DESIGN AND CONSTRUCTION OF A REACTIVE POWER CONTROL

BY

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(2006/24460EE)

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A THESIS SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF ENGINEERING IN ELECTRICAL AND ELECTRONICS ENGINEERING, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA.

NOVEMBER, 2011

DECLARATION

I, Lawal, Abdulrafiu Kehinde, declare that this work was done by me and has never been presented elsewhere for the award of a degree. I also relinquish the copyright to the Federal University of Technology, Minna.

Lawal, Abdulrafiu Kehinde 05/03/2012

(Name of student) (Signature and date)

CERTIFICATION

This is to certify that the project titled "Design and Construction of a Reactive Power Control" was carried out by Lawal, Abdulrafiu Kehinde with matric number 2006/24460EE, and submitted to the department of Electrical and Electronics Engineering, Federal University of Technology, Minna, in partial fulfilment of the requirements of bachelor degree in Engineering.

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DEDICATION

I dedicate this work to the will of the Almighty Allah.

ACKNOWLEDGEMENTS

My profound gratitude is extended to my supervisor in person of Engr. Dr. M. N. Nwohu. This work will be unjustified if I fail to mention his ever resounding commitment to the realisation of this project. From the point of conceptualization of this idea to the design, simulation, analysis of associated components and fabrication of the device, he has been supportive.

I can't but express appreciation to my colleagues and friends for their meaningful contribution to the success of this project.

I also thank my parents for their unflinching support. May the almighty Allah reward you abundantly.

ABSTRACT

This work is aimed at designing and constructing a reactive power control. This can be achieved by series connection of an equivalent capacitance to the line between the power source and the load. The construction is aimed at reducing power losses and current consumption by the load. This is the essence of this project which was realised.

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CHAPTER ONE

1.0 INTRODUCTION

Power in an electric circuit is the rate of flow of energy past a given point of the circuit. In alternating current circuits, energy storage elements such as inductance and capacitance may result in periodic reversals of the direction of energy flow. The portion of power that averaged over a complete cycle of the AC waveform, results in net transfer of energy in one direction known as real power. The portion of power due to stored energy, which returns to the source in each cycle, is known as reactive power [1].

In a simple alternating current (AC) circuit consisting of a source and a linear load, both the current and voltage are sinusoidal. If the load is purely resistive, the two quantities reverse their polarity at the same time. At every instant the product of voltage and current is positive; indicating that the direction of energy flow does not reverse. In this case, only real power is transferred.

If the loads are purely reactive, then the voltage and current are 90 degrees out of phase. For half of each cycle, the product of voltage and current is positive, but on the other half of the cycle, the product is negative, indicating that on average, exactly as much energy flows toward the load as flows back. There is no net energy flow over one cycle. In this case, only reactive energy flows—there is no net transfer of energy to the load.

Practical loads have resistance, inductance, and capacitance, so both real and reactive power will flow to real loads. Power engineers measure apparent power as the magnitude of the vector sum of real and reactive power. Apparent power is the product of the root-mean-square of voltage and current.

Engineers care about apparent power, because even though the current associated with reactive power does no work at the load, it heats the wires, wasting energy. Conductors, transformers and generators must be sized to carry the total current, not just the current that does useful work.

Another consequence is that adding the apparent power for two loads will not accurately give the total apparent power unless they have the same displacement between current and voltage (the same power factor).

Conventionally, capacitors are considered to generate reactive power and inductors to consume it. If a capacitor and an inductor are placed in parallel, then the currents flowing through the inductor and the capacitor tend to cancel rather than add. This is the fundamental mechanism for controlling the power factor in electric power transmission; capacitors (or inductors) are inserted in a circuit to partially cancel reactive power 'consumed' by the load.

Engineers use the following terms to describe energy flow in a system (and assign each of them a different unit to differentiate between them):

- Real power (P) or Active power: Watt [W]
- Reactive power (Q): volt-ampere reactive [VAR]
- Apparent power (S): volt-ampere [VA]

Reactive power does not transfer energy, so it is represented as the imaginary axis of the vector diagram. Real power moves energy, so it is the real axis.

