the speed, caused by a disturbance, will make the load torque (T_l) greater than the motor torque (T), resulting in a deceleration and restoration of the point of operation to X. Hence, at point X, the system is stable. In the second case, a decrease in the speed causes the load torque (T_l) to become greater than the motor torque (T), the drive decelerates and the operating point moves away from Y. Similarly, an increase in the speed will make the motor torque (T) greater than the load torque (T_l), which will move the operating point further away from Y. Thus, at point Y, the system is unstable.

This shows that, while in the first case, the motor selection for driving the given load is the right one; in the second case, the selected motor is not the right choice and requires changing for driving the given load. The typical existing loads with their torque-speed curves are described in the following sections.

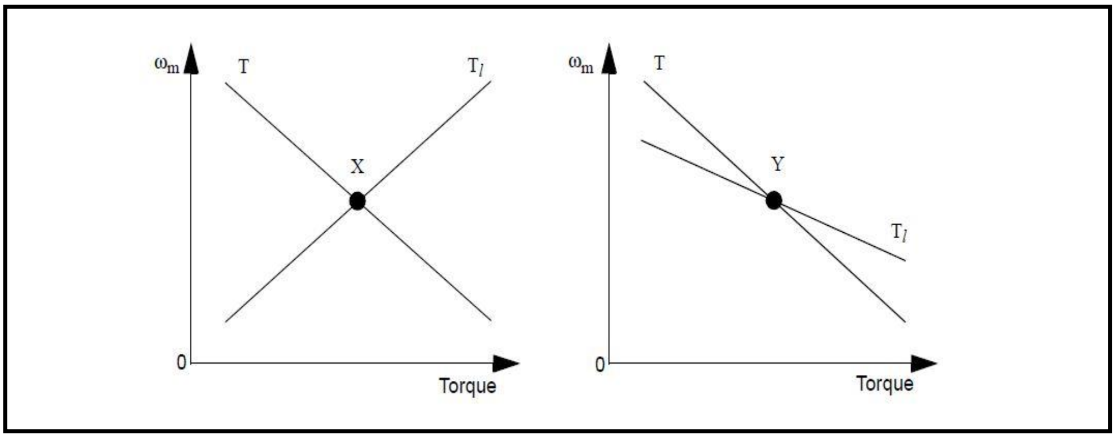


Figure (5.3) :Torque-Seed Curve – Same Motor with two different loads [28].

5.1.4 Effects of Torque on the Characteristics of Induction Motor

- **Constant Torque with Variable Speed operation**

The torque required by this type of load is constant regardless of the speed. In contrast, the power is linearly proportional to the speed. Equipment, such as screw compressors, conveyors and feeders, have this type of characteristic.

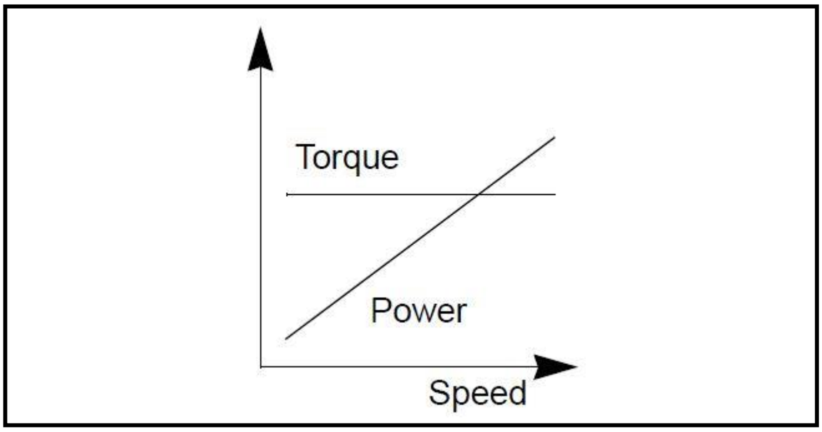


Figure (5.4) :Constant Torque, Variable Speed Loads [28].

- **Variable Torque and Variable Speed**

This is most commonly found in the industry and sometimes is known as a quadratic torque load. The torque is the square of the speed, while the power is the cube of the speed. This is the typical torque-speed characteristic of a fan or pump.

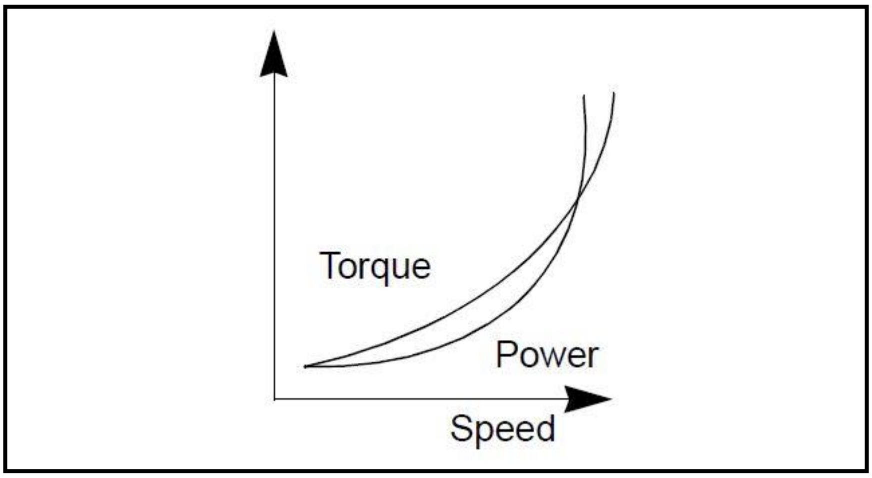


Figure (5.5) : Variable Torque, Variable Speed Loads [28].

- **Constant Power Loads**

This type of load is rare but is sometimes found in the industry. The power remains constant while the torque varies. The torque is inversely proportional to the speed, which theoretically means infinite torque at zero speed and zero torque at infinite speed. In practice, there is always a finite value to the breakaway torque required. This type of load is characteristic of the traction drives, which requires high torque at low speeds for the initial acceleration and then a much reduced torque when at running speed.

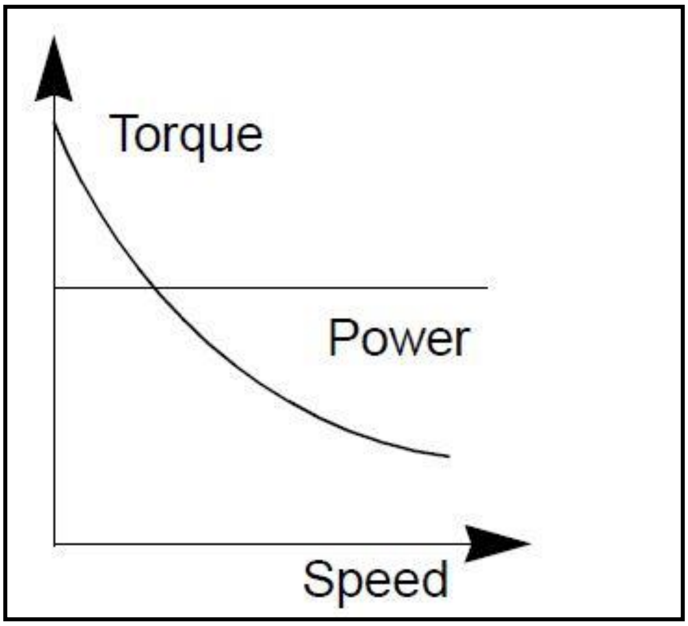


Figure (5.6) : Constant Power Loads[28].

- **Constant Power, Constant Torque Loads**

This is common in the paper industry. In this type of load, as speed increases, the torque is constant with the power linearly increasing. When the torque starts to decrease, the power then remains constant.

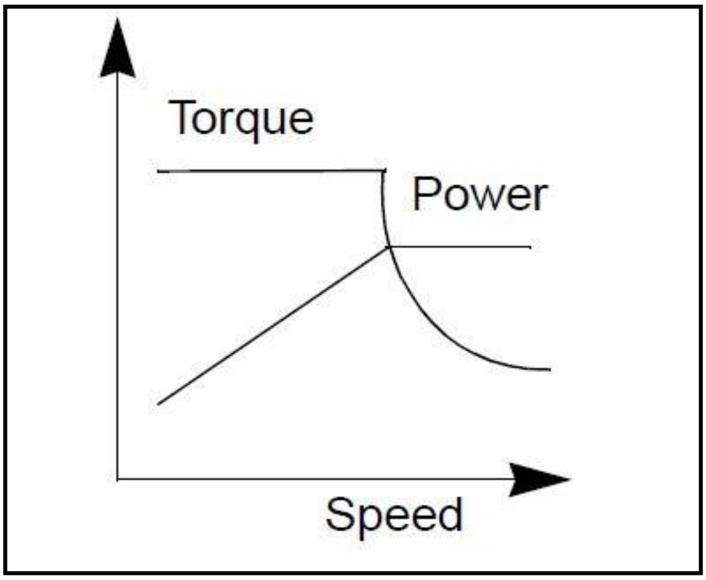


Figure (5.7) : Constant Power& Constant Torque Loads [28]**.**

5.2 Starting Method

It is well understood that induction motors draw higher currents during their starting operations than is the case under full load running conditions. Since the early days of induction motor availability, starting methods other than Direct-on-Line have been used, and in some cases mandated by Utilities, to reduce the effect of these high starting currents on the electrical distribution network. What is generally not recognized is the existence of short duration inrush currents that greatly exceed these starting currents. Furthermore, the introduction of complex starting methods to reduce starting currents is often compromised by other unanticipated inrush currents introduced by the starting system itself, unless special precautions are taken [29].

This thesis discusses the financial analysis of using variable frequency convertor for driving electrical water pumps compared with fixed frequency, so will focus particularly in two starting methods variable frequency drive and soft starter.

In general, there are five basic methods of starting induction motors. These include

i. Direct - on - Line (DOL) starting.
ii. Star - Delta or WYE - Delta starting.
iii. Autotransformer starting.
iv. Variable frequency converter.
v. Soft starting.

Except for DOL starting, the prime objective of these alternative starting methods is to reduce the supply voltage to the motor, with the express purpose of reducing the inrush currents that occur during the starting operation. Reducing the supply voltage is an extremely effective way of reducing inrush currents, since the starting currents are directly proportional to the supply voltage. Unfortunately, as a consequence, the starting torque is reduced by the SQUARE of the supply voltage, so that this limitation needs serious consideration when choosing a method of starting induction motors [29].

5.2.1 Soft Starter (SS)

Soft starters are devices that use silicon-controlled rectifiers (SCRs) for providing a low voltage to the motor from a grid voltage and fixed frequency. The value of the voltage applied to the motor can be varied over a wide range, from very small values up to the value of the grid by controlling the firing angle of the SCRs.

The consequences of this reduction in the value of the applied voltage are the decrease in electric current drawn from the grid and the reduction of the torque developed during the process of starting or stopping. figure (5.8) shows a basic schematic diagram of a soft starter with anti-parallel SCRs and the feedback from current and voltage. The interface circuit is responsible for acquiring and processing measured voltage and current signals, which are processed digitally by the control program. The command signals from the digital processing are then sent by control to a firing circuit, responsible for driving the SCRs and consequently, the induction motor [30].

Soft start devices provide two major benefits in their application[31]:

- Less stress on the motor mechanically coupled to the load due to the reduced amplitude of the pulse of the starting torque motor;
- Smoothing the motor acceleration and reducing the demand for energy flow in electric power systems due to the reduction of peak current when starting the motor.

Usually two techniques are employed to control the soft starter: voltage ramp and current control.

The voltage-ramp technique is performed through a firing-angle ramp of SCRs. Thus, although better than the non-electronic starter methods, it does not guarantee a more effective control over current and acceleration during starting process and over deceleration during stopping process [30].

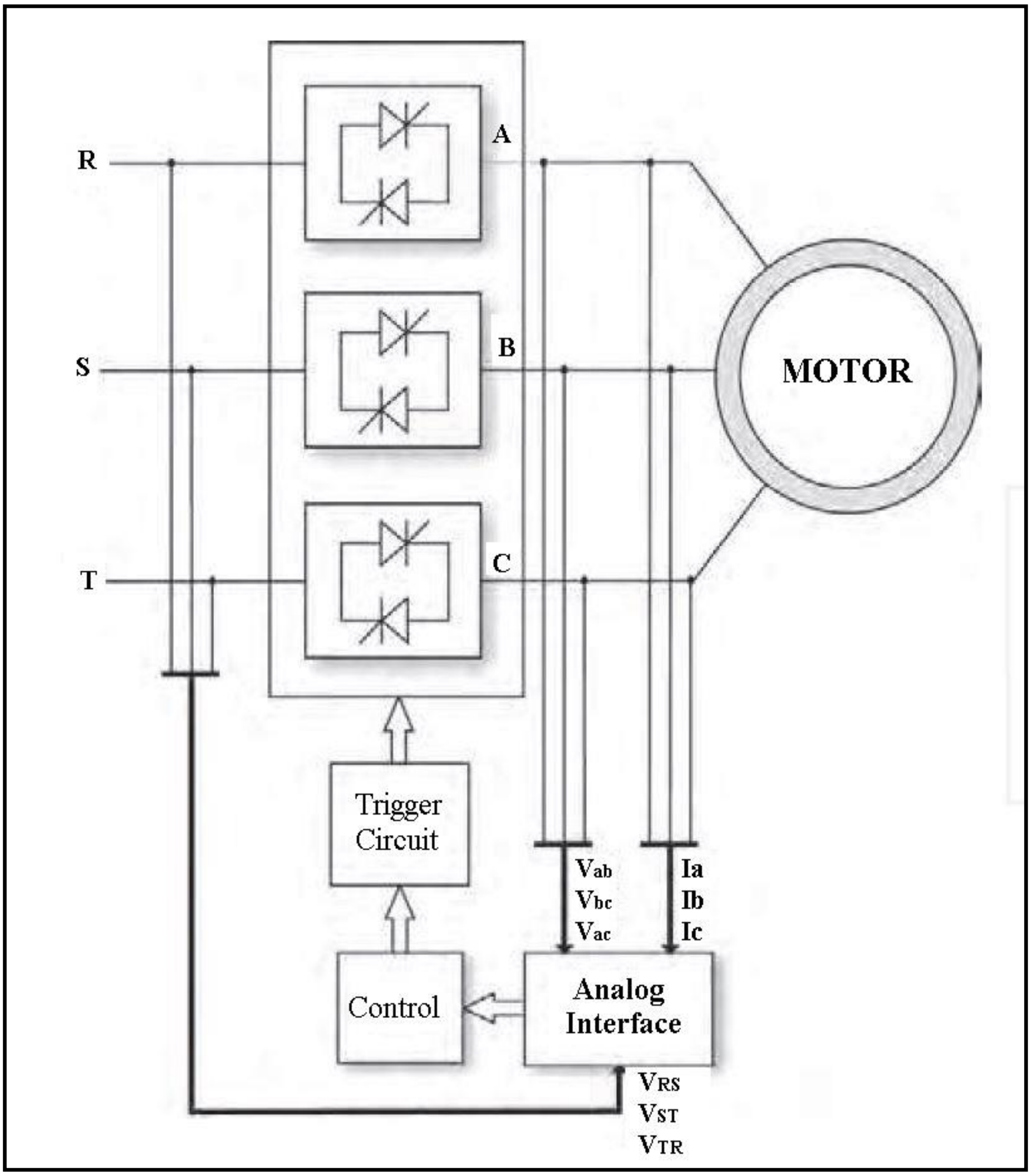


Figure (5.8) :Basic diagram of soft starter[30]

The angle ramp, shown in figure (5.9), is called voltage-ramp, due to the fact that the majority of commercial soft starters do not possess voltage feedback applied to the motor, i.e., the induction motor voltage is controlled through a firing angle ramp in an open loop. This technique is simple, and it is used in low-cost commercial soft starters. It will always produce a starting quadratic torque curve that can be applied to small hydraulic pumps and small fans [30].

