Development of Automatic Power Factor Correction System By using PIC Microcontroller through Simulation Study

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ABSTRAK

Tesis ini membentangkan rekabentuk dan analisis sistem pembetul faktor kuasa secara automatik dengan menggunakan PIC mikropengawal untuk sistem pengagihan kuasa satu fasa voltan rendah (230V / 50Hz). Faktor kuasa memainkan peranan yang penting dalam sistem elektrik. Faktor kuasa yang rendah akan menarik lebih banyak arus ke dalam sistem dan ini akan menyebabkan kepada bil elektrik yang tinggi dan kehilangan kuasa yang lebih tinggi. Cara konvensional untuk meningkatkan faktor kuasa adalah dengan memasang kapasitor bank statik, di mana ia disambungkan secara kekal ke sistem elektrik melalui suis menyatu. Walau bagaimanapun, kaedah ini tidak berkesan apabila beban berubah-ubah seterusnya menyebabkan operasi dan pembetulan kuasa faktor tidak optimal kerana pampasan kapasitif tidak berubah mengikut perubahan beban. Oleh itu, satu sistem yang akan membetulkan faktor kuasa secara automatik mengikut perubahan beban diperlukan. Jadi, di dalam projek ini sistem pembetul faktor kuasa secara automatik akan direka dan dibangunkan untuk mengatasi masalah ini. Sistem yang direka secara amnya menggunakan mikropengawal PIC 18F452 untuk mengira dan mengawal faktor kuasa dalam sistem elektrik secara automatik serta menyambung atau memutuskan sambungan kapasitor bank mengikut perubahan beban. Sistem yang direka telah diuji dalam perisian pembangunan Proteus.

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ABSTRACT

This thesis presents the design and analysis of an automatic power factor correction system using PIC microcontroller for single phase low voltage distribution system (230V/50Hz). Power factor plays a great role in an electrical system. A low power factor will draw more current in the system and this will lead to high electricity bills and higher power loses. Conventional way to improve power factor is by installing a static capacitor bank which is connected permanently to the electrical system through fused switches. However, this method is not effective as the load is usually fluctuating according to demand. Hence, the operation and power factor correction is not optimized as the capacitive compensation does not change according to load variations. Therefore, a system that will adjust the power factor automatically according to load fluctuations is needed. So, in this project an automatic power factor system will be designed and developed in order to solve this problem. The designed system is basically used a PIC 18F452 microcontroller to calculate and control power factor in an electrical system by automatically connect or disconnect capacitor banks according to load changes. The designed system has been tested in Proteus development software.

CHAPTER 1

INTRODUCTION

1.1 Project background

In recent years, electrical technology evolution has increased the number of electrical equipment and electrical demand. Therefore, as the demand for electric power increase rapidly and energy cost continues to rise, energy efficiency has become a major concern nowadays. Power quality plays great roles to maximized energy efficiency in power system as well as saving energy cost. Power factor is vital in power system as it is one of the aspect to measure overall power quality in electrical power system. According to Barsoum (2007), power factor is a measure of how effectively the current is being converted into useful works output. In other words, it is an indicator on how efficient electrical power system is being used.

Basically, power factor is the ratio of the average power or watt(W) to apparent power or volt amps (VA) which produces a figure from zero to one where it indicates the degree of distortion and phase shift in the current waveform (Sadiku, 2007). Figure one also known as unity power factor means that the power system is purely resistive and it only happen when the current and voltage waveform are in phase. Electrical power system is being utilised effectively if the power factor is high while a low power factor indicates a poor utilization of the power system (Mekhilef & Rahim, 2002). A low power factor draws more current and this leads to high electricity bills and there will be additional charges in electricity bills as most utility companies imposed penalties for power factor dropping beyond limit (Saha, Tyagi & Gadre, 2013). Low power factor may not be a major problem in residential homes, however as the commercial and industrial electrical installations nowadays have large inductive electrical load that cause lagging power factor, it will leads to low power factor and various power quality problems in power system. Thus, power factor correction plays great roles in order to increase electrical power system efficiency and reduce energy cost.

