POWER FACTOR CORRECTION OF THREE PHASE INDUCTION MOTOR FOR ENERGY SAVING

MUHAMMAD FAIZ B. AHMAD

THIS REPORT IS SUBMITTED IN PARTIAL FULFILLMENT OF REQUIREMENTS FOR THE DEGREE OF BACHELOR IN ELECTRICAL ENGINEERING (POWER INDUSTRY)

Fakulti Kejuruteraan Elektrik
Kolej Universiti Teknikal Kebangsaan Malaysia

March 2005

"Saya/~~kami~~* akui bahawa saya telah membaca karya ini pada pandangan saya/~~kami~~ karya ini adalah memadai dari skop dan kualiti untuk tujuan penganugerahan Ijazah Sarjana Muda Kepujian Elektrik (Kuasa Industri)."

Tandatangan : ....

Nama Penyelia : PROF. DR. MARIZAN B. SULAIMAN

Tarikh : 14/3/2005

ACQUISITION

"Saya mengakui laporan ini adalah hasil kerja saya sendiri kecuali ringkasandan petikan yang tiap-tiap satunya saya jelaskan sumbernya."

Tandatangan : ....

Nama Penulis : Muhammad Faiz B. Ahmad

Tarikh : ....9/03/05..........................

ACKNOWLEDGEMENTS

Alhamdulillah, thank you to Allah S.W.T, because give me a good health and hard work, finally I have been completing my final project, to get the Degree of Bachelor of Electrical Engineering (Industry Power)

I would like to express special recognition and appreciation to the Prof. Dr. Marizan for the professional support and responsible for providing guidance that had been given to complete this final year project. Without him, it would be hard to finish it.

Special thanks I will wish to all Electrical engineering lecturer and staff, for helping me to solve all confusing and problem while completing this project.

To my friend, Tasykai I like to express my gratitude, because of his blessing, money supported to buy equipments, printing , so that I have finish this project successfully.

Last but not least, to my beloved family who helping me from pre school until now, who supporting financial and others to me, thanks a lot

Finally, to who are not in the list that I can't mention your name here because of the space and I know that you are helping me from behind. A lot of love from me.

Thank you.

ABSTRACT

In electrical installations with a low power factor, significant cost savings can be made through the application of power factor corrections (PFC). These savings are achieved largely due to the way electrical utilities bill their customers. Improvement of power factor can be reduce power costs, release electrical capacity of the distribution system, raise the voltage level and reduce system losses. Using delta connection capacitor banks for PFC is a very well established approach. More than 70 percent induction motors are the most widely used motors in industrial and commercial applications. When sizing and locating capacitors for PFC, many designers tend to base their calculations on maximizing the revenue from such installation and maximizing the energy savings. This project focuses on those phenomena "other side of PFC" that can cause significant damage and disruption to a given power system. The scope of the project includes an outline on some available mathematical tools to analyze these phenomena and apply them on a study of an industrial power system. The result will be obtained from the simulation software before installation of the PFC capacitor.

ABSTRAK

Dalam pemasangan peralatan elektrik, penjimatan kos boleh dibuat melalui aplikasi pembetulan faktor kuasa. Penjimatan ini boleh diperolehi dengan besar melalui bil yang diberikan oleh pembekal tenaga elektrik kepada penggunanya. Peningkatan faktor kuasa boleh mungurangkan kos, mengurangkan kapasiti elektrik yang berlebihan melalui sistem pengagihan, meningkatkan kadar voltan serta mengurangkan kehilangan dalam system. Penggunaan sambungan delta bagi pembetulan faktor kuasa adalah pendekatan yang terbaik. Lebih kurang 70 peratus motor yang digunakan dalam industri dan penggunaan komersial adalah motor induksi. Dalam menentukan nilai kapasitor, kebanyakan pereka menentukan nilai kapasitor berdasarkan keputusan pengiraan yang dilakukan supaya dapat meningkatkan penjimatan kuasa. Projek ini memfokuskan kepada fenomena "disebalik tabir pembetulan faktor kuasa" yang mana jika tidak dilakukan boleh menyebabkan kerosakan kepada sistem tersebut. Skop projek ini termasuk penggunaan formula matematik yang sedia ada dan menganalisis fenomena serta sebagai pembelajaran dalam sistem kuasa di indutri. Keputusan yang diperolehi akan membolehkan satu perisian pengiraan sebelum kapasitor itu dipasang.