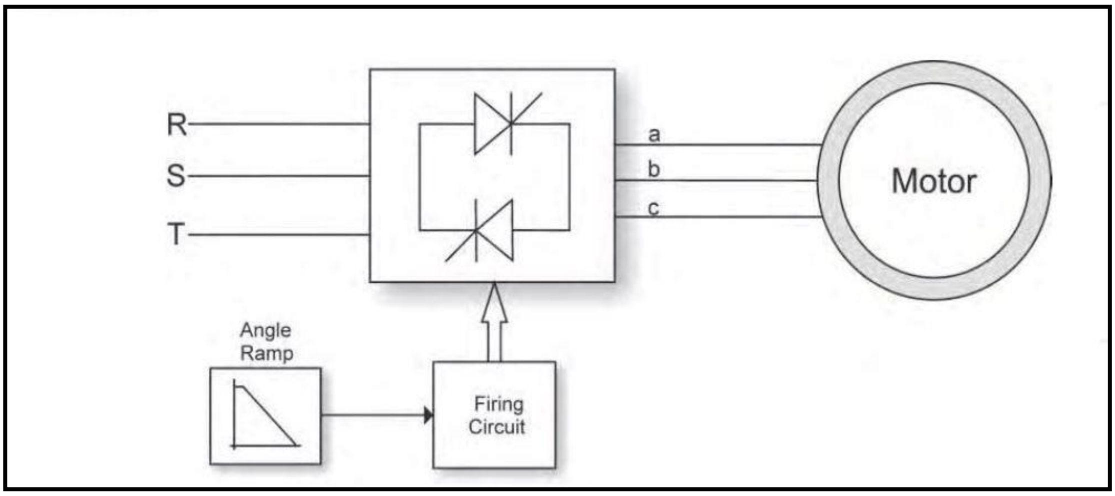


Figure (5.9) : Basic block diagram of the voltage-ramp technique[30].

5.2.2 Variable Frequency Convertor Drive

5.2.2.1 Description of variable frequency convertor

A frequency converter is a power electronic device that converts power from a supply network to a load with a controllable amplitude and frequency. A schematic diagram of one topology of frequency converters used in elevator drives is shown in figure (5.10). It consists of a three-phase, six-pulse, full-bridge diode rectifier (1), a brake chopper (2), a large filter capacitor (3) and a three-phase pulse-width-modulated voltage-source inverter (4). Measurements are taken from the voltage over the filter capacitor and from the currents of two output phases[32].

5.2.2.2 Speed control method by using variable frequency convertor

The first part of variable speed device rectifiers supply AC voltage into DC over the filter capacitor with the voltage given on average by :

$$V_{dc} = \frac{3}{\pi}\sqrt{2}\,V_n = 1.35 \times V_n \tag{5.1}$$

V_n : is the supply network phase-to-phase voltage [33].

Due to the finite interval needed by current commutation between the conducting diodes, the DC side is reduced by :

$$\Delta V_{dc} = \frac{3}{\pi}\,w_n\,L_k I_{dc} = 6 f_n L_k I_{dc} \tag{5.2}$$

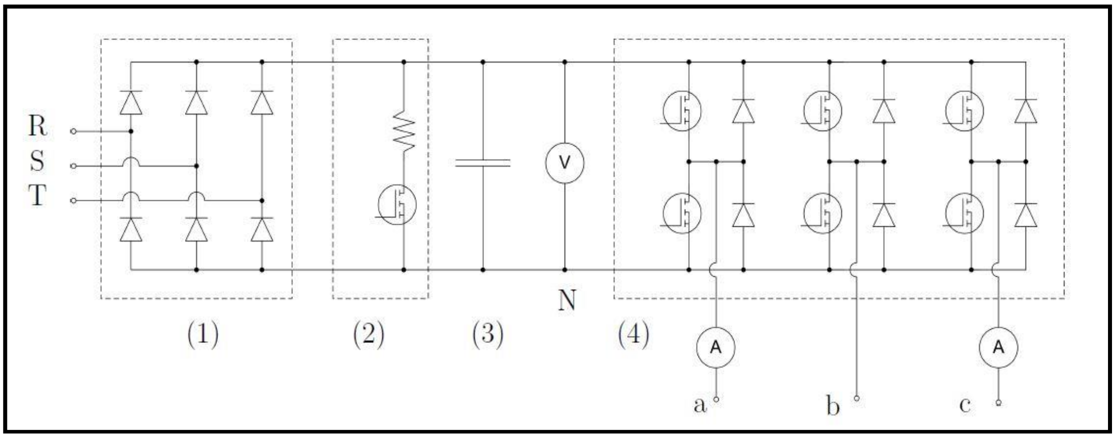


Figure (5.10) : A typical frequency converter.

Where :

$w_n = 2\pi fn$,is the angular frequency of the supply.

L_k : The short-circuit inductance of the supply network at the frequency converter's input terminals.

I_{dc}:The current I_{dc} is the current on the DC side.

The brake chopper is used to avoid voltage increase in the filter capacitor by dissipating the excess energy in the braking resistors when the power flows from the load to the supply, i.e. when the motor is braking or acting as a generator, and when the frequency converter is equipped with a diode-rectifier, which is not capable of converting this energy back to the supply.

The purpose of the PWM inverter is to create voltages with controllable magnitude and frequency. The inverter consists of three 'legs', each having two pairs of transistors and diodes, the upper and lower ones. The transistors in each one of these inverter-legs are controlled in a complementary fashion, i.e. one transistor conducts at a time, to avoid short-circuiting the filter capacitor.

The instantaneous inverter output voltages with respect to the assumed three-phase load neutral point are:

$$V_{sa} = \frac{3}{\pi} V_{aN} - \frac{1}{3}(V_{bN} + V_{cN}) \tag{5.3}$$

$$V_{sb} = \frac{3}{\pi} V_{aN} - \frac{1}{3}(V_{bN} + V_{cN}) \tag{5.4}$$

$$V_{sc} = \frac{3}{\pi} V_{aN} - \frac{1}{3}(V_{bN} + V_{cN}) \tag{5.5}$$

where :

V_{iN} ,$i \in \{a,b,c\}$, are the amplitudes of the inverter output voltages with respect to the negative DC-bus.

5.3 Parameters of Used Induction Motor

5.3.1 Technical Data for Abu Saleh Induction Motor

Three-Phase motor of pump for Abu Saleh well manufactured by U.S Electrical Motor Company has an identification number " T08 7533307-002 R00 01" Table (5.1) show all technical data for used motor.

Table (5.1) : Abu Saleh well motor ,name plate data [33].

Property	value	Property	value
Phase/Type	3-phase	Power Factor	84.6
Type	TUC	Frequency	50 HZ
Enclosure Type	TE(Totally Enclosed)	Volt	400 V
Max Temperature	48 C^0	Max KVAR	30
Duty	Continuous	Power	100 HP
Weight	1600 LBS	RPM	1480
SF	1.15	AMPS	136

Figure (5.11) : Name plate of Abu Saleh well motor.

5.3.2 Technical Data for Agriculture Company Induction Motor

Three-Phase motor of pump for Agriculture Company well manufactured by U.S Electrical Motor Company has an identification number " P 10 7382793-0001 R00 04"Table (5.2) show all technical data for used motor

Table (5.2) :Agriculture Company well motor ,name plate data [33].

Property	value	Property	value
Phase/Type	3-phase	Power Factor	87.1
Type	RU	Frequency	50 HZ
Enclosure Type	WPI(Whether Protected)	Volt	400 V
Max Temperature	40 C^0	Max KVAR	35.6
Duty	Continuous	Power	150 HP
Weight	1600 LBS	RPM	1480
SF	1.15	AMPS	196

Figure (5.12) : Name plate of Agriculture Company well motor

5.3.3 Technical Data for Waleed Ribhi Induction Motor

Three-Phase motor of pump for Waleed Ribhi well manufactured by U.S Electrical Motor Company has an identification number " T 08 7533307-002 R00 01" Table (5.2) show all technical data for used motor.

Table (5.3) :Waleed Ribhi well motor ,name plate data [33].

Property	value	Property	value
Phase/Type	3-phase	Power Factor	84.6
Type	TUC	Frequency	50 HZ
Enclosure Type	TE(Totally Enclosed)	Volt	400 V
Max Temperature	48 C^0	Max KVAR	30
Duty	Continuous	Power	100 HP
Weight	1600 LBS	RPM	1480
SF	1.15	AMPS	136

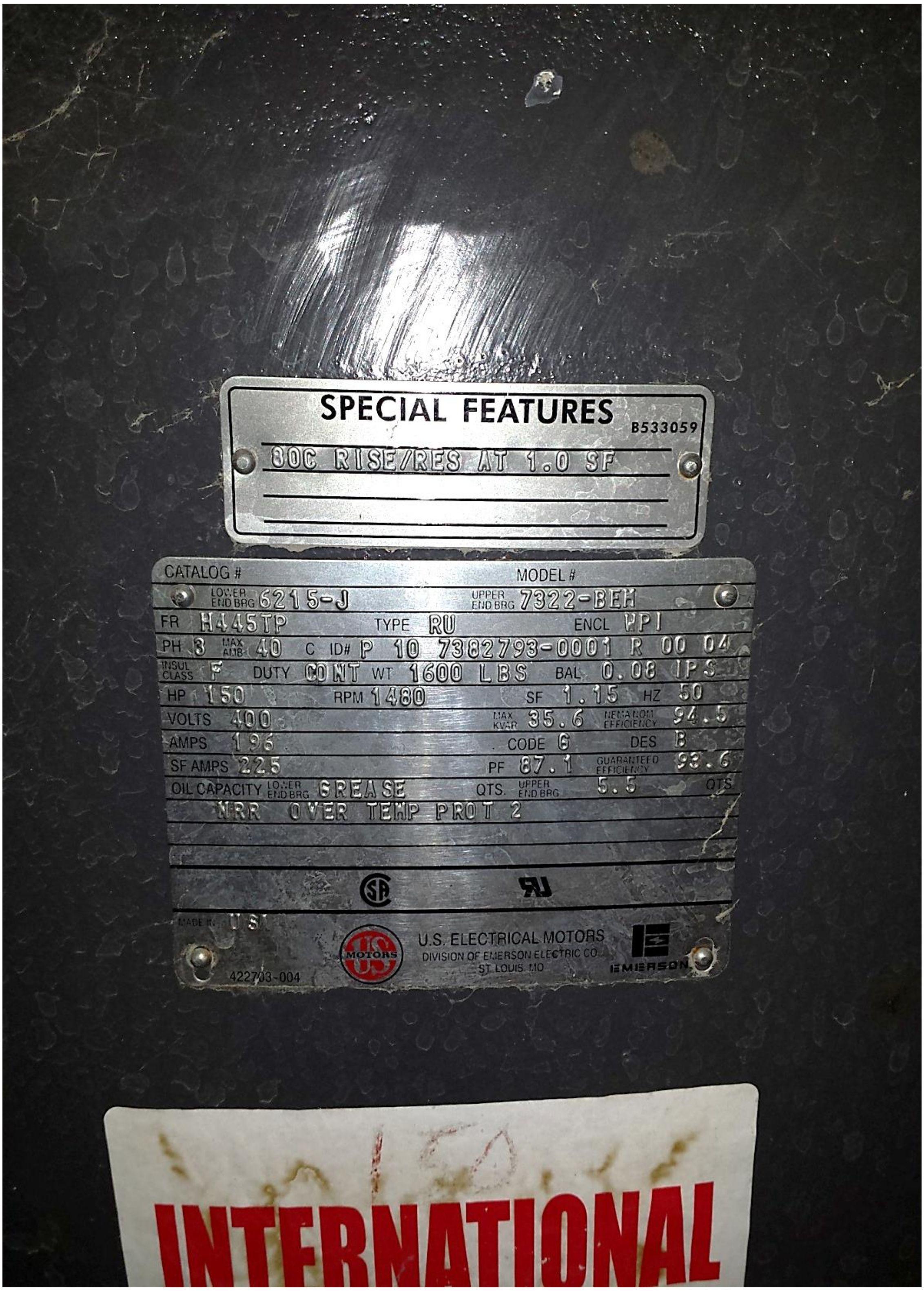


Figure (5.13) : Name plate of Waleed Ribhi Company well motor

Chapter Six

Control methods of water pumping systems and field testing results

6.1 Setup of Water Pumping System (WPS)

The correct size pump and pump motor depend on the well diameter, the water level in the well, the number of plumbing fixtures, the amount of water use, and the peak water demand. Pumps are rated in cubic meter per hour (m^3/h), and pump motors are rated in horse power (hp).[34]

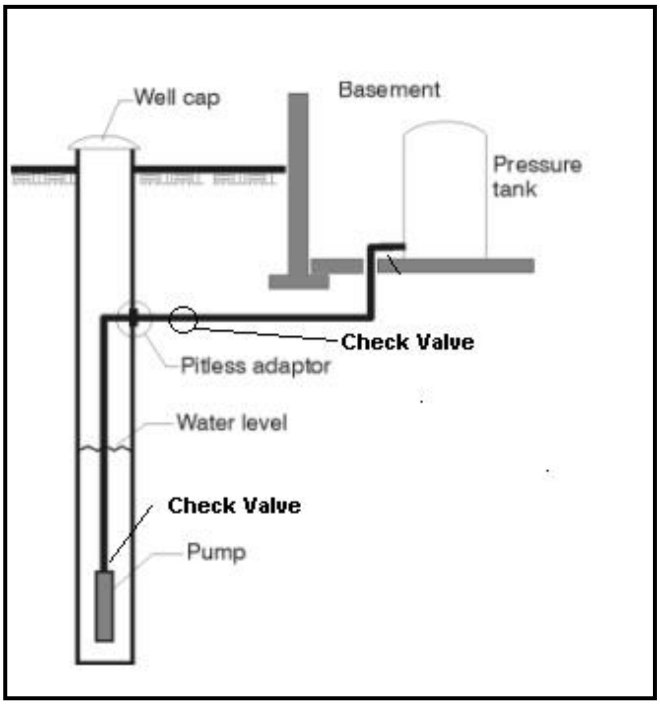


Figure (6.1) : Water Pumping System Component

As illustrated in figure (6.1) ,setup of first component a well cap is an approved manufactured cover of cast steel, aluminum, or PVC. It is fastened to the well casing with a rubber compression "O" ring or gasket between the sections. Both are incorporated to make a water tight or vector proof seal. Well caps are also vented with a brass or stainless mesh. A female threaded port is used to tie in and insert electrical cable. All well caps installed must meet state regulations [34].

The setup of second component pressure tank, most water systems include a water storage container called a pressure tank. The pressure tank is usually located in the basement or a utility room, although some types of tanks may be buried underground. It is a good idea to have a faucet placed near the pressure tank for flushing the tank and collecting water samples for testing [34].

The setup of third component check valves permit water flow only in one direction, and are required on all submersible pump installations. Their purpose is to prevent the water in the column above the pump and in the pressure tank from draining back into the well when the pump shuts off. They also prevent backspin, water hammer and up thrust inside the pump. Any of these three conditions, or a combination of them, can lead to pump or motor failure, plus shortened service life or operating problems in the system [34].

6.2 Control Circuit and Protection

The pumping system shall be designed to operate in the following modes:

a. Automatic mode – in this mode of operation the control system shall operate the pumping station automatically, without need for manual intervention[35].

b. Manual mode – in this mode of operation, the control system is overridden and the operator can operate the pump units manually via the pushbutton switches mounted on the door of the Assembly [35].

c. Protection components must be installed in the pumping system ,first one flow switch monitoring pump input/suction lines provide the most direct method of protecting pumps from costly damage due to reduced and/or fluid loss [36], the second one ,pressure switch used to make or break an electrical circuit (an electric motor, a gas engine, etc.) upon sensing either ‘high’ or ‘low’ flow line pressure, and temperature sensor used to turn off pump when temperature exceed nominal temperature.