To improve power factor, reactive power must be supplied locally into the system. This method is known as power factor correction or reactive power compensation. Power factor correction provides many benefits such as reduce the amount of electrical power used, increase system capacity, improve the voltage and reduce the heat losses of an electrical power system (Mekhilef & Rahim, 2002). The simplest way to supply reactive power is by installing a static capacitor bank into the system. This method has been continously be the most cost effective way for correcting displacement power factor (Heger et al., 2012). However, in most electrical system the absorption of reactive power is not constant (Relji et al., 2012). This is mainly because electric load can fluctuate according to the load characteristics and demands (Relji et al., 2012). Hence, power factor correction by using static capacitor banks is not effective in this situation due to its static operation and did not change according to the load change.

In order to solve this problem, an automatic system that will adjust and control the power factor to the desired power factor which close to unity depending on the load changes need to be designed. The key idea of this project is to develop an automatic system for capacitor switching through a PIC microcontroller programming. This system will be designed to monitor and control power factor automatically thus, maintaining power factor at optimum level which is close to unity even with load fluctuation.

1.2 Problem statement

Conventional way to improve power factor is by installing a static capacitor bank where it is connected permanently to electrical system through fused switches (Barsoum, 2007). However, this method is not effective as the load is usually fluctuating according to demand (Relji et al., 2012). Hence, the operation and power factor correction is not optimized as the capacitive compensation does not change according to load variation. Therefore, a system that will adjust the power factor automatically according to load fluctuation is needed. So, in this project an automatic power factor system will be design and developed in order to solve this problem.

1.3 Objective

The objectives of this project are:

i. To propose an automatic power factor correction system that contributes to energy management.
ii. To design an automatic power factor correction trough PIC microcontroller programming for low voltage distribution system.
iii. To improve power quality through the designed automatic power factor correction system.

1.4 Project scope

The project scopes for completing this project are:

i. Automatic power factor correction is designed for low voltage distribution system (230volt, 50Hz).
ii. Design an automatic switching system using PIC microcontroller programming to improve displacement power factor.
iii. Conduct and analyse simulation of the designed system by using Proteus design software

1.5 Dissertation organization

This thesis is formed by five chapters along with abstract and the references. It is organized as follows**.**

Chapter 1: The purpose of this chapter is to provide general information about the project background as well project motivation in term of power factor correction. The project objectives, problem statement and project scope are also described in this chapter.

Chapter 2: Second chapter is literature review of the power factor correction technique. It provides general information about previous researcher's works on developing an automatic power factor correction system.

Chapter 3: Third chapter is research methodology where the method and materials that have been used in the dissertation is clearly defined.

Chapter 4: This chapter provides result and discussion of the project. It includes the analysis and presentation of data collected throughout the project**.**

Chapter 5: Conclusion and future work. This chapter summarize the whole thesis and interpret the project result. The conclusion will be related to the objective of the project in the beginning of the thesis. Future work and potential area of the project will be discussed briefly in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

As the power quality becomes a hot issue in nowadays electrical system design, there are a lot of methods that has been developed by the researchers in order to improve power quality. One of the methods is by improving power factor in an electrical system. Therefore in this chapter, existing power factor correction method and consideration are discussed briefly.

2.2 Steady state supply voltage

In order to understand in details about power quality, the definition of voltage regulation and nominal supply voltage need to be understood first. According to MS IEC 60038:2006 nominal low voltages in Malaysia are 400Volt and 230Volt. During normal steady-state operational conditions the system frequency is maintained by the Grid System Operator to within ±1% of the nominal value of 50Hz, that is, between 49.5Hz and 50.5Hz. However, as the load on utility often fluctuate, it is impossible to sustain a complete constant voltage. Therefore, voltage will be supplied within an acceptable range called voltage regulation. Percentage variations of nominal voltage are from -6% and +10% range.

2.3 Overview of Power Quality in Malaysia

Power Quality is an electromagnetic compatibility problem that are used to describe an electrical behaviour in electric power grid that can harm or interrupt electrical device (Faisal, 2007). In Malaysia, as the industrial and commercial sectors are developing rapidly, power quality has become a major issue. It plays a great role as the electrical equipment nowadays becoming more sensitive compared to their predecessor years ago (Faisal,2007). Converter driven equipment such as from consumer electronics and computers normally contain both power frequency and harmonic component and this equipment not only sensitive to voltage disturbance but it is also proven to be the source of power quality disturbances in power system.