TABLE OF CONTENTS

CHAPTER		TITLE	PAGE
		Approval	
		Project Title	
		Acquisition	ii
		Acknowledgement	iii
		Abstract	iv
		Abstrak	v
		Table of content	vi
		List of Table	ix
		List of Figure	x
1	**INTRODUCTION**		
	1.1	Introduction	1
	1.2	Project Objective	3
	1.3	Project Overview	3
2	**LITERATUE REVIEW**		
	2.1	Literature Riview	4
	2.2	Comment of Review	5

3 **THEORETICAL ANALYSIS**

3.1 Power Triangle 6
3.2 Calculating power factor 9
3.3 Calculating Review 14

4 **DATA COLLECTED**

4.1 Power Factor Study 15
4.2 Induction Motor 16
4.3 Capacitor banks 19
4.3.1 Purposes of fixed capacitors 20
4.3.2 VAR support 23
4.3.3 Voltage control 23
4.3.4 Increased systems capacity 24
4.3.5 Reduced billing charges 25
4.3.6 Calculation for delta connection 26
4.3.7 Calculation for wye connection 28
4.3.8 Comparison 29

5 **RESULT**

5.1 About the Software 30
5.2 Benefits of the Project 33
5.3 Flowchart 34
5.4 Possible application in industry and discussion 36
5.5 Energy Saving 36
5.6 Future Suggestion 37

CONCLUSION 38

REFERENCES 39

APPENDIX 40

APPENDIX A

VB Programming

LIST OF TABLE

No	Title	Page
1	Table 4.1 – Power Equation	8
2	Table 4.1—Summary of benefits of applying power capacitors	21
3	Table 4.2—Voltage and kVAR ratings for 60 Hz capacitors	22

LIST OF FIGURE

No	Title	Page
1	Figure 3.1 - Power Triangle	7
2	Figure 3.2 – Example for calculation	9
3	Figure 3.3– Circuit using 22uF capacitor	11
4	Figure 4.1 - Motor current components	17
5	Figure 4.2 - Toshiba Motor full load efficiency.	18
6	Figure 4.3 - Effect of adding capacitors	20
7	Figure 4.4 - Economical system power factor	25
8	Figure 4.5 – Power Trigonometry	26
9	Figure 5.1 – Interface of the software	30
10	Figure 5.2 - The fields to key in the data	31
11	Figure 5.3 – Calculated value appear	32
12	Figure 5.4 - Flowchart	35

CHAPTER 1

POWER FACTOR CORRECTION (PFC) OF THREE PHASE INDUCTION MOTOR FOR ENERGY SAVING

1.1 Introduction

Low power factor is usually not that much of a problem in residential homes. It does however become a problem in industry where multiple large motors are used. Power Factor Correction (PFC) Capacitors are normally used to try to correct this problem.

In electrical installations with a low power factor, significant cost saving can be made through the application of power factor correction (PFC). These saving are achieved largely due to the way electrical utilities bill of their customers. Improvement of power factor can reduce power costs, release electrical capacity of the distribution system, raise the voltage level and reduce the system losses. Using delta connection capacitor banks for PFC is a very well establish approach. More than 70% motor widely used is induction motor in industrial and commercial applications.

When sizing and locating capacitors for PFC, many designers tend to base their calculations on maximizing revenue from such installation by minimizing utility bills and maximizing the energy saving. This project focuses on those phenomena "other side of PFC" that can cause significant damage and disruption to a given power system.

The scope of the project includes an outline on some available mathematical tools to analyze these phenomena and apply them on a study on an industrial power system. The result will be obtained from the simulation to the hardware which using this capacitor banks.