6.2.1 Description of Practical Control Methods

The following control drawing shown in figure (6.2) ,illustrates the control method of water pump of two tested well's , control philosophy can be described as the following procedure :

1- Operator can choose mode of operation either Automatic or Manual mode by a selector switch .

2- In automatic mode ,the operator can adjust time to run a pump then the pump will pump water until receive signal from high level sensor to turn off pump , on the other hand the pump will pump water again when receive signal from low level sensor .

3- In manual mode, the operator must turn on pump normally , in special cases the pump will be forced to turn off ,high pressure , low pressure ,high temperature , soft starter or variable frequency convertor fault and no flow case . figure (6.4) shows flow chart that describes control process for tow tested pump .

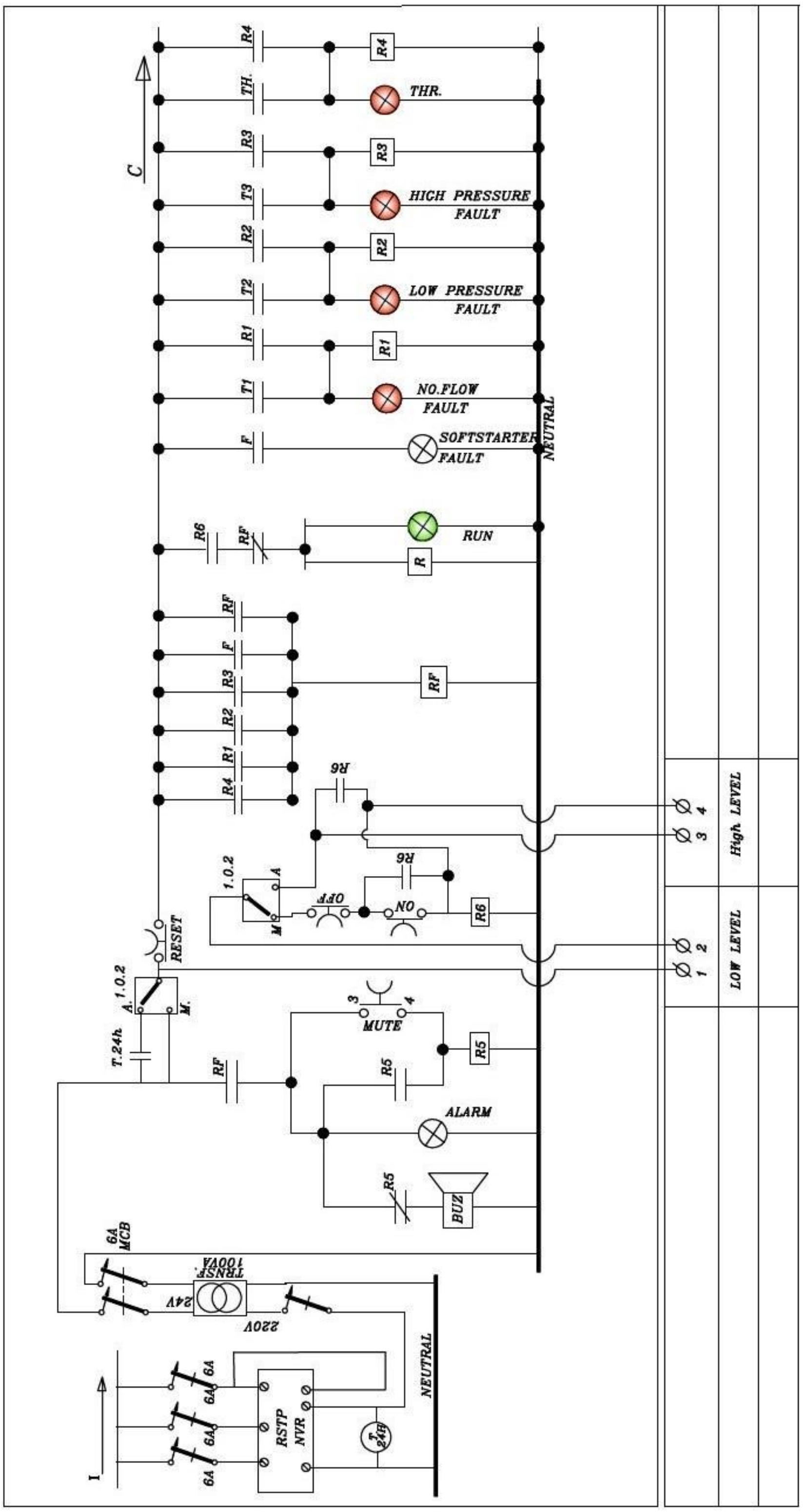


Figure (6.2) : Electrical control circuit for both tested wells .

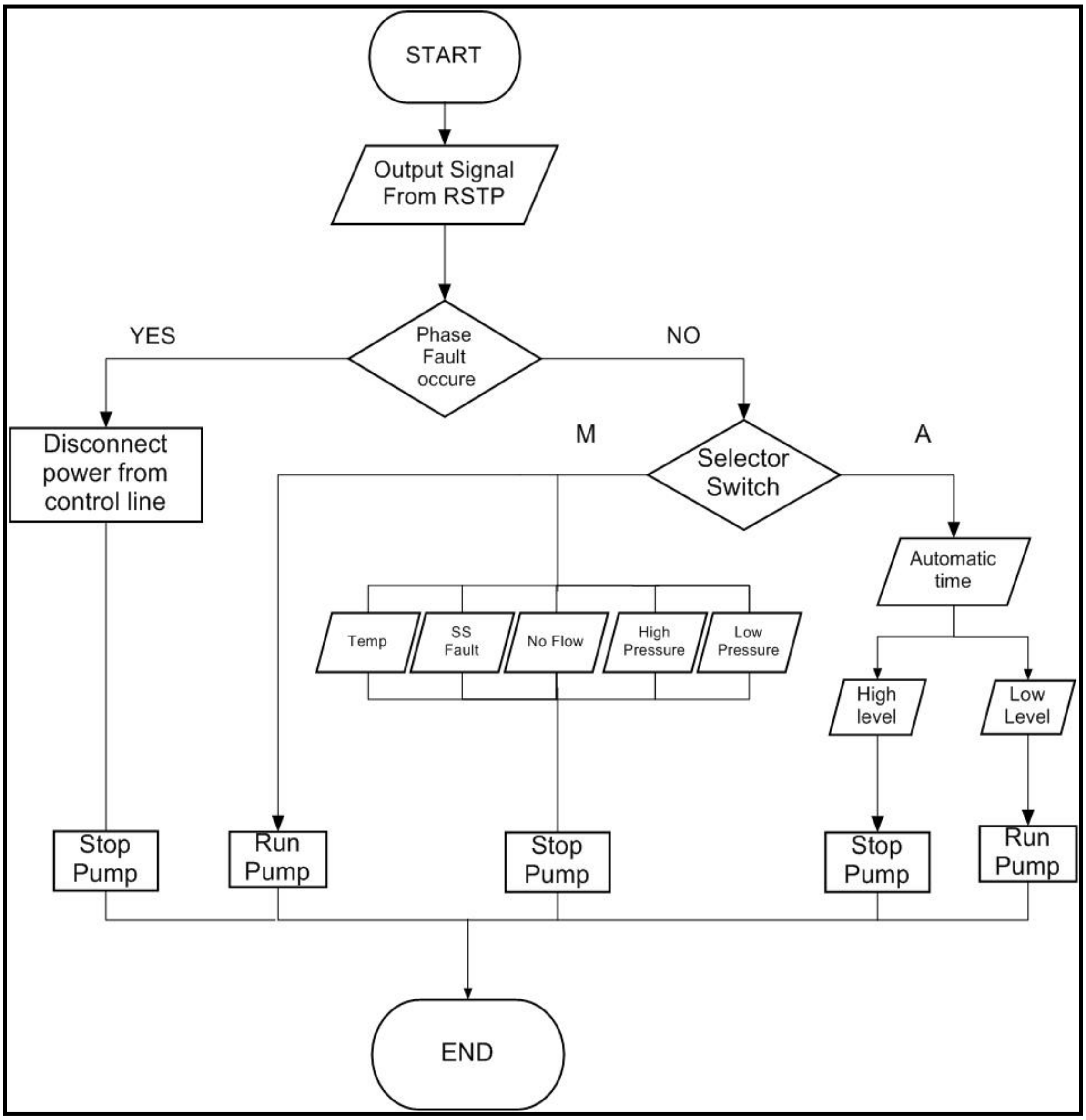


Figure (6.3) : Control method description .

6.3 Practical Result's

The procedure for the practical experiments were conducted on each well ,Abu Saleh well , Agriculture irrigation company and Waleed Ribhi was the same, the main aim of this thesis is to make financial analysis for using variable frequency convertor and soft starter for driving electrical water pump , so experiment depend on collecting data about energy consumption, used frequency, flow rate , number of consumer and head of pump.

Modern energy analyzers device was used to collect data for several tested at several periods , energy analyzer fixed on control box wall after connect device terminal wire three phase(red ,black, green) and neutral (blue) to the main power cable as figure (6.4) shows .after data have been collected and transferred to computer as Excel sheet to be analyzed and examined to get more accurate results by checking every point at trending curve .After getting and calculating energy consumption for each well , process will be more easier to calculate the energy cost for each well and compared between two driving method(SS & VFD) with take in considering the initial cost for each one .

Figure (6.4): Energy analyzer device and collecting data process

6.3.1 Practical Result for using soft starter at Abo Saleh Well

6.3.1.1 First experiment at period (2-8 /10/2013)

To calculate the quantities of pumped water during experiment period from 29-10-2013 to 31-10-2013, the water meter reading recorded before experiment (16644m^3) and the record reading at the end of the period was(17541m^3) .

From the above reading the amount of pumped water during experiment period can be calculated , by finding the difference between two reading in 2-10-2013 the reading of water meter was 607870 m^3 and in 8-10-2013 the reading of water meter was 613130 m^3 as equation (6.1).

$$613130 - 607870 = Amount\ of\ pumped\ water \tag{6.1}$$

$$Amount\ of\ pumped\ water = 613130 - 607870 = 897\text{m}^3$$

The other recorded data at the beginning of experiment by data analyzer was the energy consumption ,and it's value at 29-10-2013 (0 Wh) ,and at the end of experiment at 31-10-2013 was (306651.2Wh), the following curves shown in Figure (6.5) drawn by excel after transfering collected data from energy analyzer to PC to get exact reading .

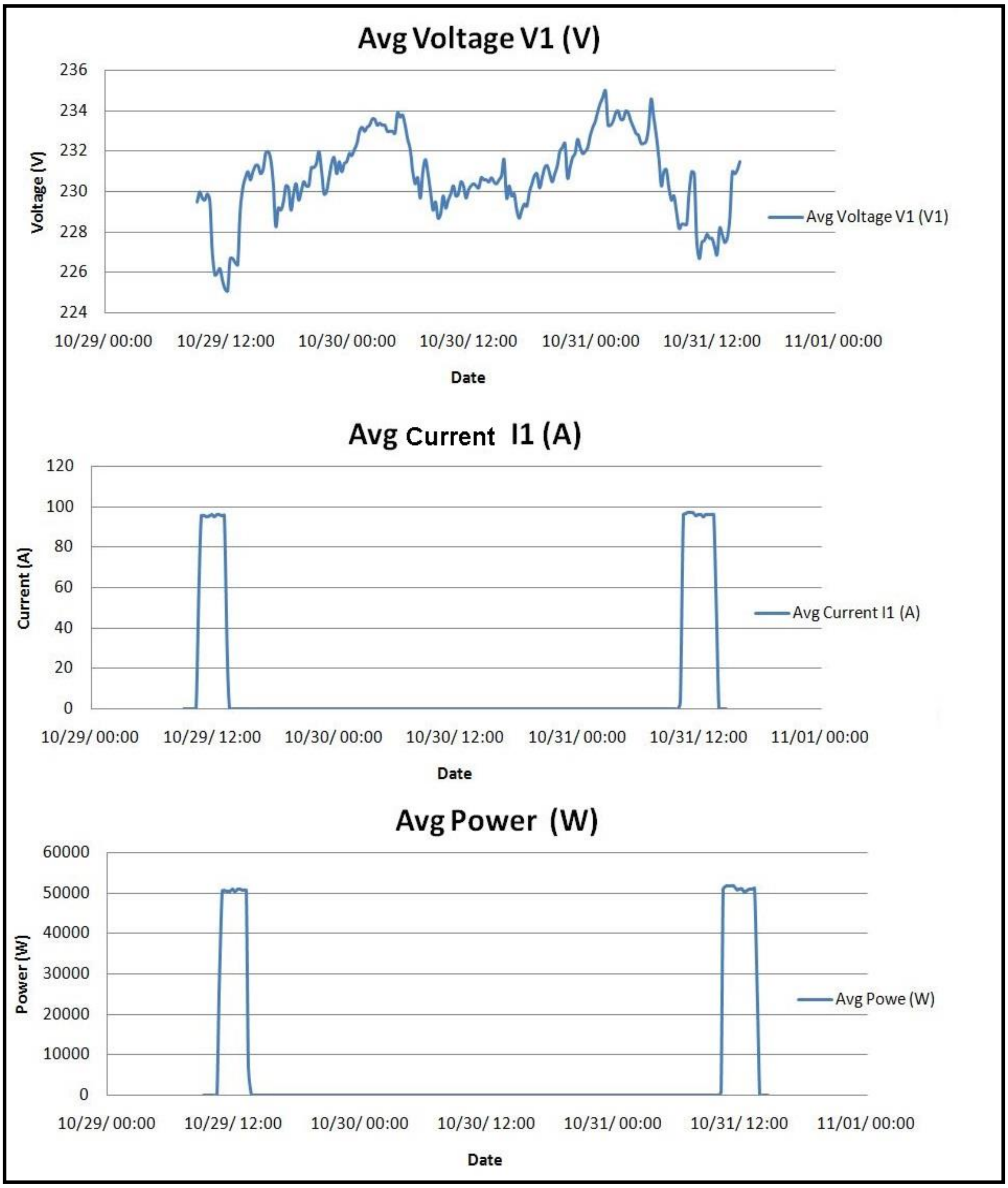


Figure (6.5): Average voltage ,current ,total power for Abu saleh pump during first testing period

As shown in previous curve we can notice that the power of the pump increase rapidly at start ,then change to be constant at about 50 kW on power curve , this value could be considered optimum power of pump , if we compared this measured value with theoretical power at optimum efficiency from data sheet the theoretical power (49.5 kW) at optimum efficiency (79%) .

However, during pump water the demand increases by farmer so other parameters will be changed head, flow rate, and pressure. These values have effect directly on power of pump either increase or decrease from the optimum power (49.5 kW) the performance test of the pump by manufacturer as shown in data sheet and chapter four illustrated the change in power and efficiency during change in head and flow rate .

$$Total\ energy\ consmption = 306651.2 - 0 = 306651.2\ Wh$$
$$= 306.651\ KWh$$

$$Total\ Cost\ during\ experiemnt = 306.651\ \times 0.63 = 193.19\ NIS.$$

All cost calculations for energy consumption in NIS , and the cost for each KWh about 0.63 NIS / KWh , previous calculation show the total cost of energy consumption for 897 m^3 pumped water , so final price of each cubic meter equals 0.215 NIS as shown in equation (6.3) .

$$Final\ cost\ for\ one\ cupic\ metre = \frac{Total\ cost}{Amount\ of\ pumped\ water} \tag{6.2}$$

$$Final\ cost\ for\ one\ cupic\ metre = \frac{193.19 NIS}{897\ \text{m3}} = 0.215\ NIS/\text{m3}$$

Soft starter method need power factor modification by using capacitors and power factor controller ,due to the value of average reactive power high about 42(kVAR) as shown in figure (6.6) and the power factor value's at first experiment changed between (0.7 -0.8) as collected data by data analyzer , so the cost of the system will increase due to increase in reactive power and decrease in power factor value .