The unit for all forms of power is the watt (symbol: W), but this unit is generally reserved for real power. Apparent power is conventionally expressed in volt-amperes (VA) since it is the product of rms voltage and rms current. The unit for reactive power is expressed as var, which stands for volt-amperes reactive. Since reactive power transfers no net energy to the load, it is sometimes called "wattless" power. It does, however, serve an important function in electrical grids and its lack has been cited as a significant factor in the Northeast Blackout of 2003.

Understanding the relationship between these three quantities lies at the heart of understanding power engineering. The mathematical relationship among them can be represented by vectors or expressed using complex numbers, $s = p + jq$ (where j is the imaginary unit) [1].

1.1 OBJECTIVE OF THE PROJECT

The objective of this project is to design a device to reduce the reactive power (VAR) consumed by loads thereby reducing the current consumed by the loads.

1.2 METHODOLOGY

The methodology employed in the actualization of this project is mainly research through the internet, relevant textbooks, simulation with multisim software package, consultation with my supervisor and colleagues. Learned individuals and technicians were also consulted.

1.3 PROJECT OUTLINE

Chapter one introduces the project work, its objective and methodology. Chapter two presents the literature review and components description. Chapter three highlights the design and implementation of the project. Chapter four discusses the testing and result. Chapter five presents the conclusion of the project.

CHAPTER TWO

LITERATURE REVIEW

2.1 HISTORICAL BACKGROUND

Reactive power flow on the alternating current transmission system is needed to support the transfer of real power over the network. In alternating current circuits energy is stored temporarily in inductive and capacitive elements, which can result in the periodic reversal of the direction of energy flow. The portion of power flow remaining after being averaged over a complete AC waveform is the real power, which is energy that can be used to do work (for example overcome friction in a motor, or heat an element). On the other hand the portion of power flow that is temporarily stored in the form of electric or magnetic fields, due to inductive and capacitive network elements, and returned to source is known as the reactive power.

AC connected devices that store energy in the form of a magnetic field include inductive devices called reactors, which consist of a large coil of wire. When a voltage is initially placed across the coil a magnetic field builds up, and it takes a period of time for the current to reach full value. This causes the current to lag the voltage in phase, and hence these devices are said to absorb reactive power.

A capacitor is an AC device that stores energy in the form of an electric field. When current is driven through the capacitor, it takes a period of time for charge to build up to produce the full voltage difference. On an AC network the voltage across a capacitor is always changing – the capacitor will oppose this change causing the voltage to lag behind the current. In other words the current leads the voltage in phase, and hence these devices are said to generate reactive power.

Energy stored in capacitive or inductive elements of the network give rise to reactive power flow. Reactive power flow strongly influences the voltage levels across the network. Voltage levels and reactive power flow must be carefully controlled to allow a power system to be operated within acceptable limits [1]. A capacitive load will cause a 90 degree phase shift between voltage and current. The resulting power will have a value of zero every time the voltage or current has a zero value since the two quantities are multiplied to get power. This is not a desirable model because although the source is generating power, no work is being done at the load. This type of power is known as "reactive" power because it counteracts the effects of true power. Reactive power is the lazy brother of true power. True power is doing all the work while reactive power is actually taking away from the power in the system making the true power work harder to get the job done. A capacitive load will introduce negative reactive power and the voltage "lags" the current waveform by 90 degree, while an inductive load will introduce positive reactive power and the voltage "leads" the current waveform by 90 degree. This is because capacitors "generate" reactive power and inductors "consume" reactive power[2].

2.2 REACTIVE POWER

Reactive power is a quantity that is normally only defined for alternating current (AC) electrical systems. The popular grid is almost entirely an AC system where the voltages and currents alternate up and down 60 times per second (not necessarily at the same time). In that sense, these are pulsating quantities. Because of this, the power being transmitted down a single line also "pulsates" although it goes up and down 120 times per second rather 60 times. This power goes up and down around some "average" value- this average value is called the "real" power and over time you pay for this in kilowatt-hours of energy. If this average value is zero, then all of the power being transmitted is called "reactive" power. You would not normally be charged for using reactive power because you are consuming some energy half the time, and giving it all back the other half of the time (for a net use of zero). To distinguish reactive power from real power, we use the reactive unit called "VAR" which stands for Volt-Ampere-Reactive. Voltage in an electrical system is analogous to pressure in a water system. Current in an electrical system is analogous to the flow of water in a water system.