We consider in induction motors because 70 percent of them are using induction motors. Penalty has to for the low power factor largely due to the way electrical utilities bills were design. By supplying this capacitor banks, energy savings can improve because the reactive current supplied by capacitor than utility. Low voltage capacitors are traditionally a high reliability maintenance-free device. This is a rate structure charge imposed to encourage the industrial, commercial and institutional user to improve power factor (PF).

With Tenaga Nasional Bhd. (TNB), penalty billing is imposed when the PF drops below 0.85 (85%). In most cases, the least expensive, the most efficient and most reliable method to reduce this charge (improved PF) is by adding properly designed fixed capacitor banks. PFC capacitors supply the necessary reactive portion of power (kVAR) for inductive devices. Because the capacitors supply this necessary power, the electric utility does not have to supply it, resulting in reduced generating costs for the utility.

1.2 Project Objective

The main objective of this project is to find the appropriate value of capacitor banks to connected delta type to induction motor. When these things happen, automatically energy saving can be achieved.

Second objective is to reduce the power bills and improve the voltage capacity. Then the power factor correction capacitor maximizing the energy saving.

Assemble simulation development to finish this project using Visual Basic 6.0.

1.3 Project overview

The first stage of the project, it was based on research for the data and information are obtained through internet, journal from IEEE and other sources.

The purpose of the study is to study power factor (PF), power factor correction(PFC), three phase induction motor, energy saving and its calculation. To study how the capacitor work. In this project, we are considering about induction motor because in industry, more than 70 percent usage is induction motor.

From the calculation and research, capacitor bank with delta connection is very well approach to correct the power factor. When power factor has been correct, automatically the motor voltage can be improve and reduce the losses.

Finally the software to calculate the correction has been established. The software named Power Factor Correction Calculation. This software can calculate the value of capacitor in delta and wye connection. Then we can differentiate why delta connection the best choose instead of wye connection. The next chapter of this report will show the calculation and the comparison between both connections.

CHAPTER 2

LITERATURE REVIEW

2.1 Literature review

Power factor is an important consideration for the energy efficiency of individual machines or entire plants. Power factor identifies how much apparent power (kVA) a facility requires from the utility in order to apply a given amount of useful power (kW).

Power factor is the ration between the KW and the KVA drawn by an electrical load where the KW is the actual load power and the KVA is the apparent load power. It is a measure of how effectively the current is being converted into useful work output and more particularly is a good indicator of the effect of the load current on the efficiency of the supply system. Power factor is defined as useful power divided by apparent power. Useful power, measured in kilowatts (kW), goes to perform useful work.

Reactive power, measured in kilovolt-amperes reactive (kVAR), comes in two forms inductance, which lags real power, and capacitance, which leads it. Inductive power is required to create and sustain the magnetic fields that inductive devices need to operate. An inductive device is any piece of equipment that uses coils. Examples of inductive devices include electric motors, electromechanical actuators, transformers, arc welders and induction furnaces. Examples of capacitive devices are capacitors themselves and fluorescent lighting.

An inductive device draws reactive power from the utility to energize its coils, and then it de-energizes its coil and gives the reactive power back to the utility. This happens every cycle. Whereas the net reactive flow is essentially zero, most power meters register only the flow of reactive power going to the consumer and do not register the return flow back to the utility. Although reactive power is not consumed, supplying cycles of reactive power occupies otherwise useable capacity on the lines and transformers on both the utility's and the consumer's power distribution systems, causing considerable line and transmission loss.

2.2 Comment of review

Selecting the proper power factor correction capacitors we must determine the overall KVAR requirements, the normal load KW and the original power must be known. This information can usually be obtained from the electric utility bill by TNB. Power factor correction capacitors can be applied at individual motors.