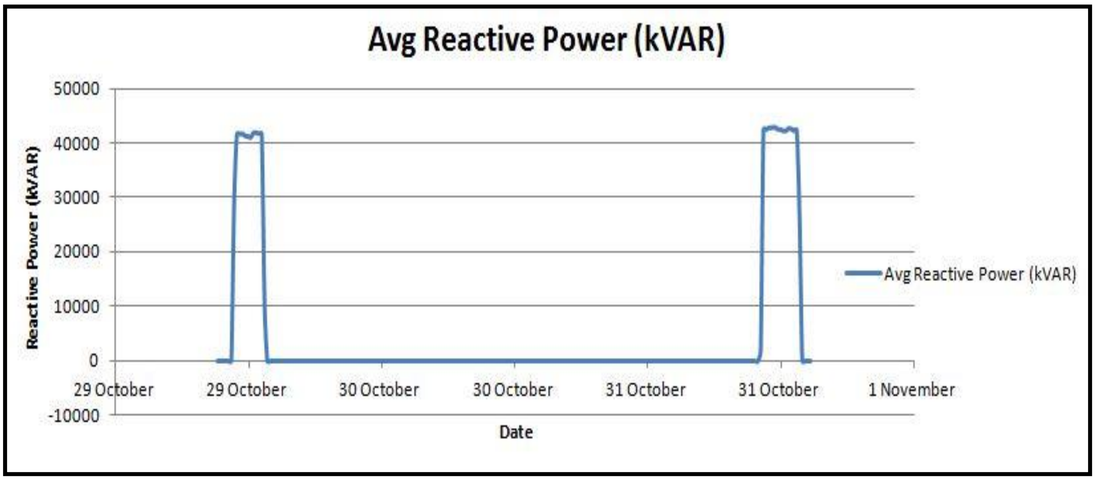


Figure (6.6): Average reactive power for Abu saleh pump during first testing period

6.3.1.2 Second experiment at period (13-17 /04/2014)

To calculate the quantities of pumped water during experiment period from 13-04-2014 to 17-04-2014, the water meter reading recorded before experiment (783460 m^3) and the record reading at the end of period was(784760m^3) .

From the above reading the amount of pumped water during experiment period can be calculated , by finding the difference between the two readings in 13-04-2014 the reading of water meter was 783460 m^3 and in 17-04-2014 the reading of water meter was 784760m^3 as equation (6.1).

$$784760 - 783460 = Amount\ of\ pumped\ water$$

$$Amount\ of\ pumped\ water = 784760 - 783460 = 1300\mathrm{m}^3$$

The other recorded data at the beginning of experiment by data analyzer was the energy consumption ,and it's value at13-04-2013 (0 Wh) ,and at the end of the experiment at 17-04-2013 was (557405.5Wh), the following curves shown in figure (6.7) drawn by excel after transfering collected data from energy analyzer to PC to get exact reading .

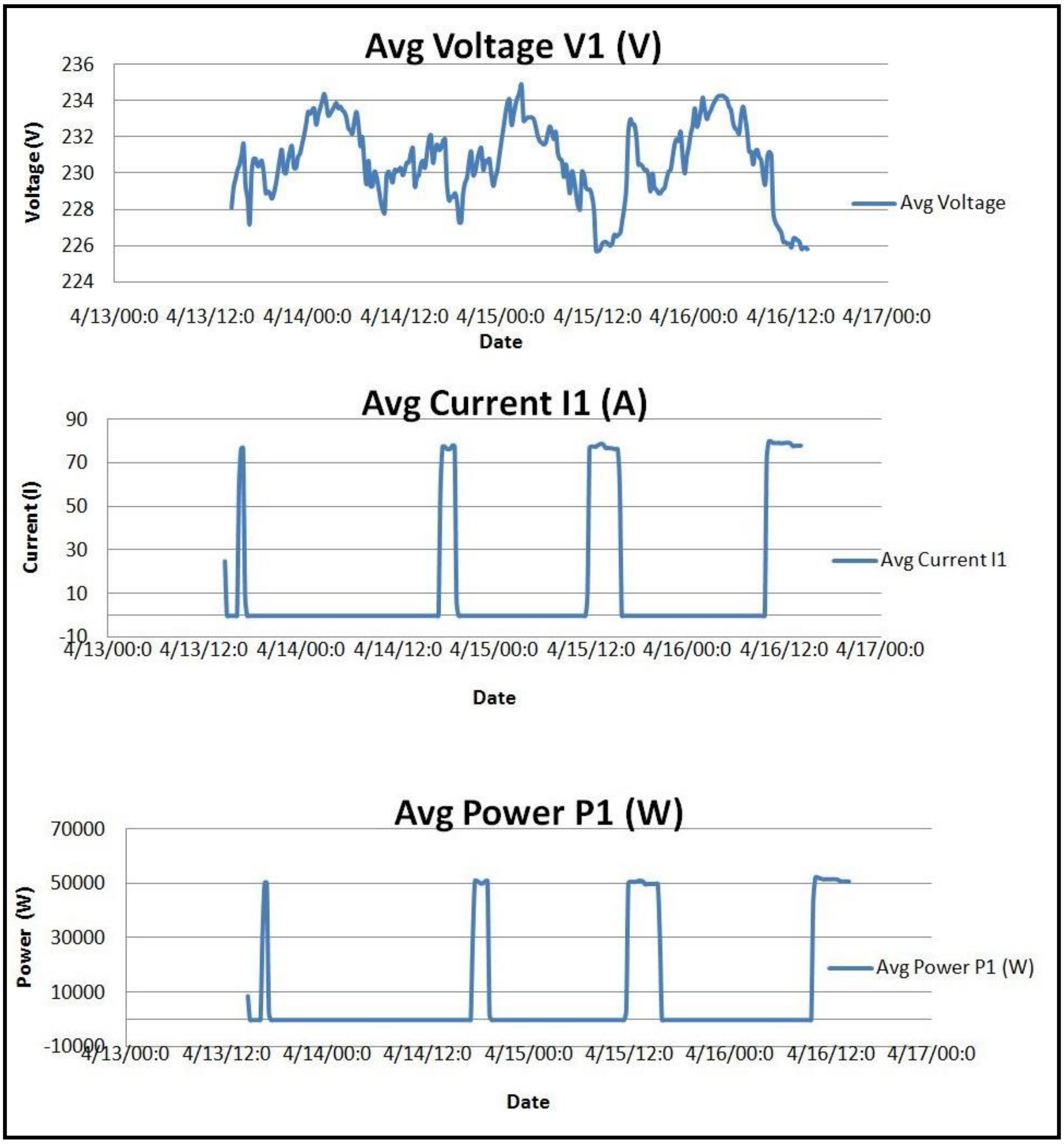


Figure (6.7): Average voltage ,current ,total power for Abu saleh pump during second testing period

$$Total\ energy\ consmption = 557405.5 - 0 = 557405.5\ Wh$$
$$= 557.405\ KWh$$

$$Total\ Cost\ during\ experiemnt = 557.405\ \ \times 0.63 = 351.165\ NIS$$

All cost calculations for energy consumption in NIS , and the cost for each KWh about 0.63 NIS / KWh , previous calculation show the total cost of energy consumption for 1300 m^3 pumped water , so final price of each cubic meter equals 0.270 NIS as shown in equation (6.3)

Note the difference in the cost per cubic meter in the second test due to the decrease in the quantity pumped .

Decrease the amount pumped back to the water pump to more than farms of different heights in the first test is not pumping water to high altitudes, so the cost is less because the flow is proportional inverse proportion to the rise.

$$Final\ cost\ for\ one\ cupic\ metre = \frac{Total\ cost}{Amount\ of\ pumped\ water}$$

$$Final\ cost\ for\ one\ cupic\ metre = \frac{351.16\ NIS}{1300\ \mathrm{m3}} = 0.270\ NIS/\mathrm{m3}$$

After getting the value of power factor for Abu Saleh well at the first experiment , well manager's decide to modify the system by adding power factor panel contain capacitors and power factor controller to get good after this about (0.9)and average reactive power about (20 kVAR) as shown in Figure (6.8) .

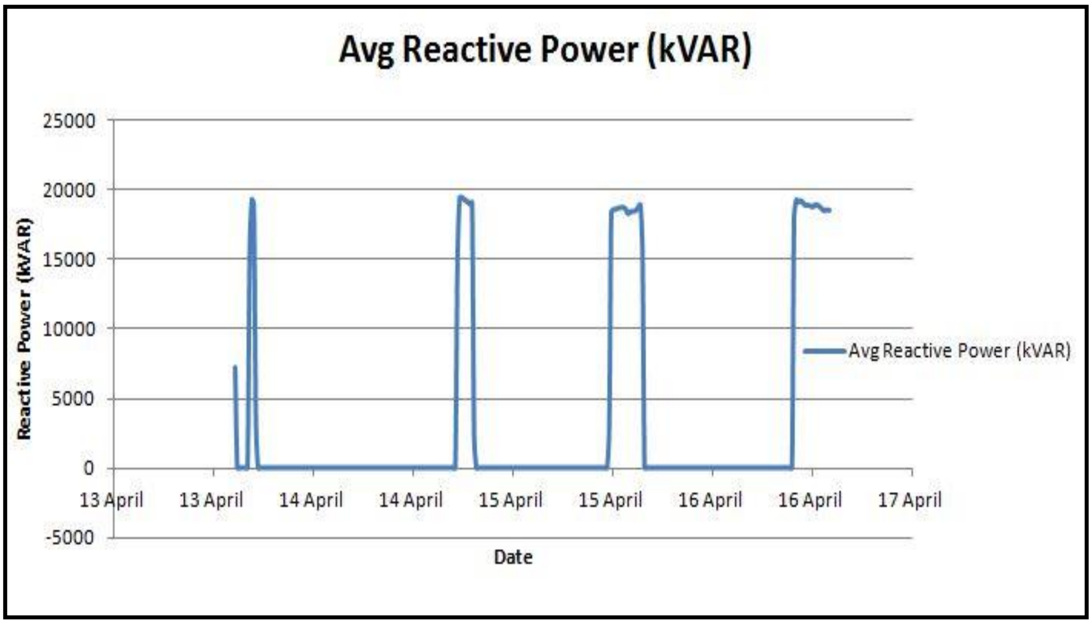


Figure (6.8): Average reactive power for Abu saleh pump during second testing period

6.3.2 Practical Results for using variable frequency drive at Agriculture Irrigation Company well

To calculate the quantities of pumped water during experiment period from 2-10-2013 to 8-10-2013, the water meter reading recorded before the experiment (60787m^3) and the record reading at the end of the period was(61313m^3) .

From the above reading the amount of pumped water during experiment period can be calculated , by finding the difference between two reading in 2-10-2013 the reading of water meter was 607870 m^3 and in 8-10-2013 the reading of water meter was 613130 m^3 as equation (6.1).

$$613130 - 607870 = Amount\ of\ pumped\ water$$

$$Amount\ of\ pumped\ water = \ 613130 - 607870 = 5260\text{m}^3$$

The other recorded data at the beginning of experiment by data analyzer was the energy consumption ,and it's value at 2-10-2013 (0 Wh) ,and at the end of the experiment at 8-10-2013 was (2581741 Wh), the following curves shown in Figure (6.9) drawn by excel after transferring collected data from energy analyzer to PC to get exact reading .

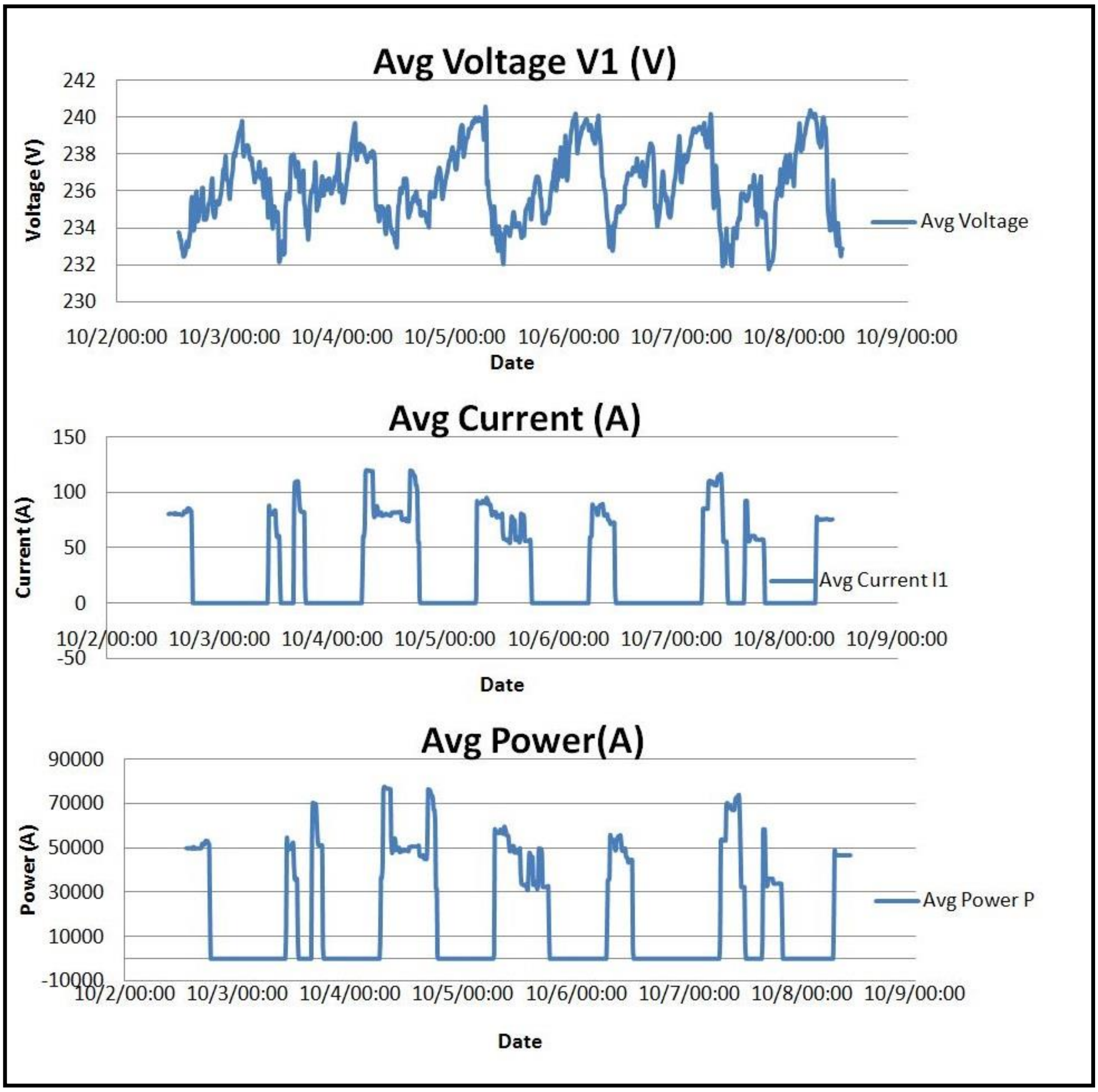


Figure (6.9): Average voltage ,current ,total power for Abu saleh pump during second testing period

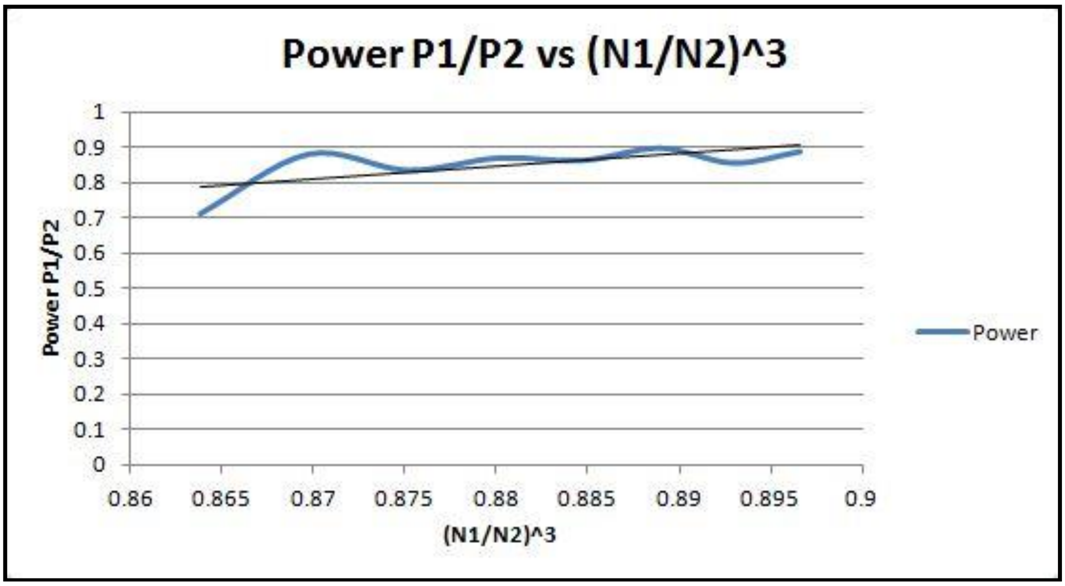
The effect of variable frequency drive clear on power curve during different period of pump ,at start power increases to be about 79 KW at frequency 50 Hz , then operator changes speed of motor by changing frequency either increasing or decreasing as demand status from framer's this change will have effect on flow rate to get balance between demand and flow rate as equation (6.4) shows the relation between change in speed of motor and change of flow rate .