2.4 Role of power factor correction toward power quality

Power quality problem such as harmonic distortion may decrease the average power transmitted to the load which resulting the supply source to supply more power to the power system (Heger et al., 2012). This situation would affect the phase angle between voltage and the current and leads to poor power factor. Low power factor in an electrical system will ultimately lead to power losses, significant voltage drop, transformer losses and even penalty charges in electric bills (Barsoum, 2007). According to Faizal (2007), there are two ways to solve power quality problems which are either to clean up the power lines or make the equipment robust. Throughout these years, the easiest and convenient way to clean up power lines is through power factor correction. Although implementing capacitor bank to improve power factor is the most convenient and low cost method, there are lots of factors must be considered to prevent any adverse effect in power system.

2.5 Load characteristic

Basically, electrical load is the real power (kW) consumed in an electric system. To design a good electrical system or equipment, the characteristic of the load need to be studied in detail to ensure the designed system will operate according to the desired operation and no system failure occur.

2.5.1 Linear Load

Linear load is an electrical load with current that is linearly proportional to the voltage supplied. Figure 2.1 shows the vector diagram of the linear load. Based on figure 2.1, voltage and current waveform of linear load are both sinusoidal and at the same frequency. For sinusoidal voltage and current, the instantaneous current and voltage are expressed as:

$$u(t) = u' \cos(\omega t + \varphi U) \quad (2.1)$$

$$i(t) = i' \cos(\omega t + \varphi I) \quad (2.2)$$

While the instantenous value of power, p(t) as the product of the instantenoues values of current and voltage is:

$$p(t) = u'i' \cos(\omega t + \varphi U) \cos(\omega t + \varphi I) \quad (2.3)$$

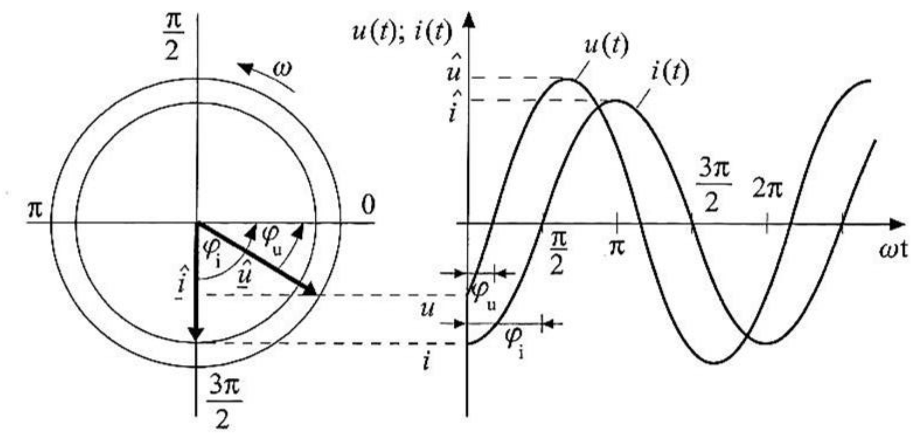

Figure 2.1: Vector diagram of linear load (Hofmann & Schlabbach, 2012)

Linear load is usually made up with only resistive and reactive components such as motor, heater and incandescent light. According to Mitchell (1992), linear load can be divided into two types which are a current waveform in phase with the voltage caused by resistive component and a waveform that is lagging or leading caused by reactive component. The phase position depends on the amount of inductance, resistance and capacitance of the impedance. The phase angle between current and voltage waveform are used to denote the displacement power factor of an electrical system.

