SMART AUTOMATIC POWER FACTOR CORRECTION DEVICE

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ELECTRICAL & ELECTRONICS ENGINEERING
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by

Lee Jun Jia

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Electrical and Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

(Assoc Prof Dr. Irraivan Elamvazuthi)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

LEE JUN JIA

ABSTRACT

This document will discuss on research and theory of the chosen topic for Final Year Project, which is **Smart Automatic Power Factor Correction Device (PFCD)**. The objective of this project is to conduct study on the theory of power factor correction, application in industry and residential, simulate the circuit of power factor with different load, experimentally test the power factor concept and further improve it to a smart automatic power factor correction device. The automatic power factor correction device can automatically detect the voltage and current at the system and initialize appropriate value of capacitor. One of the challenges of this project is to accurately measure the power factor and automatic trigger capacitors to achieve unity power factor. Besides, the cost of the project is one of the concerns. Simulation and modeling involved in this project. Research and experiments be done for the prototype to verify the function of power factor correction device.

ACKNOWLEDGEMENT

I would like to take this opportunity to extend my greatest appreciation and gratitude to my supervisor, Assoc Prof Dr. Irraivan Elamvazuthi, for his guidance and great support throughout the project.

Secondly, my appreciation goes to Power Electronics lecturer, Pn. Khairul Nisak Binti MD Hasan. The extensive knowledge and insightful advice from her have guided me in my project. Useful advices and discussions from her enable me to finish my work.

I am grateful for the excellent department, start and students in Universiti Teknologi PETRONAS for their support and technical help. Particularly, I would like to thank UTP lab technician, Mr Yasin for their initiative guidance and technical help. I would like to express my gratitude to my friends for their hands and sharing the knowledge with me.

Last but not least, I would like to dedicate this dissertation to my family for their support in these years. With full cooperation from the various people above, I have successfully achieved the objective of Final Year Project.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The quality of power has become a hot topic recently. This is because with the rapid increase in number of the electronic appliances. Researches also reveal the importance of power quality toward electric appliances and the power system at home. For the industry users, power quality will bring direct impacts on the machinery, power equipment and the product of the factory. This is even obvious in the high technology industry such as semiconductor chip fabrication. Efficiency is an important measurement on power quality.

Power factor is a measurement of how effective of a facility utilize the electrical energy in the power system. In another words, it is used to measure how effectively the current is being converted into useful work output. In the electrical energy, active power does work and reactive power produces an electromagnetic field for inductive loads.

Lightly-loaded or varying-load inductive equipment such as HVAC systems and presses are the examples of equipment that can have a poor power factor. The power factor in a facility will vary over time. Power factor will also vary with different types of loads, and the overall mix of various types of loads. Inductive loads, such as motors, will tend to reduce the power factor.

All the users should be concerned about low power factor because it means that they are using a facility's electrical system capacity inefficiently. Power utilities will charge industry users on the low power factor because it increased the cost of power utilities to supply enough power. For residential users, no surcharge on low power factor by the power utilities because the existing of reactive power does not included in the monthly electrical bill. However, the increased current will lead to higher dissipation power lost at the load, which will lead to electricity bill charge increased.

Besides, low power factor will cause other problems in the power system such as extra losses in feeder cables, significant voltage drop, reduction of effective capacity of cables, reduction in power available at the transformer, significant voltage drop at the secondary of transformer and significant losses in transformer.

Low power factor is generally solved by adding power factor correction capacitors to a facility's electrical distribution system. Figure 1 shows a simplified industrial system with power factor correction capacitor. [1]

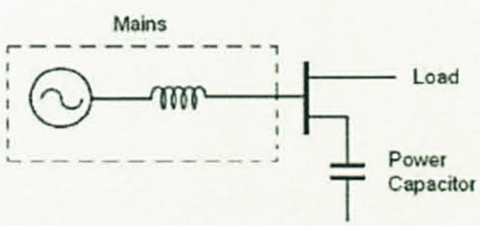

Figure 1: Simplified Industrial system with PFC capacitor

Power factor correction capacitors supply the necessary reactive portion of power (kVAR) for inductive devices. By supplying its own source of reactive power, a facility frees the utility from having to supply it. This generally results in a reduction in total customer demand and energy charges.

Power factor correction requirements determine the total amount of capacitors required at low voltage buses. The power factor characteristics of plant loads typically are determined from billing information, however, in the case of a new installation, typical load power factors will determine the required compensation.

There are two types of power factor correction device. The preferable type of PFC is Active Power Factor Correction (Active PFC) since it provides more efficient power frequency. Because Active PFC uses a circuit to correct power factor, Active PFC is able to generate a theoretical power factor of over 95%. Active Power Factor Correction also diminishes remarkable total harmonics, automatically corrects for AC input voltage, and is capable of a full range of input voltage. Since Active PFC is the more complex method of Power Factor Correction, it is more expensive to produce an Active PFC power supply.