Let's go back to the notion that voltage and current may not go up and down at the same time, only real power is being transmitted. When the voltage and current go up and down at different times, reactive power is being transmitted. How much reactive power and which direction it is flowing on a transmission line depend on how different these two times are.

Two extreme examples of the time relationship between voltage and current are found in inductors and capacitors. An inductor is a coil of wire that is used to make motors. A capacitor is made of parallel conductive plates separated by an insulating material. The electrical properties of these two devices are such that if they are both connected to the same AC voltage source, the inductor absorbs energy during the same "half cycle" that the capacitor is giving energy. And similarly, the inductor produces energy during the same "half cycle" that the capacitor absorbs energy. Neither of them absorbs any real power over one complete cycle. Thus, when a motor needs reactive power, it is not necessary to go all the way back to electric power generators on the transmission grid to get it. You can simply put a capacitor at the location of the motor and it will provide the VARS needed by the motor. This relieves the generator and all the lines between the generator and the motor of having to transmit those VARS. They are provided "locally" by the capacitor. This means that with the capacitors installed, the current in the lines will be smaller than when the capacitors are not installed. This is a good thing because current in the lines causes heat and every line can only handle a limited amount of current. Since the line current is smaller when the capacitors are installed, the voltage drop along the lines is also less, making it more likely that the motor will have a voltage closer to the desired value. When there are not enough VARS flowing locally to the loads, the generators must supply them remotely, causing unnecessarily large currents and a resulting drop in voltage everywhere along the path [2].

2.3 POWER FACTOR

The ratio between real power and apparent power in a circuit is called the power factor. It's a practical measure of the efficiency of a power distribution system. For two systems transmitting the same amount of real power, the system with the lower power factor will have higher circulating currents due to energy that returns to the source from energy storage in the load. These higher currents produce higher losses and reduce overall transmission efficiency. A lower power factor circuit will have a higher apparent power and higher losses for the same amount of real power.

The power factor is one when the voltage and current are in phase. It is zero when the current leads or lags the voltage by 90 degrees. Power factors are usually stated as "leading" or "lagging" to show the sign of the phase angle of current with respect to voltage.

Purely capacitive circuits cause reactive power with the current waveform leading the voltage wave by 90 degrees, while purely inductive circuits cause reactive power with the current waveform lagging the voltage waveform by 90 degrees. The result of this is that capacitive and inductive circuit elements tend to cancel each other out.

waveform lagging the voltage waveform by 90 degrees. The result of this is that capacitive and inductive circuit elements tend to cancel each other out.

Where the waveforms are purely sinusoidal, the power factor is the cosine of the phase angle (φ) between the current and voltage sinusoid waveforms. Equipment data sheets and nameplates often will abbreviate power factor as "cos □" for this reason.

Example: The real power is 700 W and the phase angle between voltage and current is 45.6°. The power factor is $\cos(45.6^0) = 0.700$. The apparent power is then: $\left(\frac{700W}{\cos(45.6^0)}\right) = 1000VA$ [3].

Various causes which may be attributed to low power factor include:

- Inductive loads. Especially lightly loaded induction motors and transformers.
- Induction furnaces
- Arc lamps and arc furnaces with reactors
- Fault limiting reactors
- High voltage

2.4 APPARENT POWER

The apparent power is a combination of both reactive power and true power. True power is a result of resistive components and reactive power is a result of capacitive and inductive components. Almost all circuitry on the market will contain a combination of these components. Since reactive power takes away from true power, it must be considered in a system to ensure that the apparent power output from a system is sufficient to supply the load. This is a critical aspect of understanding AC power source because the source must be capable of supplying the necessary volt-amp power for a given application. As with any product, understanding the needs and specifications of the end user will ensure a successful application [4].