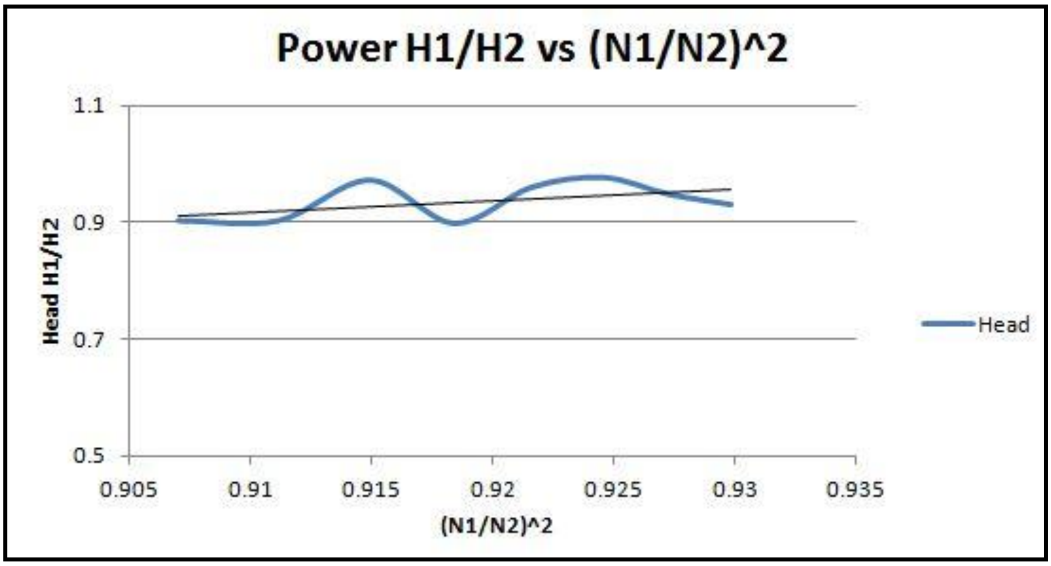
$$\frac{Q1}{Q2} = \frac{N1}{N2} \tag{6.4}$$

Where :

Q : Flow rate of pumped water m^3/h .

N : Speed of motor (rpm)





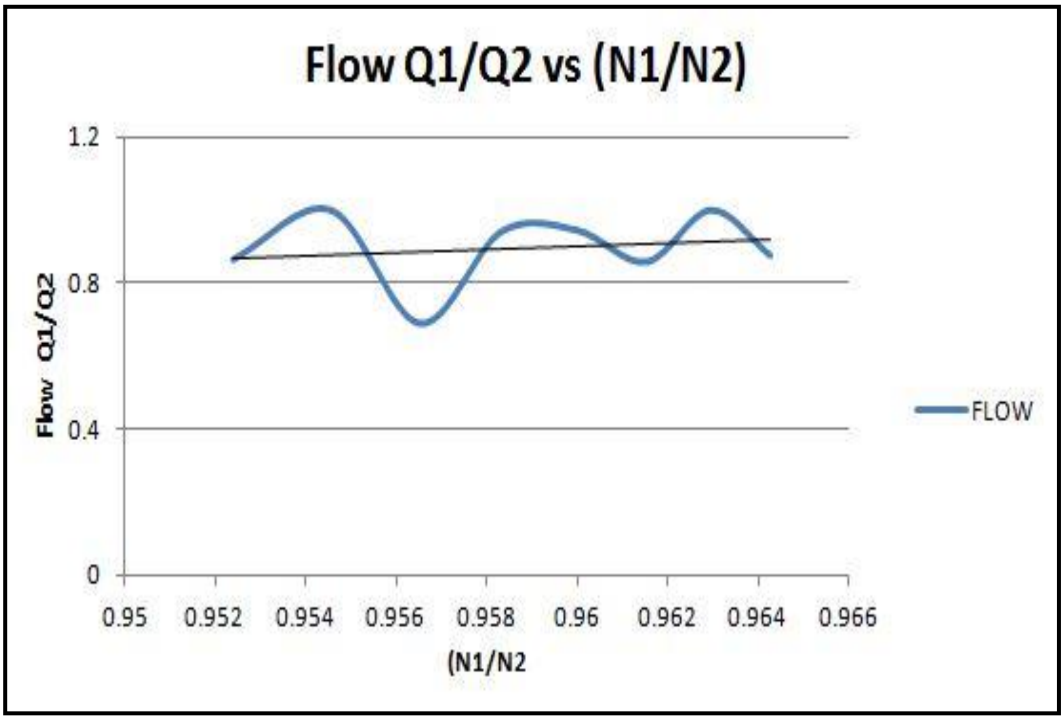


Figure (6.10): Pump Affinity Laws Applied to Agriculture irrigation well

$$Total\ energy\ consmption = 2581741 - 0 = 2581741\ Wh$$
$$= 2581.741\ KWh$$

$$Total\ Cost\ during\ experiemnt = 2581.741\ \times 0.63 = 1626\ NIS$$

All cost calculations for energy consumption in NIS , and the cost for each KWh about 0.63 NIS / KWh , previous calculation show the total cost of energy

consumption for 5260 m^3pumped water , so final price of each cubic meter equal 0.309 NIS as shown in equation (6.3) .

$$Final\ cost\ for\ one\ cupic\ metre = \frac{Total\ cost}{Amount\ of\ pumped\ water}$$

$$Final\ cost\ for\ one\ cupic\ metre = \frac{1626\ \ NIS}{526O\ \mathrm{m3}} = 0.309\ NIS/\mathrm{m3}$$

The power factor and average reactive power values with variable in the irrigation company well that use variable frequency drive , were good about 0.9 for power factor and (25 kVAR) for average reactive power as shown in figure (6.11) without using capacitor bank in the system .

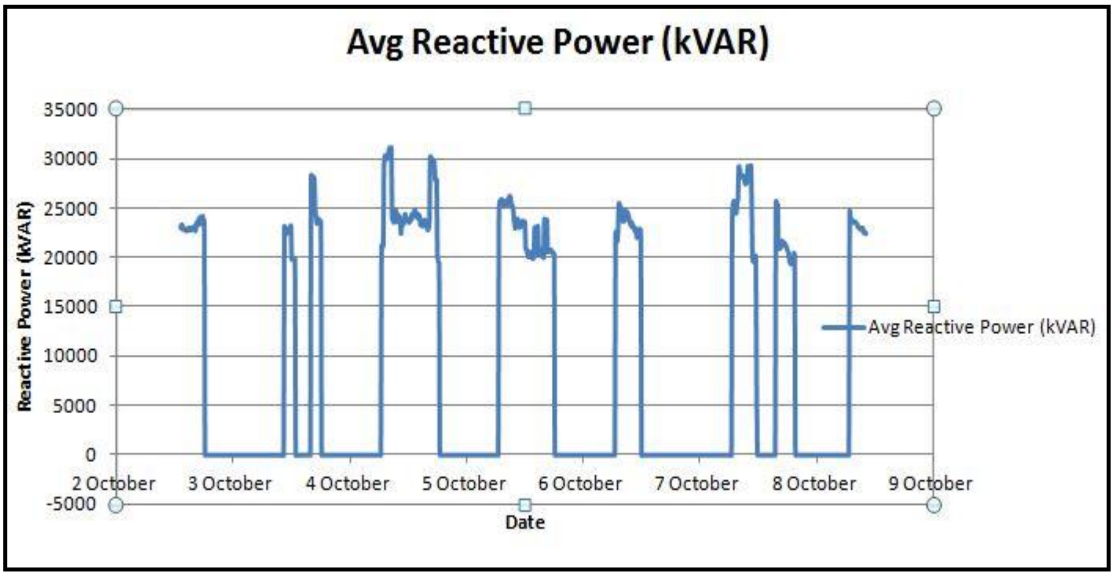


Figure (6.11): Average reactive power for irrigation company pump

The importance of variable frequency drive clearly show on irrigation company well through need to pump water for several farmers at different periods ,also the number of farmers affect the flow rate ,pressure during change in motor speed table (6.1) show the effect on parameters when the operator pump water for two customers and table (6.2) for four costumers.

Table (6.1) :Changes on flow rate , pressure ,power during change on frequency , when pump water for two costumers .

f (Hz)	Power (kW)	Pressure (bar)	N (rpm)	Flow rate (m^3/h)	Head m	Efficiency %
40	32	0.1	1164	95	84.01937	77.8404
42	45	1	1222.2	110	93.19368	70.9603
44	51	2	1280.4	110	103.3874	69.3445
46	61	2.3	1338.6	160	106.4455	86.7857
48	70	3.5	1396.8	170	118.6779	89.451
50	81	4	1455	180	123.7747	85.3188
52	90	4.3	1513.2	210	126.8328	91.7698
54	105	5	1571.4	210	133.9684	83.0298
56	118	6	1629.6	240	144.1621	90.7857

Sample of calculation , efficiency of pump at frequency 42 Hz , pressure 1 bar (100,000 Pa) , flow rate 110 (m^3/h):

$$\eta = \frac{\mathbf{Phyd}}{\boldsymbol{Pin \times motor\ eff \times VFD\ eff}} \times \mathbf{100}\ \% \tag{6.5}$$

$$P_{hyd} = 2.725 \times \mathbf{Q} \times \mathbf{H}$$

$$\eta = \frac{\mathbf{2.725 \times Q \times H}}{\boldsymbol{Pin} \times \mathbf{0.92 \times 0.97}} \times \mathbf{100}\%$$

$$\boldsymbol{H} = \frac{\Delta \boldsymbol{P_{tot}}}{\boldsymbol{\rho.g}} + \text{Static head} \tag{6.6}$$

$$\boldsymbol{H} = \frac{\mathbf{100{,}000}}{\mathbf{1000 \times 9.81}} + \mathbf{83} = 93.19 \text{ m}$$

$$\eta = \frac{\mathbf{2.725 \times 110 \times 93.19}}{\mathbf{45000 \times 0.92 \times 0.97}} \times \mathbf{100}\% = \mathbf{69.55}\ \%$$

Where :

η : Efficiency of pump

$\mathbf{P_{hyd}}$:Hydraulic power(Watt)

$\mathbf{P_{in}}$:Input power for pump (Watt)

Motor eff: efficiency of motor (0.92) [37].

VFD eff :Variable frequency drive efficiency (0.97) [38].

$\Delta \boldsymbol{P_{tot}}$: Total pressure difference across the pump [Pa]

ρ : density of fluid , for water 1000(kg/m^3)

g :gravity (9.81 m/s^2)

Sample of calculation ,Speed of induction motor at frequency 42 Hz , pressure 1 bar (100,000 Pa) , flow rate 110 (m^3/h):

$$\boldsymbol{asynchronous\ speed} = \frac{\boldsymbol{120 \times f}}{\boldsymbol{No.motor\ pole}} \times (\boldsymbol{1 - S}) \qquad (6.7)\ [38]$$

$$\boldsymbol{S} = \frac{\boldsymbol{n_s - n_r}}{\boldsymbol{n_r}} = \frac{\boldsymbol{1500 - 1450}}{\boldsymbol{1450}} = \boldsymbol{0.034}$$

$$\boldsymbol{asynchronous\ speed} = \frac{\boldsymbol{120 \times 42}}{\boldsymbol{4}} \times (\boldsymbol{1 - 0.034}) = \frac{\boldsymbol{120 \times 42}}{\boldsymbol{4}} \times \boldsymbol{0.96} =$$

1217.2 rpm

Where :

$\boldsymbol{f}$: Used frequency in Hz.

$\boldsymbol{S}$: Slip of asynchronous induction motor .

$\boldsymbol{n_s}$: Stator electrical speed , for irrigation company pump (1475) shown in table (4.4).

Table (6.2) : Changes on flow rate , pressure ,power during change on frequency , when pump water for two costumers .

f (Hz)	Power (kW)	Pressure (bar)	N (rpm)	Flow rate (m^3/h)	Head m	Efficiency %
44	51	1	1280.4	140	93.19368	78.1149
46	60	2	1338.6	165	103.3874	86.8113
48	70	2.3	1396.8	180	106.4455	83.5745
50	84	2.8	1455	205	111.5423	83.1153

The importance of variable frequency convertor appears clearly in previous test through determining the best frequency to get best efficiency of a pump during pump water in different two cases ,first case when pump water for two customers and the second case pump water for four customers , from the efficiency term in each previous table we will find optimum efficiency for each case during change in pressure , head during change in frequencies as shown in figure(6.12) and efficiency calculated as following tables.