CHAPTER 3

THEORETICAL ANALYSIS

3.1 Power Triangle

We know that reactive loads such as inductors and capacitors dissipate zero power, yet the fact that they drop voltage and draw current gives the deceptive impression that they actually do dissipate power. This phantom power is called reactive power, and it is measured in a unit called Volt-Amps-Reactive (VAR), rather than watts. The mathematical symbol for reactive power is the capital letter Q [1]. The actual amount of power being used, or dissipated, in a circuit is called true power, and it is measured in watts, symbolized by the capital letter P [1], as always. The combination of reactive power and true power is called apparent power, and it is the product of a circuit's voltage and current, without reference to phase angle. Apparent power is measured in the unit of Volt-Amps (VA) and is symbolized by the capital letter S [1]. Refer Figure 3.1 to show the power triangle. Using the laws of trigonometry, we can solve for the length of any side (amount of any type of power), given the lengths of the other two sides, or the length of one side and an angle. [5]

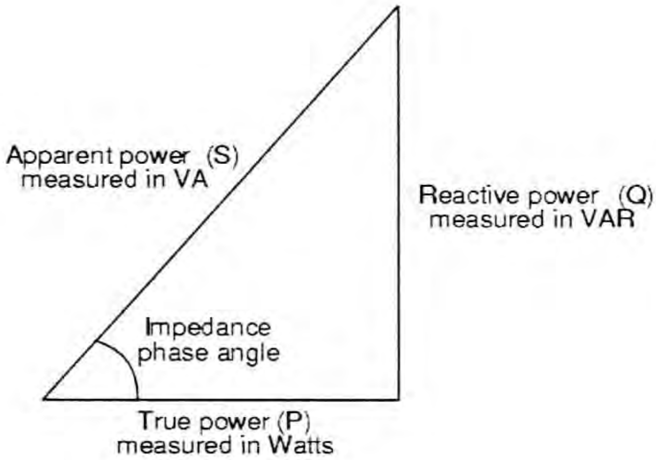


Figure 3.1 - Power Triangle

Power dissipated by a load is referred to as true power. True power is symbolized by the letter P and is measured in the unit of Watts (W). Power merely absorbed and returned in load due to its reactive properties is referred to as reactive power. Reactive power is symbolized by the letter Q and is measured in the unit of Volt-Amps-Reactive (VAR). Total power in an AC circuit, both dissipated and absorbed/returned is referred to as apparent power. Apparent power is symbolized by the letter S and is measured in the unit of Volt-Amps (VA). These three types of power are trigonometrically related to one another. In a right triangle, P is adjacent length, Q is opposite length, and S is hypotenuse length. The opposite angle is equal to the circuit's impedance (Z) phase angle.

As a rule, true power is a function of a circuit's dissipative elements, usually resistances (R). Reactive power is a function of a circuit's reactance (X). Apparent power is a function of a circuit's total impedance (Z). Since we're dealing with scalar quantities for power calculation, any complex starting quantities such as voltage, current, and impedance must be represented by their polar magnitudes, not by real or imaginary rectangular components. For instance, if I'm calculating true power from current and resistance, I must use the polar magnitude for current, and not merely the real or imaginary portion of the current. If we are calculating apparent power from voltage and impedance, both of these formerly complex quantities must be reduced to their polar magnitudes for the scalar arithmetic [5].

There are several power equations relating the three types of power to resistance, reactance, and impedance (all using scalar quantities) refer to Table 4.1:

Table 4.1 – Power Equation

P = true power $P = I^2R$ $P = \frac{E^2}{R}$

Measured in units of ***Watts***

Q = reactive power $Q = I^2X$ $Q = \frac{E^2}{X}$

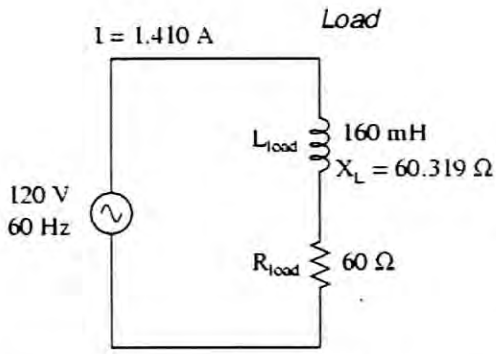
Measured in units of ***Volt-Amps-Reactive (VAR)***