CHAPTER THREE

DESIGN AND IMPLEMENTATION

This chapter discusses in detail the steps involved in the design, simulation and implementation of the project. Here, every term used in this work is defined, also necessary calculations are shown.

3.1 DEFINITION OF TERMS

AC power flow has three components: real power (also known as active power) (P), measured in watts (W); apparent power (S), measured in volts-amperes (VA); and reactive power (Q), measured in volt-amperes reactive (vars).

The power factor is defined as:

$\phi = \cos^{-1}\left(\frac{p}{s}\right)$ from power triangle (1)

In the case of a perfectly sinusoidal waveform, P, Q and S can be expressed as vectors that form a vector triangle such that:

$s^2 = p^2 + q^2$ (2)

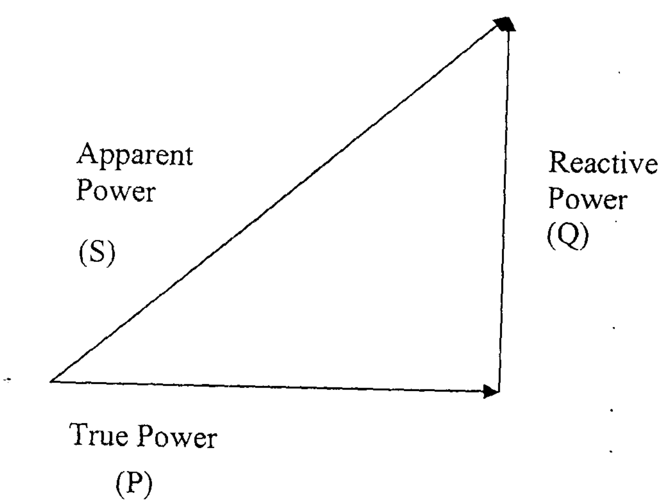

Figure 2.1: Power Triangle

Since the units are consistent, the power factor is by definition a dimensionless number between 0 and 1. When power factor is equal to 0, the energy flow is entirely reactive, when the power factor is 1, all the energy supplied by the source is consumed by the load. Power factors are usually stated as "leading" or "lagging" to show the sign of the phase angle.

If a purely resistive load is connected to a power supply, current and voltage will change polarity in step, the power factor will be unity (1), and the electric energy flows in a single direction across the network in each cycle. Inductive loads such as transformers and motors (any type of wound coil) consume reactive power with current waveform lagging the voltage. Capacitive loads such as capacitor banks or buried cable generate reactive power with current phase leading the voltage. Both types of load will absorb energy during part of the AC cycle, which is stored in the device's magnetic or electric field, only to return this energy back to the source during the rest of the cycle.

For example, to get 1kW of real power, if the power factor is unity, 1kVA of apparent power needs to be transferred $\left(\frac{1kW}{1}\right) = 1kVA$. At low values of power factor, more apparent power needs to be transferred to get the same real power. To get 1kW of real power at 0.2 power factor, 5kVA of apparent power needs to be transferred $\left(\frac{1kW}{0.2}\right) = 5kVA$. The apparent power must be produced and transmitted to the load in conventional fashion, and is subject to the usual distributed losses in the production and transmission processes.

Electrical loads consuming alternating current power consume both real and reactive power. The vector sum of real and reactive power is apparent power. The presence of the reactive power causes the real power to be less than the apparent power, and so, the electric load has a power factor less than 1[5].