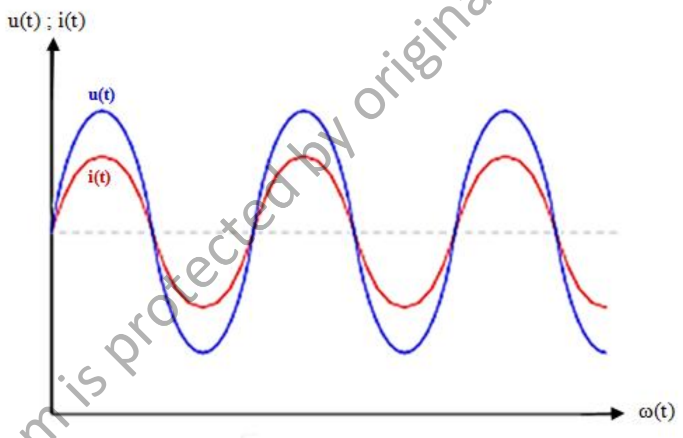

Figure: 2.2: Resistive linear load

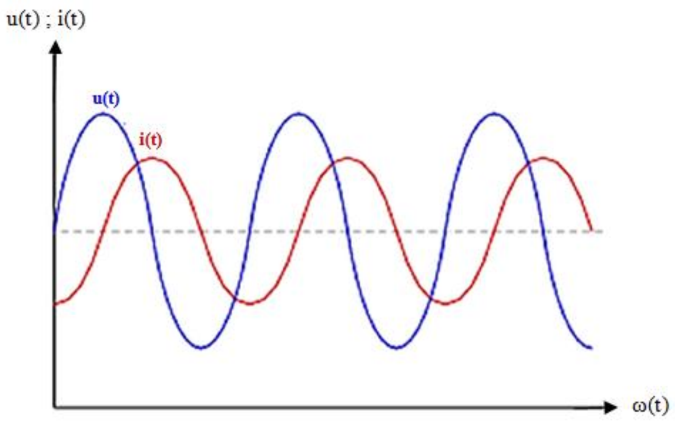

Figure 2.3: Inductive linear load

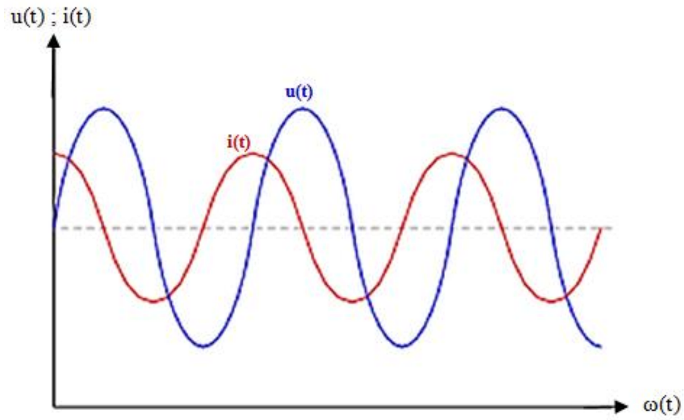

Figure 2.4: Capacitive linear load

As shown in figure 2.2, the current waveform and voltage are in phase for resistive linear load thus providing a unity power factor. Therefore, for resistive loads true power and apparent are the same. However, if the load is reactive, it will store energy and releasing it during a different part of the cycle causing the current waveform to shift. Figure 2.3 shows the inductive linear load waveform while figure 2.4 shows the capacitive linear load waveform. When the load is inductive, the inductance tends to oppose the flow of current by storing energy then releasing it later in the cycle. Thus, the current waveform lags behind the voltage waveform. When the load is capacitive, the opposite occurs, and the current waveform leads the voltage waveform

2.6 Power factor correction technique

There are many methods that have been used throughout these years to compensate reactive power. The most popular method is by installing a capacitor bank in power system. However, as electrical technology developing rapidly, many researchers has designed and developed new devices and system to maximize power quality.

2.6.1 The synchronous condenser

The synchronous condenser is a specialized application of the synchronous generator which is used solely to generate or consume reactive power. Synchronous generators are usually operated without mechanical input in order to take advantage of their reactive power capabilities. The stand-alone synchronous condenser is electrically the same as a synchronous generator without any mechanical power input. In appearance, the synchronous condenser looks like an electric motor without any mechanical shaft connection to a load. For synchronous condenser operation, the DC current flowing through the rotor is adjusted to control the reactive output or the voltage magnitude at the condenser terminals.