S = apparent power $S = I^2Z$ $S = \frac{E^2}{Z}$ $S = IE$

Measured in units of ***Volt-Amps (VA)***

3.2 Calculating power factor

As was mentioned before, the angle of this power triangle graphically indicates the ratio between the amounts of dissipated or consumed power and the amount of absorbed/returned power. It also happens to be the same angle as that of the circuit's impedance in polar form. When expressed as a fraction, this ratio between true power and apparent power is called the power factor for this circuit. Because true power and apparent power form the adjacent and hypotenuse sides of a right triangle, respectively, the power factor ratio is also equal to the cosine of that phase angle. Using values from the example circuit as refer to Figure 3.2 below: [5]



$P = \text{true power} = I^2R = 119.365\ W$

$Q = \text{reactive power} = I^2X = 119.998\ VAR$

$S = \text{apparent power} = I^2Z = 169.256\ VA$

$$\text{Power factor} = \frac{\text{True power}}{\text{Apparent power}}$$

$$\text{Power factor} = \frac{119.365\ W}{169.256\ VA}$$

$$\text{Power factor} = 0.705$$

$$\cos 45.152^\circ = 0.705$$

Figure 3.2 – Example for calculation

It should be noted that power factor, like all ratio measurements, is a unitless quantity. For the purely resistive circuit, the power factor is 1 (perfect), because the reactive power equals zero. Here, the power triangle would look like a horizontal line, because the opposite (reactive power) side would have zero length. For the purely inductive circuit, the power factor is zero, because true power equals zero. Here, the power triangle would look like a vertical line, because the adjacent (true power) side would have zero length. The same could be said for a purely capacitive circuit. If there are no dissipative (resistive) components in the circuit, then the true power must be equal to zero, making any power in the circuit purely reactive. The power triangle for a purely capacitive circuit would again be a vertical line (pointing down instead of up as it was for the purely inductive circuit). [5]

Power factor can be an important aspect to consider in an AC circuit, because any power factor less than 1 means that the circuit's wiring has to carry more current than what would be necessary with zero reactance in the circuit to deliver the same amount of (true) power to the resistive load. If our last example circuit had been purely resistive, we would have been able to deliver a full 169.256 watts to the load with the same 1.410 amps of current, rather than the mere 119.365 watts that it is presently dissipating with that same current quantity. The poor power factor makes for an inefficient power delivery system.

Poor power factor can be corrected, paradoxically, by adding another load to the circuit drawing an equal and opposite amount of reactive power, to cancel out the effects of the load's inductive reactance. Inductive reactance can only be canceled by capacitive reactance, so we have to add a capacitor in parallel to our example circuit as the additional load. The effect of these two opposing reactances in parallel is to bring the circuit's total impedance equal to its total resistance (to make the impedance phase angle equal or at least closer, to zero).

Since we know that the (uncorrected) reactive power is 119.998 VAR (inductive), we need to calculate the correct capacitor size to produce the same quantity of (capacitive) reactive power. Since this capacitor will be directly in parallel with the source (of known voltage), we'll use the power formula which starts from voltage and reactance as refer to below:

It should be noted that power factor, like all ratio measurements, is a unitless quantity. For the purely resistive circuit, the power factor is 1 (perfect), because the reactive power equals zero. Here, the power triangle would look like a horizontal line, because the opposite (reactive power) side would have zero length. For the purely inductive circuit, the power factor is zero, because true power equals zero. Here, the power triangle would look like a vertical line, because the adjacent (true power) side would have zero length. The same could be said for a purely capacitive circuit. If there are no dissipative (resistive) components in the circuit, then the true power must be equal to zero, making any power in the circuit purely reactive. The power triangle for a purely capacitive circuit would again be a vertical line (pointing down instead of up as it was for the purely inductive circuit). [5]

Power factor can be an important aspect to consider in an AC circuit, because any power factor less than 1 means that the circuit's wiring has to carry more current than what would be necessary with zero reactance in the circuit to deliver the same amount of (true) power to the resistive load. If our last example circuit had been purely resistive, we would have been able to deliver a full 169.256 watts to the load with the same 1.410 amps of current, rather than the mere 119.365 watts that it is presently dissipating with that same current quantity. The poor power factor makes for an inefficient power delivery system.