3.2 DESIGN MODULE

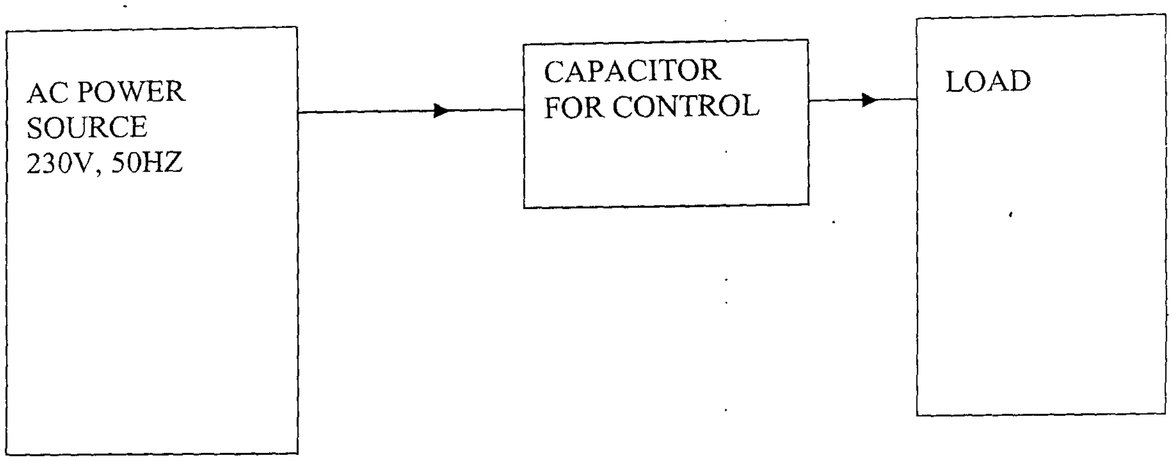

Figure 3.1: Design modules

The design module is as depicted in Figure 3.1 above. The figure shows every part of the design, the link from module to module up to the final part of the design which is the load. The system indicates the actual aim of the work, which is to reduce the reactive component in the system by installing a reactive power control unit, and finally connecting to the load.

3.3 DESIGN ANALYSIS AND SIMULATION

This project work was simulated on the environment of NI multisim software package and it was found to be achievable. The simulation was made based on a system feeding a load.

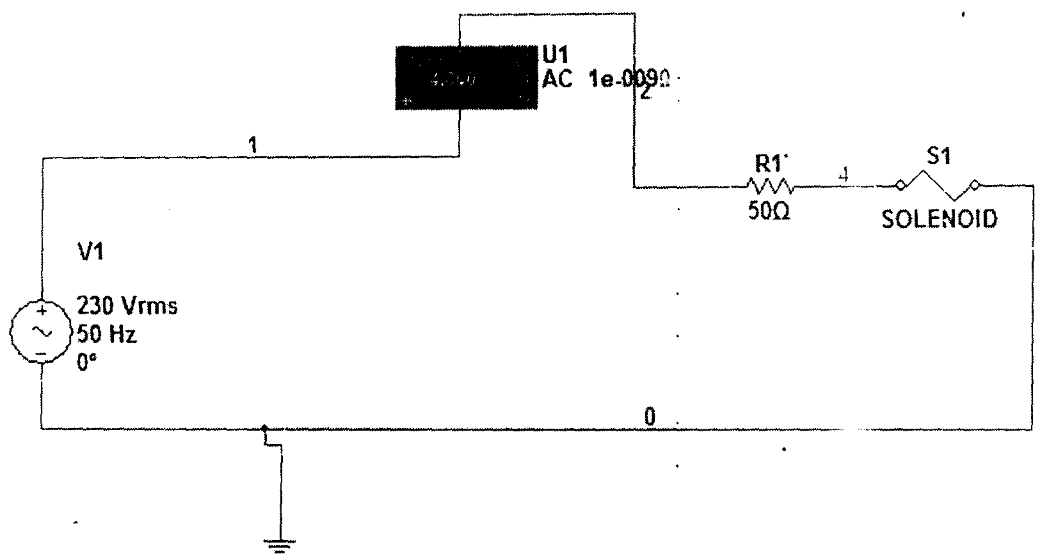

Figure 3.2: Simulation before applying capacitor

The circuit used in the simulation above shows a source feeding a load with a wattmeter connected across to read the real power (P) flowing in the network.