Table (6.3): Changes in flow rate and head through change pressure at 45 Hz frequency.

f (Hz)	Power (kW)	Pressure (bar)	Flow rate (m^3/h)	Head m	Efficiency %
45	47	3.6	87.8	119	67.88136462
45	51	3.1	109.9	114	75.01347984
45	57	2.4	122.8	107	70.39052978

Table (6.4): Changes in flow rate and head through change pressure at 46.5 Hz frequency.

f (Hz)	Power (kW)	Pressure (bar)	Flow rate (m^3/h)	Head m	Efficiency %
46.5	61.5	2.8	133	111	73.30041762
46.5	61.89	3.4	124	117	71.58038158
46.5	54	4	105	123	73.03105857

Table (6.5): Changes in flow rate and head through change pressure at 48 Hz frequency.

f (Hz)	Power (kW)	Pressure (bar)	Flow rate (m^3/h)	Head m	Efficiency %
48	57.9	4.5	106.288	128	71.75011244
48	58.689	4	113.96	123	72.93026428
48	61.689	3.5	125.87	118	73.51965396
48	64.689	3.2	133.83	115	72.64869639

Table (6.4): Changes in flow rate and head through change pressure at 50 Hz frequency. +

f (Hz)	Power (kW)	Pressure (bar)	Flow rate (m^3/h)	Head m	Efficiency %
50	84	2.8	205	111	82.71885205
50	81	4	180	123	83.46406694
50	79.89	4.5	149	128	72.89718567

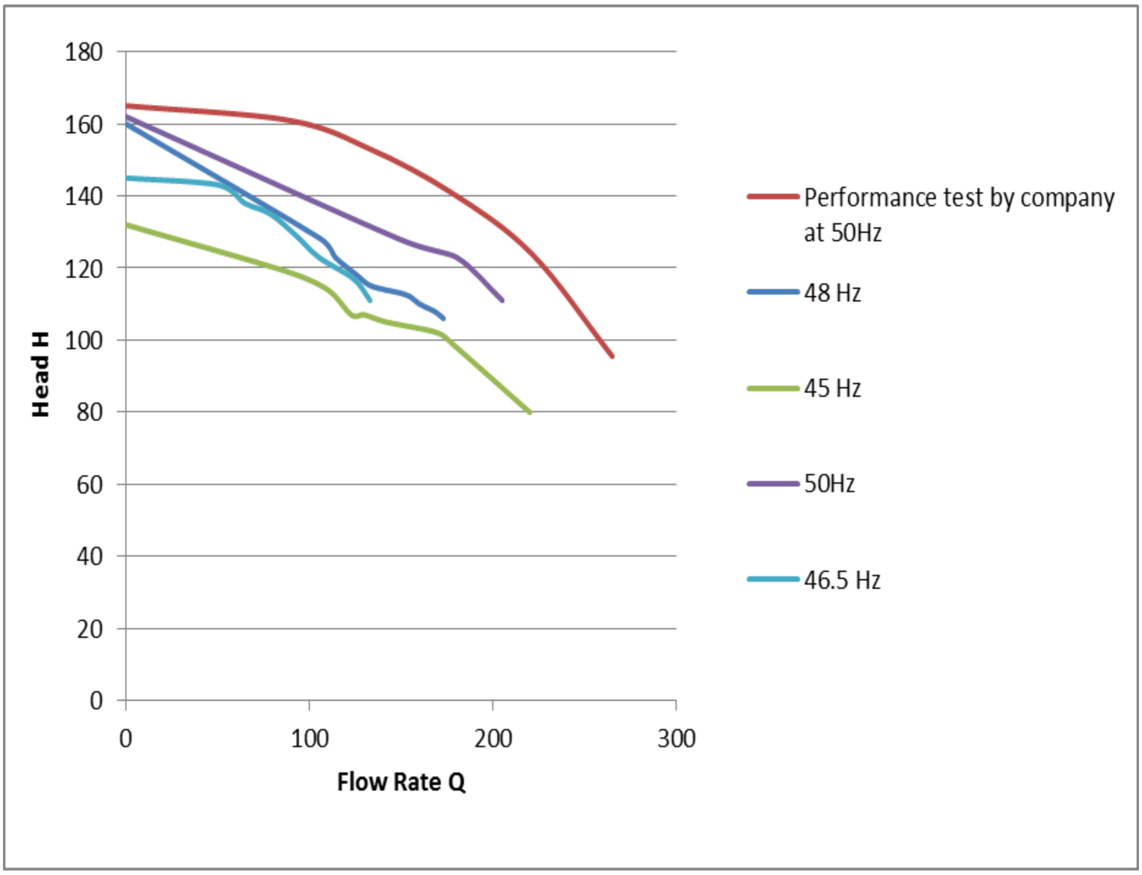


Figure (6.12) : Effect of speed variation on pump characteristics

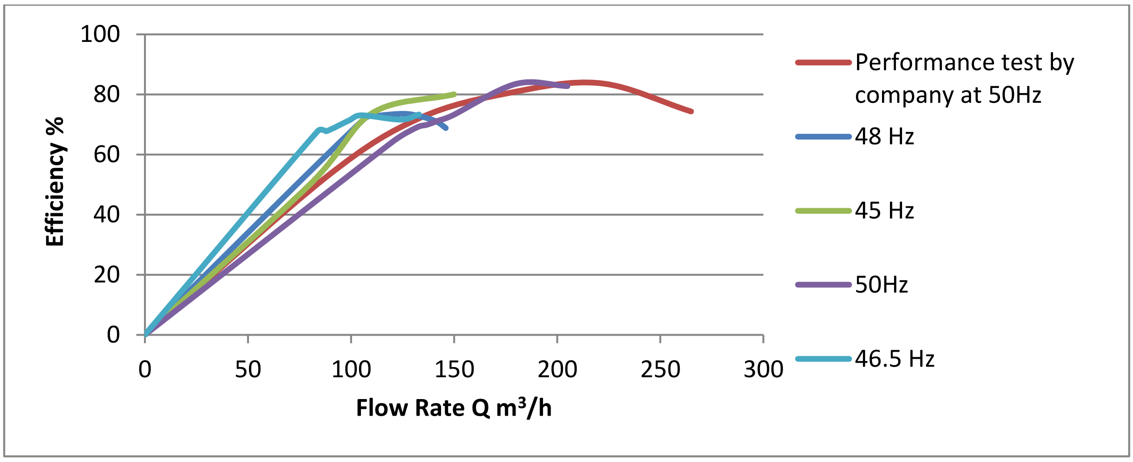


Figure (6.13):flow rate versus Efficiency of pump at deferent speeds.

At constant flow rate (Q) the variation of pumping head (H) is proportional to the supply frequency squared only in the range below the flow rate value corresponding to the peak efficiency of the pump. As previous curve show we can note the effect of change speed of the pump characteristic flow rate, head and power as affinity laws three frequencies was experimented, through experiment at each selected frequency the control vales changed step by step then record pressure cage and flow meter reading to check changing in head , flow rate through changing frequency to choose optimum operating point for pump for each frequency as demand required .

6.3.3 Practical Results for using variable frequency drive at Waleed Ribhi Well.

Mr. Waleed Ribhi well neglected from analysis due to problem in mechanical structure that caused water leakage in his network causing high cost for pumped water shown as follows.

To calculate the quantities of pumped water during experiment period from 17-09-2013 to 19-09-2013, the water meter reading recorded before experiment ($125413\,m^3$) and the record reading at the end of period was($126693 m^3$) .

From the above reading the amount of pumped water during experiment period can be calculated , by find the difference between two reading in 17-09-2013 the reading of water meter was 607870 m^3 and in 19-09-2013 the reading of water meter was 613130 m^3 as equation (6.1).

$$126693\ - 125413 = Amount\ of\ pumped\ water$$

$$Amount\ of\ pumped\ water = \ 126693\ - 125413 = 1280 m^3$$

The other recorded data at beginning of experiment by data analyzer was the energy consumption ,and it's value at 17-19-2013 (0 Wh) ,and at the end of experiment at 19-19-2013 was (1475612Wh), the following curves shown in figure (6.12) drawn by excel after transferring collected data from energy analyzer to PC to get exact reading .

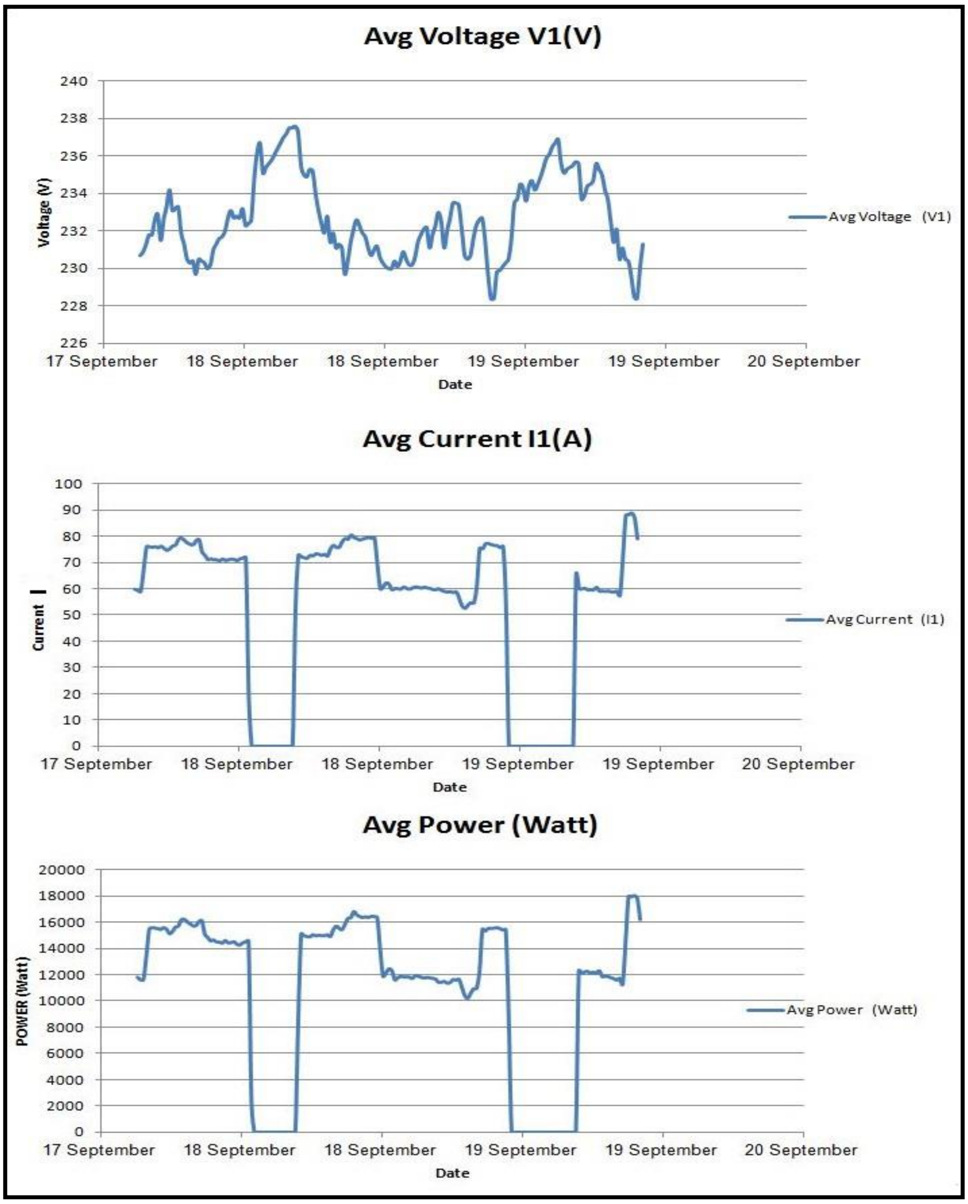


Figure (6.14) :Average voltage ,current ,total power for Waleed Ribhi pump during second testing period

$$Total\ energy\ consmption = 1475612\text{Wh} - 0 = 1475612\text{Wh}$$

$$Total\ Cost\ during\ experiemnt = 1475.612\ KWh \times 0.63\ \frac{\text{NIS}}{\text{KWh}}$$

$$= 918.29\ NIS$$

All cost calculations for energy consumption in NIS , and the cost for each KWh about 0.63 NIS / KWh , previous calculation show the total cost of energy consumption for $1280m^3$ pumped water , so final price of each cubic meter equal 0.717NIS as shown in equation (6.3) .

$$Final\ cost\ for\ one\ cupic\ metre = \frac{Total\ cost}{Amount\ of\ pumped\ water}$$

$$Final\ cost\ for\ one\ cupic\ metre = \frac{918.29\ NIS}{1280\text{m3}} = 0.717\ NIS/\text{m3}$$

The power factor and average reactive power values with variable in the Mr.Waleed Ribhiwell that use variable frequency drive , were good about 0.9 for power factor and (25 kVAR) for average reactive power as shown in figure (6.15) without using capacitor bank in the system .

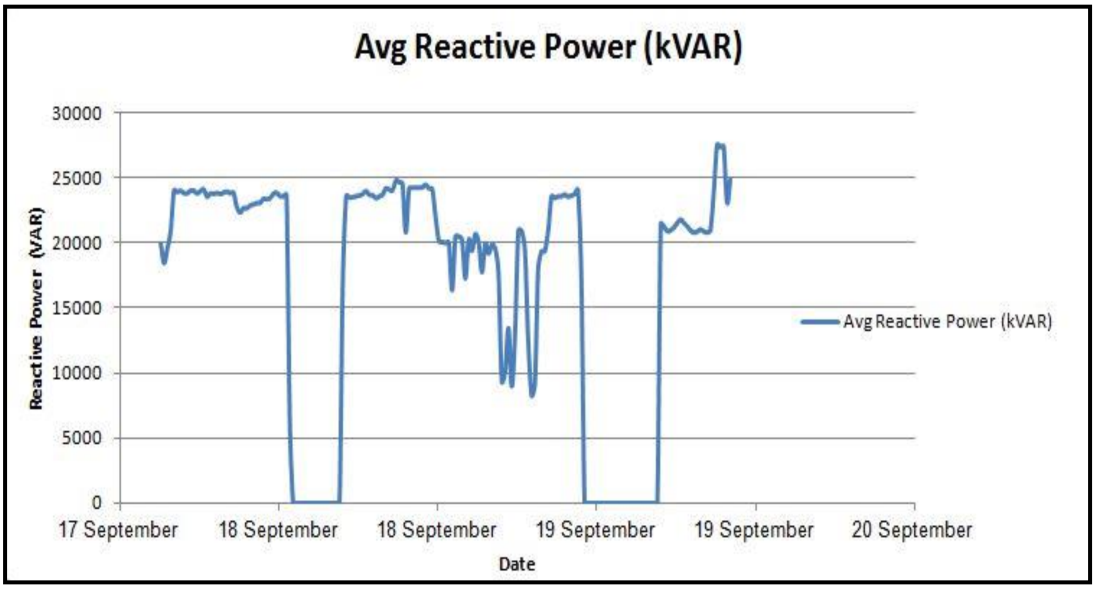


Figure (6.15): Average reactive power for Waleed Ribhi pump .

Chapter Seven

Financial Analysis

7.1 Introduction:

From the previous result, we can conclude that the primary purpose of VFD is to control the speed of an AC motor. It works by electronically changing the frequency of the power supplied to the motor. The applied voltage is also changed so that the ratio of voltage to frequency (V/Hz) is approximately constant. Since the operating speed of an AC motor is mostly determined by the frequency of the applied power, adjusting the frequency is the best means of adjusting the speed. A VFD also provides "soft" starting. When the motor is started, a very low frequency is applied and the motor starts and runs without drawing a high current. If the voltage is properly controlled, the motor can produce up to 150% of rated torque while drawing proportional current. To accelerate the motor, the frequency is gradually increased so that the required torque is provided while accelerating with limited current. But, soft starter electronically reduces the voltage applied to the motor during starting. That limits the starting current, but also limits the starting torque. Since AC motors can produce considerably more torque than their rated continuous running torque, starting with limited torque is usually acceptable. Once the motor reaches full speed, the voltage is increased to the normal running voltage for efficient operation.

7.2 Financial Analysis:

This section shows the financial analysis through comparison between soft starters and VFD cost for different sizes of both types as table (7.1) shows.

Table.(7.1): Financial Comparison between soft starter and VFD cost.

Type	Soft starter	VFD	Ratio of VFD/SS
75 HP	1330 $	3330 $	2.5
100 HP	1520 $	4166 $	2.7
150 HP	1720 $	5000 $	2.9

From the above table we can notice that initial cost for soft starter is cheaper, on the other hand VFD provides better value and can provide energy savings of up to 50 percent, thereby producing more cost savings over the life of the equipment[39], also the result of tests on previous chapter shows the importance of bypass contactors with capacitors bank to modified power factors and average reactive power values to be acceptable , so the initial cost for soft starter will increase through these additions as table (7.2) shows.

Table.(7.2): Additional cost for required components (manufactured Siemens) used with soft starter.

Component	Cost
By pass contactor 75 HP	330 $
By pass contactor 100 HP	430 $
By pass contactor 150hp	600 $
Main circuit breaker 25KVAR	15 $
Contactor capacitor 25KVAR	100 $
Capacitor bank 25KVAR	70 $

At Abo Saleh well soft starter (100 HP) totally cost will be with all additional components as equ (7.1)

$$\text{Total cost of soft starter system} = Soft\ starter\ cost + \text{Bypass contacors} + \text{Main circuit breaker} + contactor\ capicitor + capacitor\ ban \qquad (7.1)$$

$$\text{Total cost of soft starter system} = 1520\ \$ + 430\ \$ + 15\ \$ + 100\ \$ + 70\ \$ = 2135\ \$$$

VFDs can be two to three times the initial cost of Soft Starters, and generally require a slightly higher expertise to integrate into a process .On the other hand, VFD controller can help the farmers to get along running hours with low cost ,through selecting low frequency for pumping low amount of water as demand decreases by farmers , so power consumption will be less in this case versus constant frequency at 50 Hz in soft starter .