Poor power factor can be corrected, paradoxically, by adding another load to the circuit drawing an equal and opposite amount of reactive power, to cancel out the effects of the load's inductive reactance. Inductive reactance can only be canceled by capacitive reactance, so we have to add a capacitor in parallel to our example circuit as the additional load. The effect of these two opposing reactances in parallel is to bring the circuit's total impedance equal to its total resistance (to make the impedance phase angle equal or at least closer, to zero).

Since we know that the (uncorrected) reactive power is 119.998 VAR (inductive), we need to calculate the correct capacitor size to produce the same quantity of (capacitive) reactive power. Since this capacitor will be directly in parallel with the source (of known voltage), we'll use the power formula which starts from voltage and reactance as refer to below:

$$Q = \frac{E^2}{X}$$

. . . solving for X . . .

$$X = \frac{E^2}{Q}$$

$$X = \frac{(120\ V)^2}{119.998\ VAR}$$

$$X = 120.002\ \Omega$$

$$X_C = \frac{1}{2\pi fC}$$

. . . solving for C . . .

$$C = \frac{1}{2\pi f X_C}$$

$$C = \frac{1}{2\pi(60\ Hz)(120.002\ \Omega)}$$

$$C = 22.105\ \mu F$$

Then use a rounded capacitor value of 22 μF and see what happens to the circuit as refer to figure 3.3 :

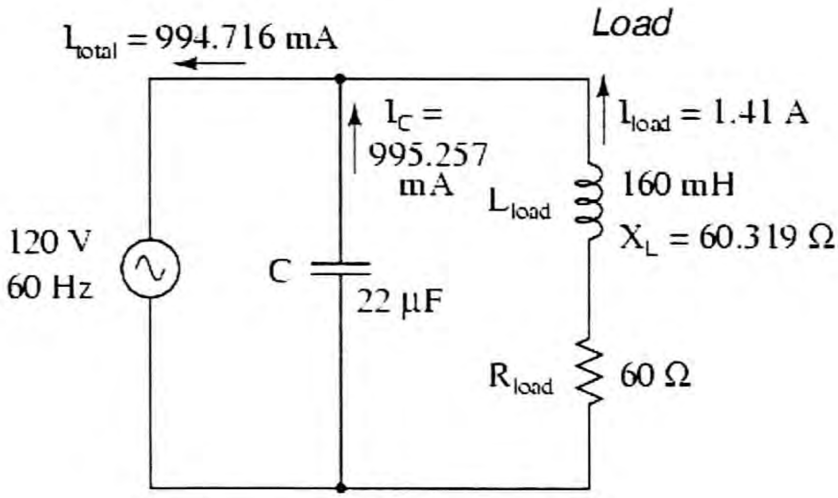


Figure 3.3– Circuit using 22uF capacitor

$Z_{total} = Z_C // (Z_L -- Z_R)$

$Z_{total} = (120.57\ \Omega \angle -90^{\circ}) // (60.319\ \Omega \angle 90^{\circ} -- 60\ \Omega \angle 0^{\circ})$

$Z_{total} = 120.64 - j573.58m\ \Omega$ *or* $120.64\ \Omega \angle 0.2724^{\circ}$

$P = \text{true power} = I^2R = 119.365\ W$

$S = \text{apparent power} = I^2Z = 119.366\ VA$

The power factor for the circuit, overall, has been substantially improved. The main current has been decreased from 1.41 amps to 994.7 milliamps, while the power dissipated at the load resistor remains unchanged at 119.365 watts. The power factor is much closer to being 1, refer to below:

$$\text{Power factor} = \frac{\text{True power}}{\text{Apparent power}}$$

$$\text{Power factor} = \frac{119.365\ W}{119.366\ VA}$$

$$\text{Power factor} = 0.9999887$$

$$\text{Impedance (polar) angle} = 0.272^{\circ}$$

$$\cos 0.272^{\circ} = 0.9999887$$