The main advantage of the synchronous condenser is that its reactive output is variable between the limits of the machine. This allows the system operator to apply an optimum amount of leading or lagging reactive power, as required, to regulate a bus voltage or reduce system losses. Another advantage is a condenser's ability to maintain its maximum reactive output across a range of voltages. This feature is especially important when reactive power sources are necessary for system stability.

The main disadvantages of the synchronous condenser are their large size, operational costs, and installation costs. A significant amount of real estate is required for installation. Implementing a synchronous condenser along a distribution line in an urban area can be quite difficult and expensive. The synchronous condenser also must consume some active power for its operation to overcome friction and rotational losses. A DC generator must also be employed to provide the variable DC current for excitation. This generator places a mechanical load on the machine which increases real power consumption. The condenser also uses brushes to provide the electrical connection between the stationary and rotating parts of the machine. These brushes must be replaced periodically, resulting in maintenance costs. The construction of a synchronous machine requires all of the same high-value components required in making a large motor. The synchronous machine must also have a suitable enclosure, foundation, service equipment, protection equipment, and control equipment. These factors made the use of synchronous condensers on distribution systems limited. They found more applications in sub transmission or transmission systems where larger amounts of reactive power were required and economies of scale could justify the costs associated with a synchronous condenser.

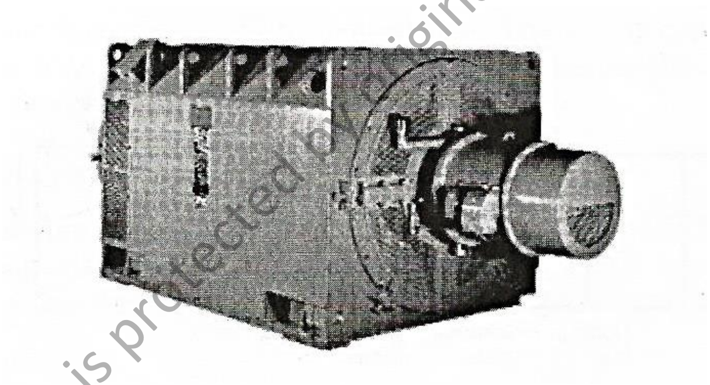

Figure 2.5: Synchronous condenser (Natarajan,2005)

2.6.2 Static shunt capacitor bank

Capacitor bank is a device that consist banks of various sizes of capacitor that use conventionally to improve displacement power factor, reduce line losses, improved feeder voltage profile, and lower power line loadings (Perera-Lluna et al., 2014). This method is basically connected in parallel with power system through one or more breaker switched capacitor unit along with intelligent control unit, current transformer and potential transformer (Lin et al., 2012).

Capacitors have many advantages over synchronous generators and condensers. It takes very little space in comparison to a synchronous machine. It also can be attached to an existing distribution pole, requiring no additional space for its installation. The capacitor uses a very small amount of real power per kVA and therefore has less operational cost. A capacitor has no moving parts and requires no periodic maintenance. Many capacitors are connected directly to an electrical system without any means of automatic switching, eliminating the costs associated with control systems. Automatically switched capacitors are typically connected to the power system using on or off contactors which are simpler to control than the field current regulators associated with synchronous machines. The design and application of a shunt capacitor installation is very straightforward and much simpler for the system engineer than other forms of reactive power supply. Capacitors are readily available in a variety of sizes and voltage ratings. The raw materials used in making a capacitor cost less than the materials used in making synchronous machines, resulting in a lower cost per kVAr.

Despite their many advantages, shunt capacitors have several shortcomings when compared to the synchronous machines. First, this method is lacking in term of it efficiency if the load fluctuate as it does not correct power factor according to load changes. Another problem encountered with the use of capacitors is the gradual loss of output which occurs over time. This is due to several phenomenons which occur in the construction of the capacitors' conductive surfaces and dielectrics, but is a maintenance concern which must be addressed periodically. On a three-phase distribution system, capacitors are applied in sets of three, sometimes in groups of more than one capacitor per phase. In the event that one or two of the groups is connected or disconnected instead of all three due to one fuse blowing or a malfunctioning switch, a voltage unbalance could occur on the distribution system. This voltage unbalance can result in