From the simulation, the following data were gathered:

Real power, $P = 998.095W$

Current, $I = 4.600A$

Apparent power, $S = 1058VA$

The Reactive power is then found using the relation:

$$Q = \sqrt{\left(S^2 - P^2\right)} \tag{3}$$

$$Q = \sqrt{\left(1058^2 - 998.095^2\right)} = 350VAR$$

Now, working towards a new reactive power of 500VAR. We use the relations [2]

$$Q_{new} = \frac{V^2}{X_c} \tag{4}$$

$$X_c = \frac{230^2}{500} = 105.8\Omega$$

$$C = \frac{1}{2\pi \times f \times X_c} \tag{5}$$

$$C = \frac{1}{2\pi \times 50 \times 105.8} = 30\mu f$$

From the result obtained above, we need 30µf capacitance in order to achieve the desired reactive power.

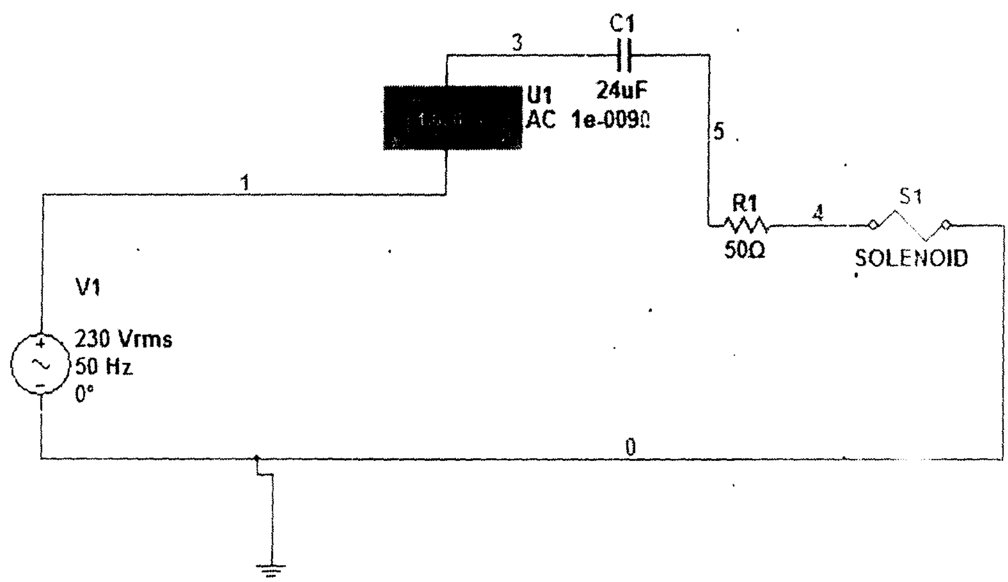

Figure 3.3: Simulation after applying capacitor

3.4 AC POWER UNIT

The power source used in the design and implementation of this work is a single phase 230V, 50Hz AC power. This source is connected directly to other circuit module and components.