It is worth mentioning that in Tulkarm the cost to pump 130m^3/hr is 120NIS/hr and the cost in Al-Fari'a to pump 60m^3/hr is 120NIS/hr for soft start control but the cost of running hour when using VFD between 60NIS to 140 NIS differs about the running hours that the farmers need and it is adjustable by the frequency to determine the running periods.

7.3 Energy Saving Using Variable Frequency Convertor

To determine energy saving when using variable frequency at irrigation company well we need to calculate average of operation hour per day then calculate energy consumption cost per day with VFD finally compare it with energy consumption cost with soft starter at constant frequency and constant power consumption .

Energy analyzer data recorded during experiment period between 2-10-2013 to 8-10-2013 , record the operation time for the pump about 52 hours during six days . and total energy consumption exactly (2581.7404 KWh) ,also cost of kilowatt per hour equals 0.63 NIS.

$$Avg\ operation\ hour\ per\ day = \frac{52\ hr}{6\ days} = 8.67\ hr/day$$

$Avg\ power\ consumption\ per\ day = \frac{2581.7404\ \text{KWh}}{6\ days} =$

$430.29\ KWh/day$

$$Avg\ total\ Cost\ per\ day = 430.29 \frac{KWh}{day} \times \frac{0.63NIS}{KWh}$$

$$= 271.083NIS/day$$

$$Avg\ total\ Cost\ per\ year = \frac{271.083NIS}{day} \times 243 \frac{day}{year}$$

$$= 65873NIS/year$$

Chapter Eight

Conclusions And Recomendations

8.1 Conclusion

The main advantage of more than VFD Soft Starter is the speed limit . VFDs can vary the output frequency from zero to a frequency above the main motor . Rpm constant (revolutions per minute) of electric motors prevents tuning the performance of the pump

To fit with variable operating conditions , and therefore are usually reduce output pump or smothered . Variable frequency drives electric motors have

The ability to adjust the pump performance to match the operating conditions by reducing the speed of the motor and pump motor variable frequency can affect the efficiency of the pumping station for irrigation , because both the efficiency of the engine and drive efficiency decrease with decreasing rpm. Engine efficiency.

Here are some of the advantages of using variable frequency drives in well pumps :

a. Increased Reliability

Adjustable speed motor-drive systems are more reliable than traditional mechanical approaches such as using louvers, valves, gears, or turbines to control speed and flow. Because electric drives have no moving parts they provide very high reliability [39].

b. Energy Saving

Such energy cost savings are especially used in variable-torque centrifugal fan and pump applications, where the load’s torque and power vary with the square and cube, respectively of the speed. This change gives a large power reduction compared to fixed-speed operation for a relatively small reduction in speed. Also by Using a variable frequency drive to control the fluid flow with a fully open throttle saves a considerable amount of power. As most of the drives operate at part load most of the time, the accumulated energy saving or the corresponding financial benefit, may be substantial over a prolonged period of time. Because this type of fluid flow control is common in industry, widespread application of variable-frequency drives with power electronics area can help in large energy conservation. The main aim of this paper is to reduce the energy consumption by the implementation of VFD and hence the proper control of fluid flows [40].

c. Speed Variations

In some cases in pumping system we need to vary the speed of pump to change the amount of flow rate as demand either increases flow or decreases it.

d. **High Power Factor**

Power converted to motion, heat, sound, etc. is called active power and is measured in kilowatts (kW). Power that charges capacitors or builds magnetic fields is called reactive power and is measured in kVAR. The vector sum of the kW and the kVAR is the Apparent Power and is measured in KVA. Power factor is the ratio of kW/KVA. Typical AC motors may have a full load power factor ranging from 0.84 to 0.88. As the motor load is reduced, the power factor becomes low. The advantage of using VFD's is that it includes capacitors in the DC Bus itself which maintains high power factor on the line side of the VFD. This eliminates the need of additional expensive capacitor banks [41].

e. Soft starting of one or multiple motors:

When electric drives soft start large motors, the problem associated with large inrush current (mechanical wiring stress, wiring overheating and voltage dip on connected bus) is eliminated. This removes limitations on motor frequency of starts, reduces insulation damage, and provides extended motor life. With synchronization logic, one drive can start multiple motors [39].

f. **Extended equipment life and reduce maintenance**

The VFD's greatly reduce wear to the motor, extend life of the equipment and decrease maintenance costs. Due to optimal voltage and frequency control it offers better protection to the motor from issues such as electro thermal overloads, phase protection, under voltage, over voltage etc. When you start a load with a VFD you will not subject the motor or driven load to the "instant shock" of across the line starting, but can start smoothly, thereby eliminating belt, gear and bearing wear.

Table(8.1): Major comparison between soft starters and VFDs .[42]

Characteristics	SS	VFD
Initial cost	Lower	Higher
Reduces motor starting voltage	Yes	Yes
Reduces motor starting current	Yes	Yes
Reduces energy use	Some	More
Extends motor, equipment life	Yes	Yes
Varies motor speed	No	Yes
Efficiency	~ 99.5%	~ 95% - 97%
Operational complexity	Lower	Higher
Current feedback via CTs	Yes	Yes
Torque per amp ratio	Moderate	Very high
Performance parameters	Few	Many
Tuning functions	Few	Many

8.2 Recommendations

Based on the studies carried out in this thesis, the following recommendations can be made:

a. A soft starter adjusts the voltage applied to the motor to control its current and torque characteristics during startup. Silicon-controlled rectifier arrays are configured back-to-back so that the control circuit can gate them on both positive and negative excursions of the AC waveform. The control circuit controls the slope of the acceleration and deceleration ramps. The amount of the AC line voltage waveform allowed to pass through to the motor is directly proportional to the gate-firing ramp. This allows regulating the voltage applied to the motor from zero up to line voltage.

b. Soft starters offer lower initial cost, limited digital and analog diagnostic signals, simple RUN/STOP control schemes, and the ability to reduce peak current draws and mechanical shock to equipment. Soft starter applications include very large (200-500 hp) pumps, fans, mixer, and centrifuges that generally require very few starts and stops.

c. VFDs offer many application benefits such as energy efficiency, reduced stress on motors and equipment, diagnostic capabilities, and process control integration—the primary reason to use a VFD is to control motor speed. For applications that the load varies from time to time as demand the variable frequency convertor is a more suitable solution , but in constant load on motor ,pump . etc, soft starter will be a cheap solution.

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Appendix (A)

Data sheet for using pump

Pump Data Sheet - National Pump Company

Company: SMI
Name: Hassan Ismail
Date: 4/10/2012

1. A. Abu Saleh (Tulkarm)
Q = 120 m³/hr, H = 120 m @ 1500 rpm

Powered By PUMP-FLO™

Pump:

Size: J8XHC (25 stage)

Type: VERT.TURBINE
Synch speed: 1500 rpm

Speed: 1475 rpm
Dia: 6.6 in

Curve: CVJ8XH4P6CY

Impeller:

Specific Speeds:

nq: 87
S: 122

Dimensions:

Suction: ---
Discharge: ---

Pump Limits:

Temperature: 82.2 °C
Pressure: 3262 kPa g
Sphere size: 15 mm

Power: ---
Eye area: 8264 mm²

Search Criteria:

Flow: 120 m³/hr

Head: 120 m

Fluid:

Water
Density: 997.2 kg/m³
Viscosity: 1.104 cP

NPSHa: ---

Temperature: 15.6 °C
Vapor pressure: 1.773 kPa a
Atm pressure: 101.4 kPa a

Motor:

Standard: IEC
Enclosure: TEFC

Size: 55 kW
Speed: 1500
Frame: 250S

Sizing criteria: Max Power on Design Curve

---- Data Point ----

Flow:	120 m³/hr
Head:	120 m
Eff:	79%
Power:	49.5 kW
NPSHr:	2.92 m

---- Design Curve ----

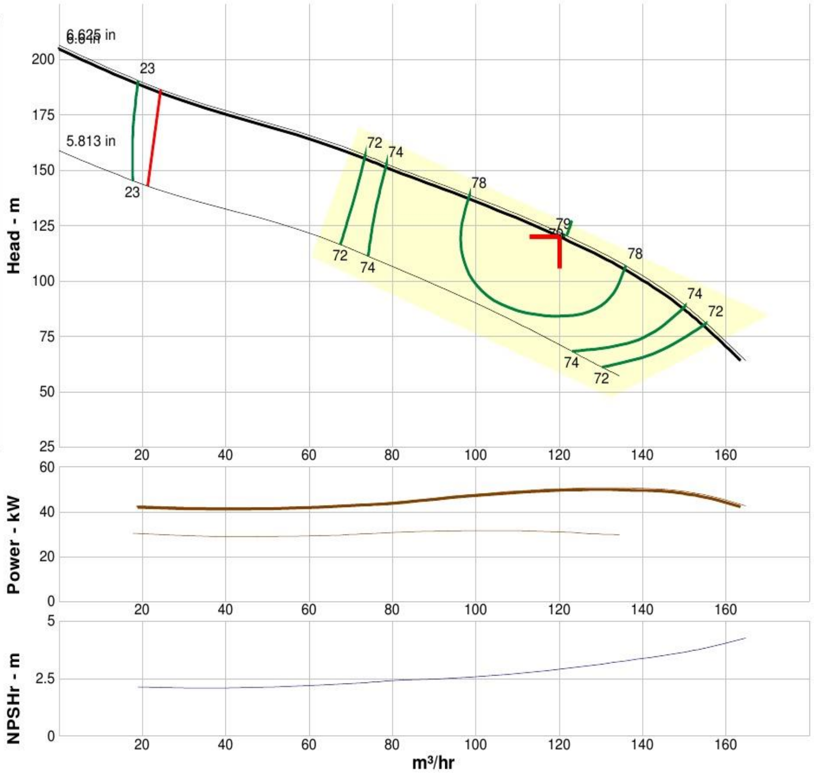
Shutoff head:	205 m
Shutoff dP:	2002 kPa
Min flow:	24.2 m³/hr

BEP: 79% @ 121 m³/hr

NOL power:
49.7 kW @ 136 m³/hr

-- Max Curve --

Max power:
50.7 kW @ 136 m³/hr



Performance Evaluation:

Flow m³/hr	Speed rpm	Head m	Efficiency %	Power kW	NPSHr m
144	1475	94.7	76	48.8	3.49
120	1475	120	79	49.5	2.92
96	1475	139	78	46.6	2.54
72	1475	156	71	43	2.32
48	1475	171	49	42.6	2.23

National Pump Selector 9

Selected from catalog: 50CY032107 Vers: 50cy0321

Pump Data Sheet - National Pump Company

Company: SMI
Name: Hassan Ismail
Date: 4/16/2014

1. Agricultural irrigation company (Tulkarm)
Q = 237 m³/hr, H = 115 m @ 1500 rpm

NATIONAL PUMP COMPANY
A GORMAN-RUPP COMPANY

Pump:

Size: E12MC (9 stage)

Type: VERT.TURB CLOSED IMP
Synch speed: 1500 rpm
Speed: 1450 rpm
Dia: 9.75 in
Curve: CVE12M4P6CY
Impeller:
Specific Speeds: nq: 49, S: 46
Dimensions: Suction: ---, Discharge: ---

Pump Limits:

Temperature: 82.2 °C
Pressure: 2600 kPa g
Sphere size: 16 mm
Power: ---
Eye area: 9077 mm²

Search Criteria:

Flow: ---
Head: ---

Fluid:

Water
Density: 998.3 kg/m³
Viscosity: 0.9946 cP
NPSHa: ---
Temperature: 20 °C
Vapor pressure: 2.339 kPa a
Atm pressure: 101.4 kPa a

Motor:

Standard: IEC
Enclosure: TEFC
Size: 111 kW
Speed: 1500
Frame: 280M
Sizing criteria: Max Power on Design Curve

---- Data Point ----

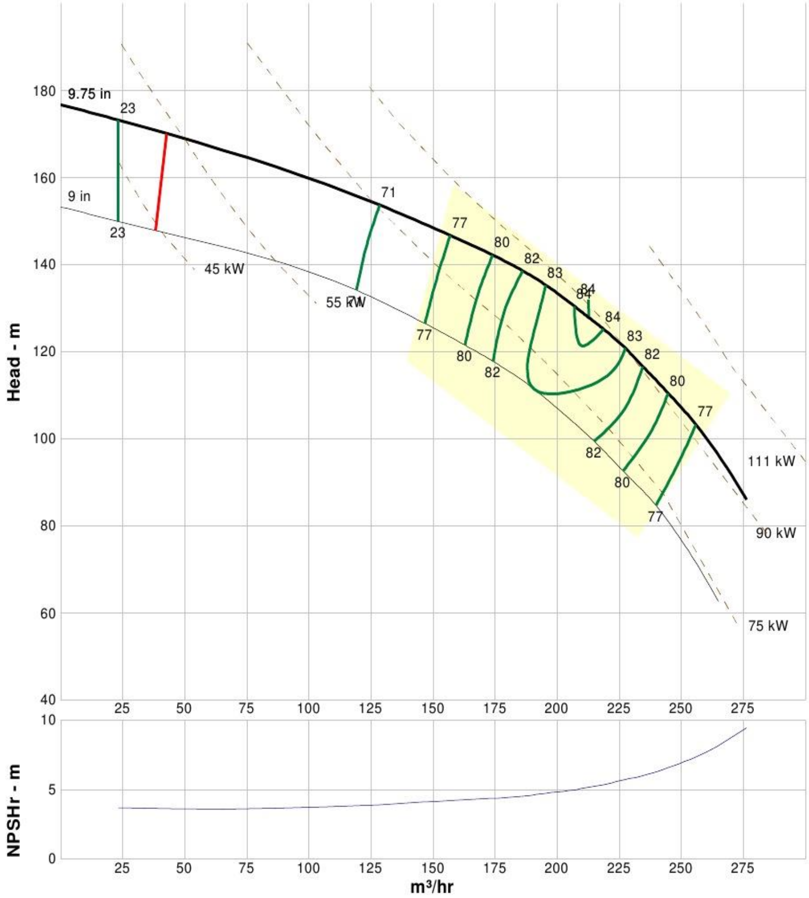
Flow: 213 m³/hr
Head: 128 m
Eff: 84%
Power: 88 kW
NPSHr: 5.19 m

---- Design Curve ----

Shutoff head: 177 m
Shutoff dP: 1731 kPa
Min flow: 42.6 m³/hr
BEP: 84% @ 213 m³/hr
NOL power:
93.3 kW @ 256 m³/hr

-- Max Curve --

Max power:
93.3 kW @ 256 m³/hr



Performance Evaluation:

Flow m³/hr	Speed rpm	Head m	Efficiency %	Power kW	NPSHr m
265	1450	95.5	74.3	92.2	8.3
221	1450	124	83.7	89	5.47
177	1450	141	80.5	84.5	4.42
133	1450	153	72	76.5	3.97
88.4	1450	161	52.7	65	3.84

National Pump Selector 10.6.0.0

Selected from catalog: National Pump Company.50 Vers: 6c011120

Appendix (B)