The most common type of PFC is Passive Power Factor Correction (Passive PFC). Passive PFC uses a capacitive filter at the AC input to correct poor power factor. Passive PFC may be affected when environmental vibration occurs. Passive PFC requires that the AC input voltage be set manually. Passive PFC also does not use the full energy potential of the AC line.

1.2 Problem Statement

There are a lot of electrical devices that available in market that claiming to be able to save up to 30% of power by installing it. All these so-called "power saver" advertised in attractive way and the advertisement containing experimental results as well as users' testimonial but no real prove. Figure 2 shows one of the power savers that available in market.

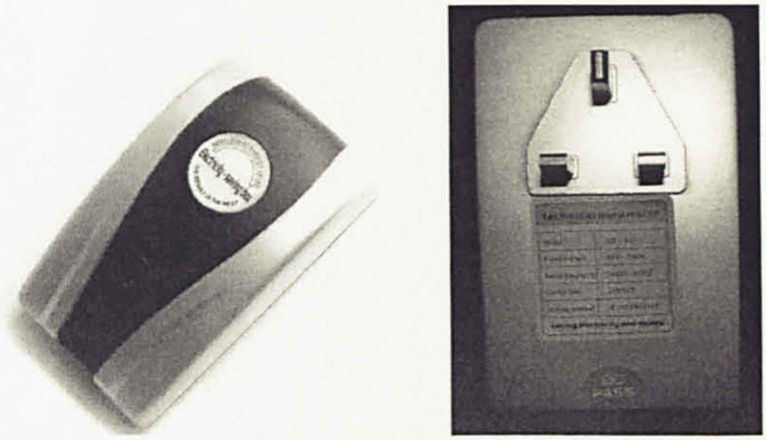

Figure 2: Power factor correction device that available in market

Besides, power factor correction devices that currently available in the market are normally compensate the power factor with the fixed capacitance. This power factor correction device are said to be lead to potential problem such as harmonic distortion and transient overvoltage.

The fixed value capacitor not able to vary according to load and this may cause the capacitors not last long. The fixed value capacitor power factor correction device will also lead to over compensated and make the power factor to non unity.

1.3 Objective and Scope of Study

With defined problem statement, the main objectives of this research are:

- To study concept of power factor and power factor correction.
- To design a better power factor correction operation device.

The scope of work for this project is to conduct studies on power factor correction device that is available in the market. This includes theoretically calculating and experimentally testing the ability of power factor correction device. Research and simulation are conducted and come out with a prototype.

The function of smart automatic power factor correction device is tested. Accuracy of measuring power factor is one of the main focuses, and this device should be able to initialize the appropriate amount of capacitance in order to compensate the low power factor.

The scope of study includes reviewing the power electronics syllabus such as text book and notes, related research papers and internet information, and the programming language of PIC (Programmable Interface Circuit).

CHAPTER 2

LITERATURE REVIEW

2.1 Power Factor Correction

Review for the study was taken abundantly from journals and internet. Basically, spot to be highlighted for the study consists of the concept of power factor correction, calculation on the capacitor value, sensing and measuring the power factor, and switching and triggering the appropriate value of capacitance. Here are some notes taken for the studies:

The PFC increases power factor, by reducing the amount of reactive power that the load draws from the utility company. Power factor of 1 is said to be unity and all the power consumed by facilities or machines goes to produce useful work. As the motor operates, this reactive power is "pulled" and "pushed" to and from the PFCD by the motor. The amount of reactive power purchased from the utility company by power factor optimization has been greatly reduced, or eliminated.

The significance of power factor lies in the fact that utility companies supply customers with volt-amperes, but bill them for watts. Power factors below 1.0 require a utility to generate more than the minimum volt-amperes necessary to supply the real power (watts).

Figure 3, 4 and 5 show the waveform of instantaneous and average power calculated from AC voltage and current with a unity power factor, zero power factor and lagging power factor. [9]