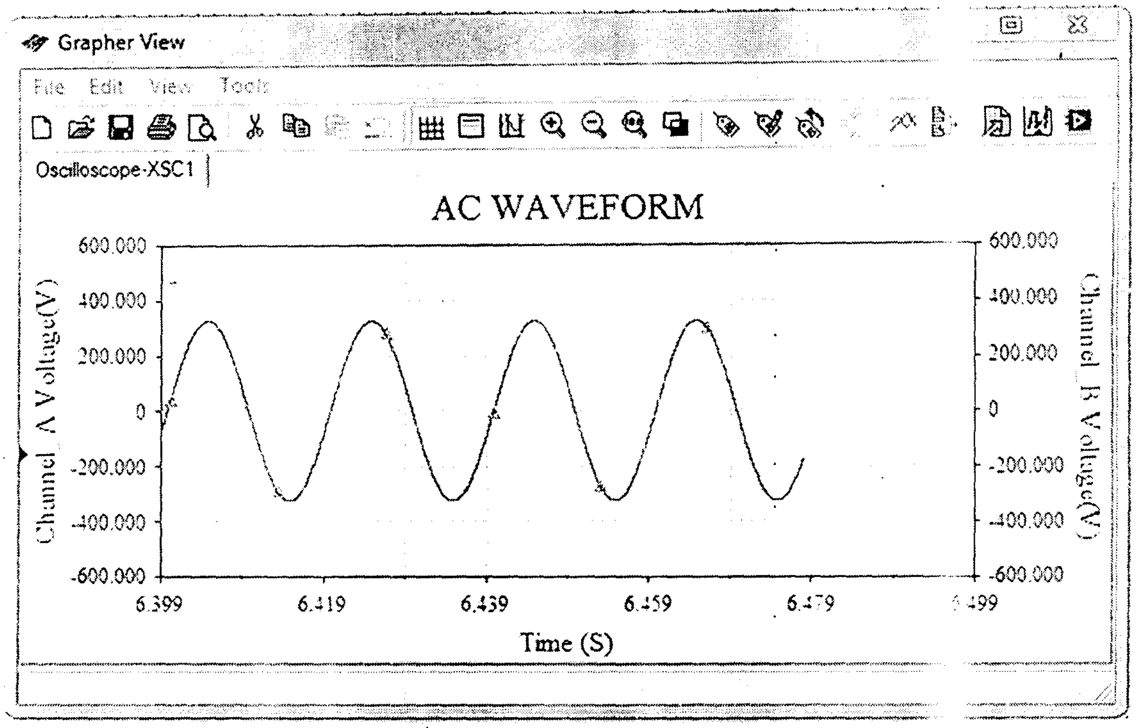

Figure 3.4: Capture of a single phase waveform

The voltage value obtained from Figure 3.4 above is 325.802V. This value is the peak value of voltage. The rms value can be obtained thus:

$$v_{rms} = \frac{v_{peak}}{\sqrt{2}} \tag{7}$$

$$v_{rms} = \frac{325.802}{\sqrt{2}} = 230V$$

3.5 REACTIVE POWER CONTROL UNIT

The reactive power control unit is the main unit in the design since it performs the main objective of the work. This unit contains capacitor with the required capacitance needed to regulate the reactive power consumed by the load. This unit also reduces current drawn from the source. The capacitor employed in this work is a 24μf, 300V.

3.6 CAPACITOR

A capacitor is composed of two conductors separated by an insulating material called a Dielectric. The dielectric can be paper, plastic film, ceramic, air or a vacuum. The plates can be aluminium discs, aluminium foil or a thin film of metal applied to opposite sides of a solid dielectric. The conductor - dielectric - conductor sandwich can be rolled into a cylinder or left flat. Sometimes capacitors are used to smooth a current in a circuit as they can prevent false triggering of other components such as relays. When power is supplied to a circuit that includes a capacitor: the capacitor charges up. When power is turned off the capacitor discharges its electrical charge slowly. They are essential, for example, in radio and television receivers and in transmitter circuits. The type of capacitor employed in an application is dependent on the function required of it. Capacitors store charges and energy; they can be connected in series and parallel depending on desired result. Capacitors are of different types and ratings. We have both electrolytic and non-electrolytic capacitors. Electrolytic capacitors are polarized which means they have a positive and negative lead and must be positioned in a circuit the right way round (the positive lead must go to the positive side of the circuit). They also have a higher capacitance than non-electrolytic capacitors. Non-electrolytic capacitors usually have a lower capacitance. They are not polarized (do not have a positive and negative lead) and can be placed any way around in a circuit. They are normally used to smooth a current in a circuit [6].

The type of capacitor used for the power factor correction is the non-electrolytic type. These are motor starting capacitors which take alternating current.

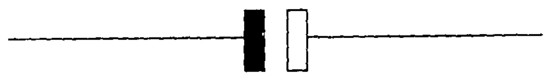

Figure 3.5: Symbol of a non-electrolytic capacitor

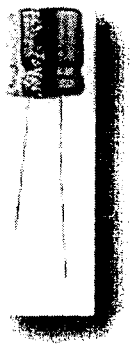

Plate I: Pictorial view of an electrolytic capacitor. Plate II: A Non-electrolytic capacitor.

From the pictures in Plate I and Plate II above, it would be observed that an electrolytic capacitor has one of the leads longer while a non-electrolytic capacitor has both leads in equal length.

3.7 CIRCUIT DIAGRAM

The circuit diagram shows the component to component connections.