Electrical drawings for pump control box

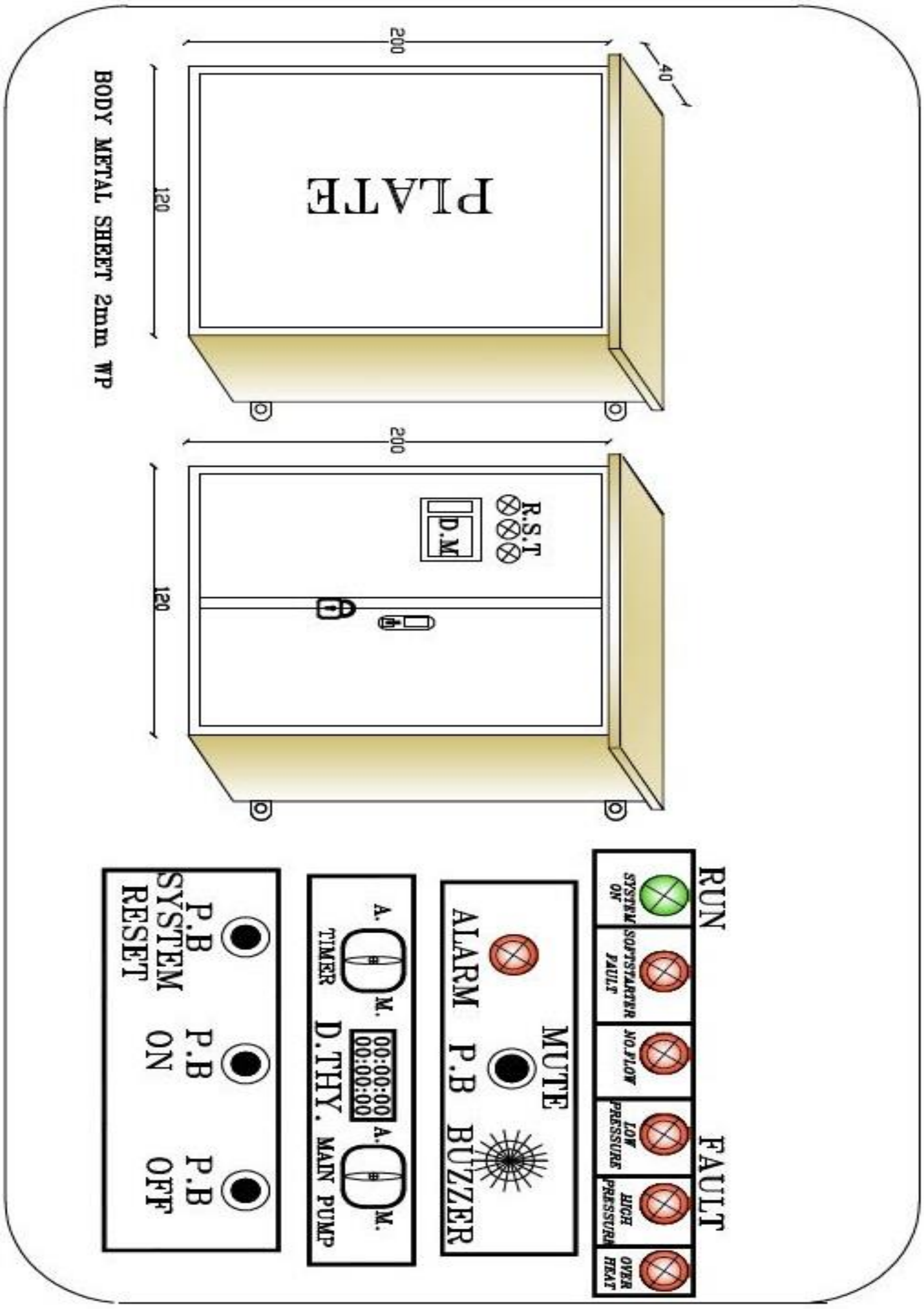


Figure A1: Front plate of the control panel

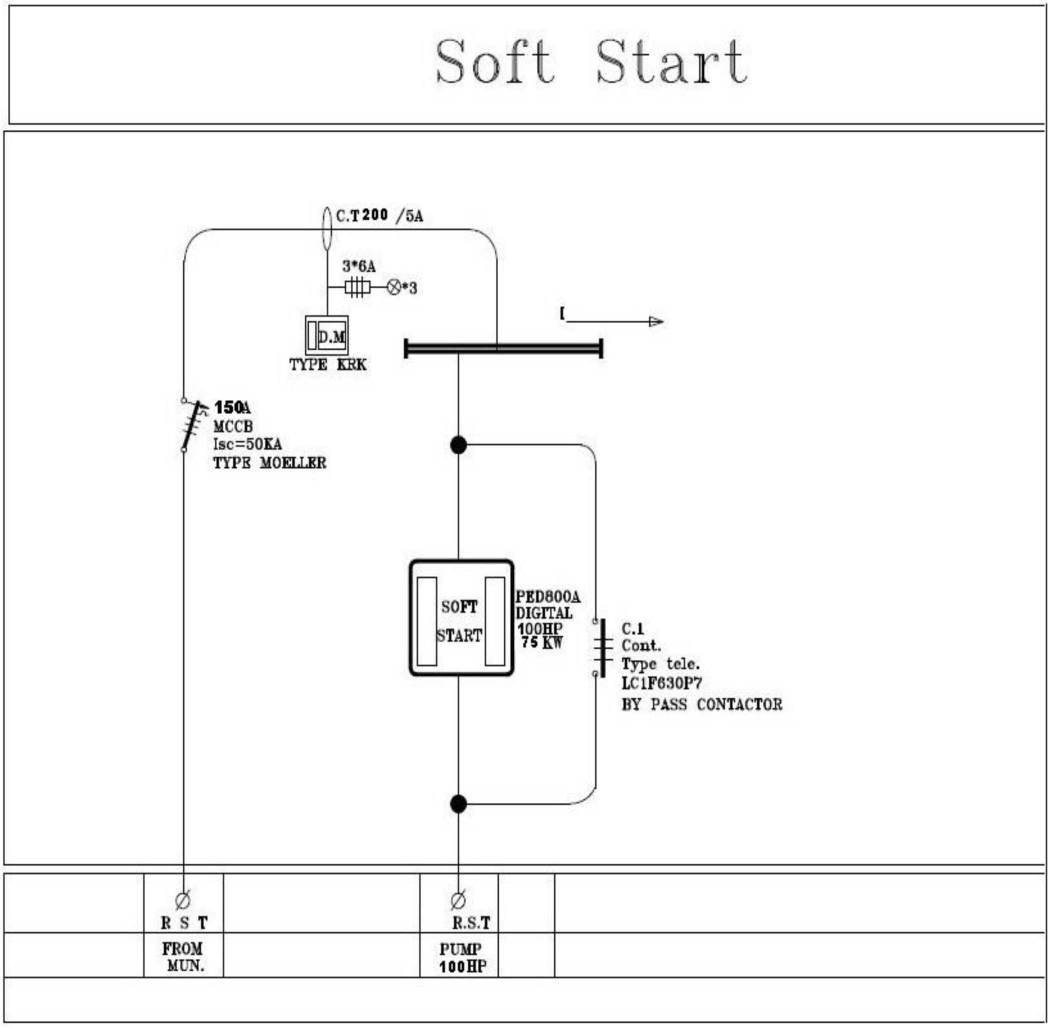


Figure A2: Power Circuit of the Control System

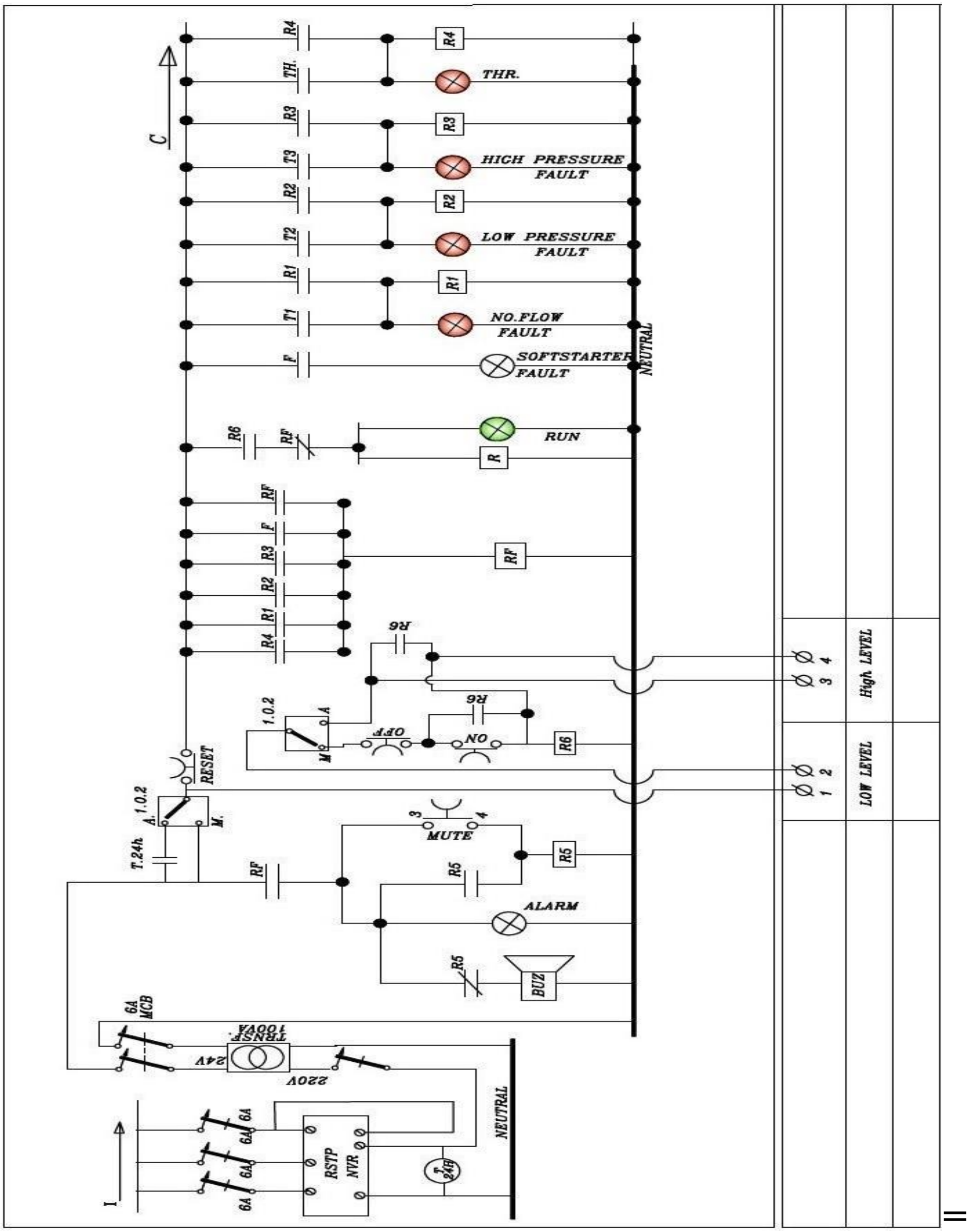


Figure A3: Control Circuit of the Control System

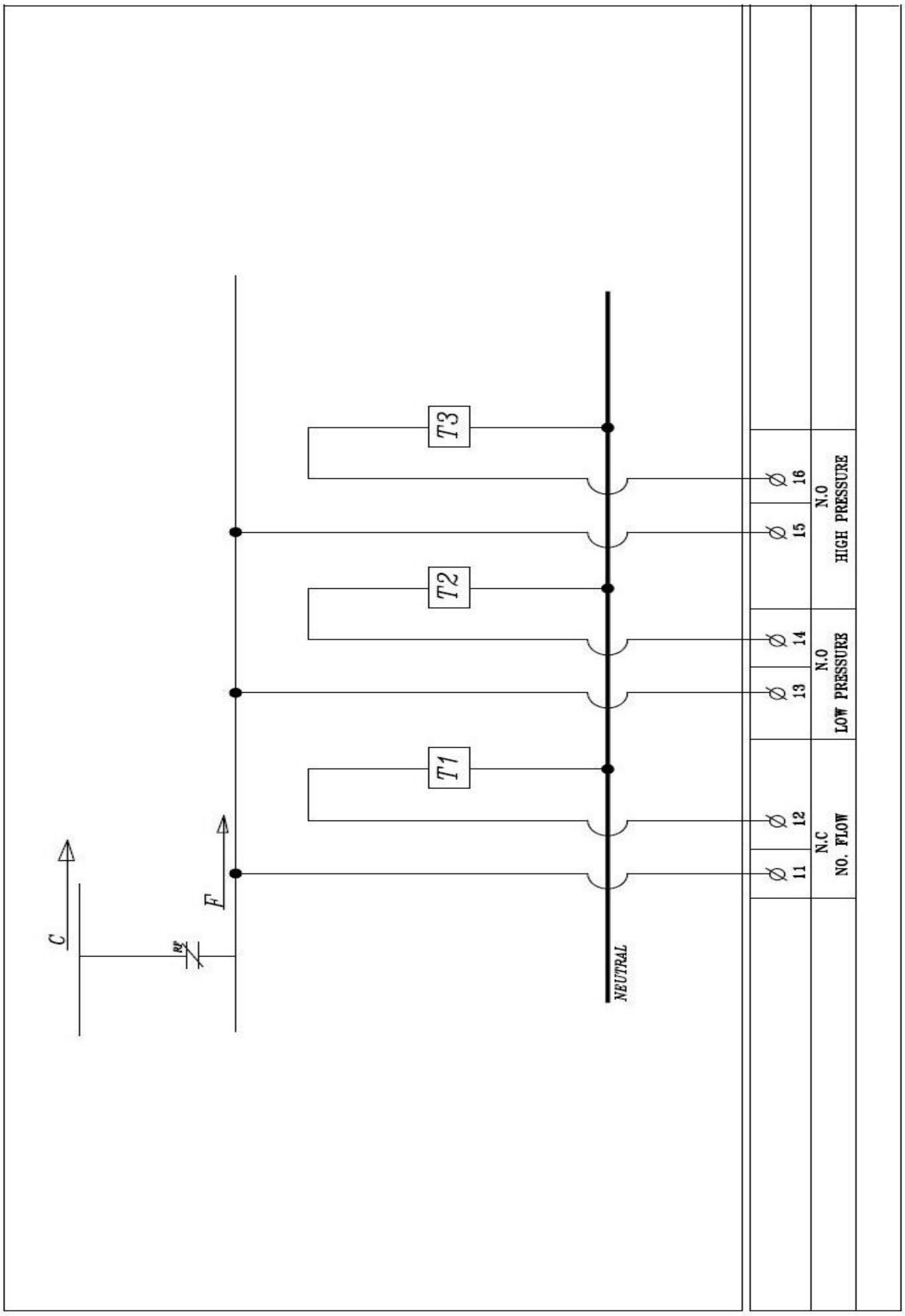


Figure A4: Control Circuit of the Control System

جامعة النجاح الوطنية

كلية الدراسات العليا

التحليل المالي و التقني في استخدام نظام التردد المتغير في مضخات المياه بالمقارنة مع التردد الثابت

اعداد

أنور ياسر ربع

اشراف

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.

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الملخص

تقنية تغيير السرعه للتحكم بضخ المياه من الابار الارتوازيه اصبحت في وقتنا الحالي من التقنيات المستخدمه في هذا المجال لما لها من فوائد عديده تعود على مستخدميها حيث انها تقلل من استهلاك الطاقه وبالتالي تقليل التكاليف على المزارعين وضخ المياه بكفاءه عاليه بالمقارنه مع التقنيات الاخرى المستخدمه.

هذا البحث قائم على دراسة العديد من انواع التحكم المستخدمه لضخ المياه وكذلك دراسة ثلاثه ابار ارتوازيه دراسه عمليه ونظريه في منطقه طولكرم حيث تستخدم هذه التقنيه في بئرين والبئر الثالث يستخدم تقنيه التردد الثابت.

يعرض هذا البحث تحليل للطالقه المستهلكه في الثلاثة ابار لمقارنه تكاليف الضخ في الابار التي تستخدم تقنيه تغيير التردد مع البئر الذي يستخدم تقنيه التردد الثابت.