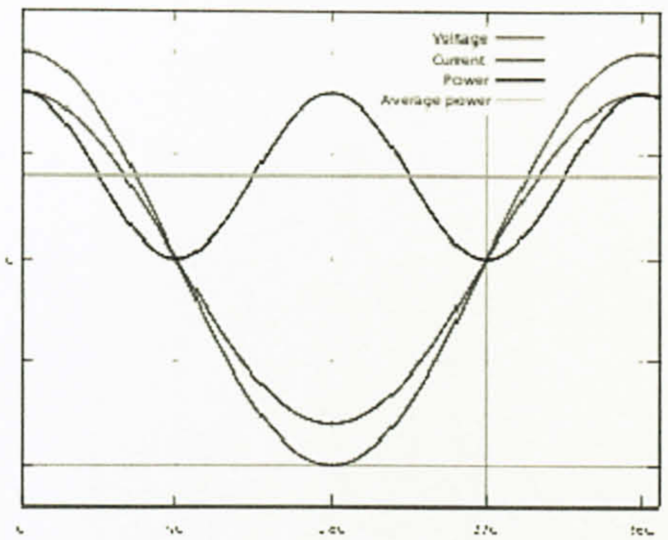

Figure 3: Waveform with unity power factor

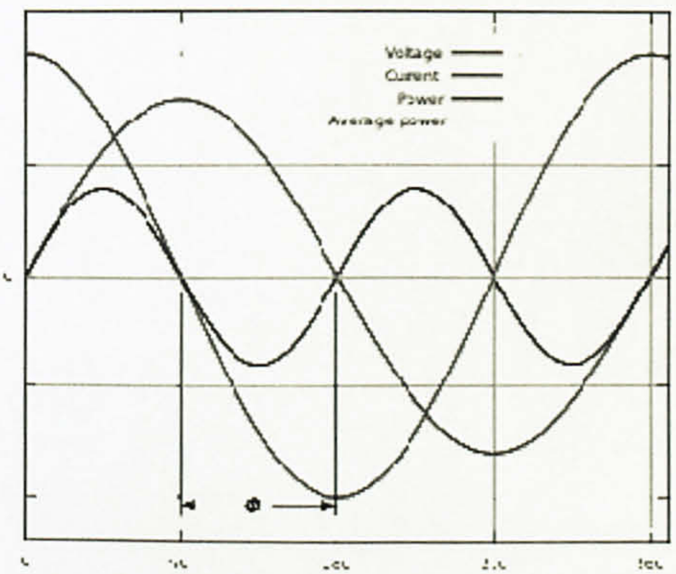

Figure 4: Waveform with zero power factor

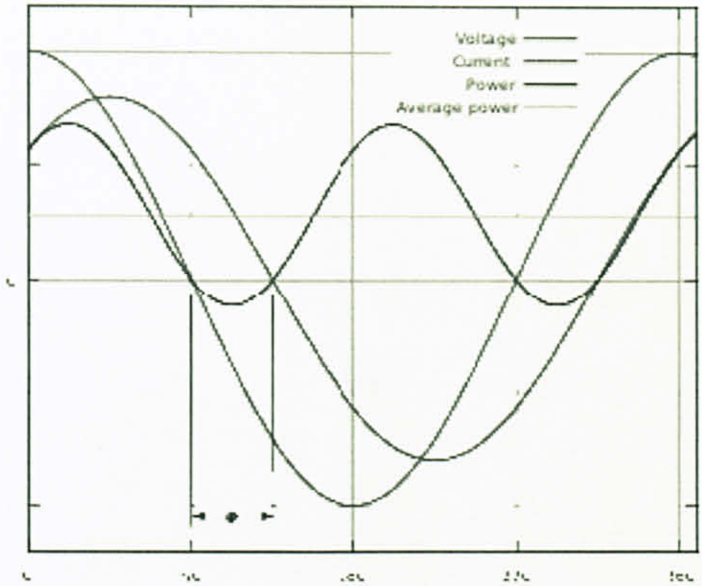

Figure 5: Waveform with lagging power factor

The Power Factor (Pf) is contributed by the formula:

Power Factor (Pf) = Cos θ $=\frac{KW}{KVA}$

where KW is the unit of real power and KVA is the unit of apparent power.
Real Power also is the average power absorbed by a resistive load and it can be written as

$$P = \frac{Vrms^2}{R} \text{ or } Irms^2\ X\ R$$

Where $V_{rms} = V_{peak} / \sqrt{2}$

Low power factor increases generation and transmission costs. For example, if the load power factor were as low as 0.7, the apparent power would be 1.4 times the real power used by the load. Line current in the circuit would also be 1.4 times the current required at 1.0 power factor, so the losses in the circuit would be doubled (since they are proportional to the square of the current).

Alternatively all components of the system such as generators, conductors, transformers, and switchgear would be increased in size (and cost) to carry the extra current. A power factor of 0.6 means to perform 100KW of useful work, 167KVA of apparent power is required. In the 480V power supply, it is demanding 347 amps of electric current.

In the case that installed power factor correction device that theoretically able to raise the power factor up to 0.95, it only requires 105 KVA of the apparent power and required current drop to 219 amps, a reduction of 37%. [2]

Knowing the process of energy storage in capacitors and inductive device are important to understand the power factor. When the voltage in AC circuits varies in the sinusoidal form, it will passes through the zero and starts toward the peak (maximum voltage) alternately. Inductive device is giving up the energy from electromagnetic field while capacitor stores energy in its electrostatic field at that time.