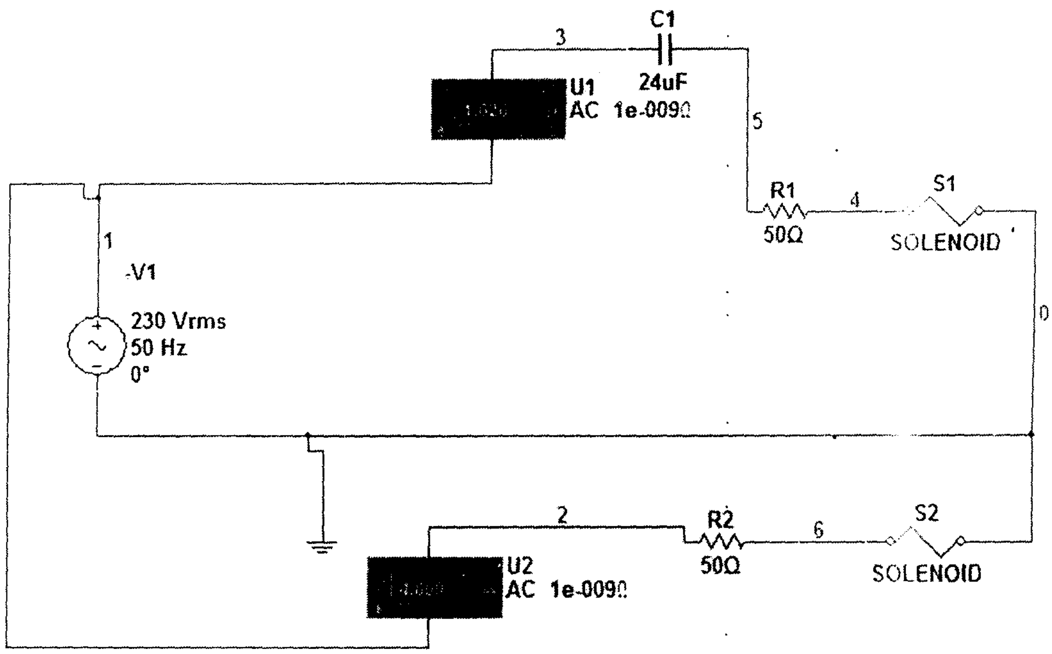

Figure 3.6: Circuit diagram

As explained earlier in the circuit module. The system consists of two parts for comparison. From the circuit diagram, the source feeds the two systems and they share a common. For the control to be effected in only one part, capacitor is connected only in a line while the other part is connected directly to load without a capacitor. The current consumed in the controlled part is found to be smaller compared to the other part.

CHAPTER FOUR

TESTS, RESULTS AND DISCUSSION

4.1 TESTS

The different results obtained as the construction was tested are represented in the table below.

The readings on the table are obtained from tests carried out on the simulation.

4.2 RESULTS

Table 4.1: Simulation results

	BEFORE CONTROL	AFTER CONTROL
REAL POWER(P)	998.095W	998.095W
APPARENT POWER (S)	1058VA	373.98VA
CURRENT(I)	4.600A	1.626A
REACTIVE POWER (Q)	1058VAR	- 925VAR

4.3 DISCUSSION OF RESULTS

From Table 4.1, it can be observed that the current drawn by the load reduced which is as a result of the reduction in reactive power of the load, likewise the apparent power. Thus, the current consumption has been reduced by the installed capacitor hence, the current in the line is smaller than when the capacitors are not installed. The negative reactive power means that the reactive power is flowing in the direction opposite from convention. This also means that the current leads the voltage due to the capacitance. The reduction in current drawn depends also on the capacitance in the system.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

It can be concluded from the results obtained and discussed in this work that: the reactive power consumed by a load can be reduced by connecting an equivalent capacitance in series between the source and the load.

It can also be seen that the load consumes smaller current when the reactive power is reduced.

5.2 RECOMMENDATIONS

An improvement that could be made to this reactive power control is to provide an automatic means of determining and providing the reactive power required to drive the load by switching in the appropriate capacitance in the line depending on the demand or condition of the load.

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