As the AC varying in sinusoidal form, when it reaches the maximum voltage, it starts to decrease. At this moment, capacitor giving up the stored energy while inductive stores energy. The capacitors and inductors take turn to magnetize current between them. [2]

The resonant frequency response to the exciting frequency produced by loads (non-linear), harmonic frequency happened, hence voltage and current will be dominated and distorted. This will caused higher voltage across the capacitor and high current through the component of capacitor. [1]

2.2 Capacitor Bank

Capacitor bank always refers to the capacitors that installed within an isolating non-conductor metal box. Capacitor bank has two types which are fixed and switched. For the fixed capacitor bank, it is permanently connected to the conductors (primary) through fused switches. It is fixed and cannot be removed as it's name. However, for the switched capacitor bank, it is also connected to the primary system but is through the automated switches, which is able to let users to put the capacitor bank on line or taken off line depending the situation.

The exact amount of capacitors can be estimated by the equation:

$$C = \frac{\mathrm{VAR}}{2\pi \mathrm{f}\ \mathrm{X}\ Vr^2}$$

where, VAR = capacitor unit VAR rating

C = capacitor (farads)

F =frequency (cycles/second)

Vr =capacitor unit rated voltage

Inductive will lead to positive reactive power while the capacitive reactance will lead to negative reactive power. To perform power factor correction, negative reactive power is needed, hence capacitor will be the main component of the power factor correction device. Figure 6 shows the power triangle which displays the relation of real, reactive and apparent power.

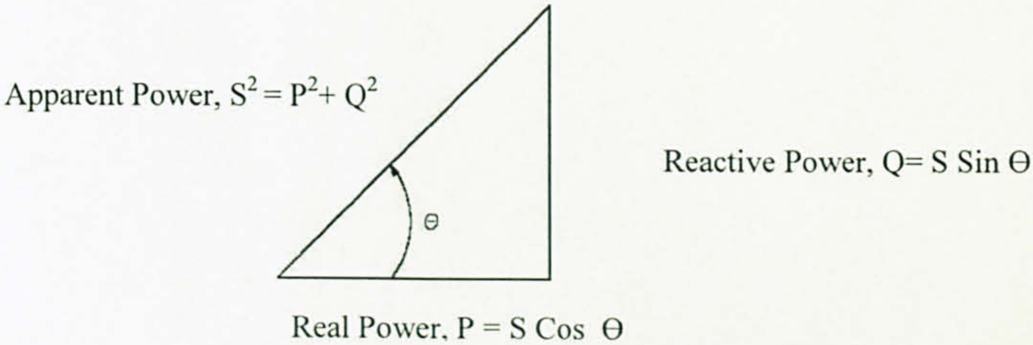

Figure 6: Power Triangle

Most of the power system will have inductive loads because of the coil in the machinery, hence capacitor is employed here to reduce the lagging current that able to shrink the phase angle distance from real power and apparent power [3]

Most of the power system capacitor is Y-connected on three phase distribution feeder. It is important for the neutral to be grounded in case of capacitor fault that might not blow the circuit breaker or fuse to isolate the faulty capacitor. This will make the capacitor bank might explode. Anyway, left the neutral line to be ungrounded will has the advantage of reduce the harmonic resonant. [3]

Table 1 lists some examples of load with the corresponding power factor. From the table, we can observe that the power factor for the industry really needs the power factor correction device to improve the efficiency and avoid penalty by the power utility. It also shows the studies on power factor correction device is very potential to be one of the future trends. [3]

Table 1: Typical power factors of end use equipment

Load	Typical Power Factor
Incandescent lamps	1.0
Florescent Lamps	0.95-0.97
Synchronous motors	1.0 to 0.8 leading
Squirrel cage motors	
High speed	0.75-0.90
Low speed	0.85-0.92
Wound rotor	0.8-0.9
Induction motors	
Fractional HP	0.55-0.75
1-10 HP	0.75-0.85
Arc furnace	0.65-0.70
Power converter	0.50-0.90

2.3 Programmable Interface Circuit (PIC)

The PIC is the microcontroller is a family of Harvard architecture microcontrollers made by Microchip Technology. It is popular with both industrial developers and hobbyist alike due to the low cost, wide availability, large user base and extensive collection of application notes. It 40 pins, which enable users to define the input and output pin except certain defined pins. [10]

Microcontroller PIC 16F877A is used to carry out the calculation in the circuit. Figure 7 shows the microcontroller PIC 16F877A. [4]

Figure 7: Microcontroller PIC 16F877A

The microcontroller programmed by using PIC C Compiler (PCW). It is easier to use in microcontroller programming, simple interface for users, no need to define header files separately and robust for this project.

CHAPTER 3

METHODOLOGY

3.1 Project Methodology

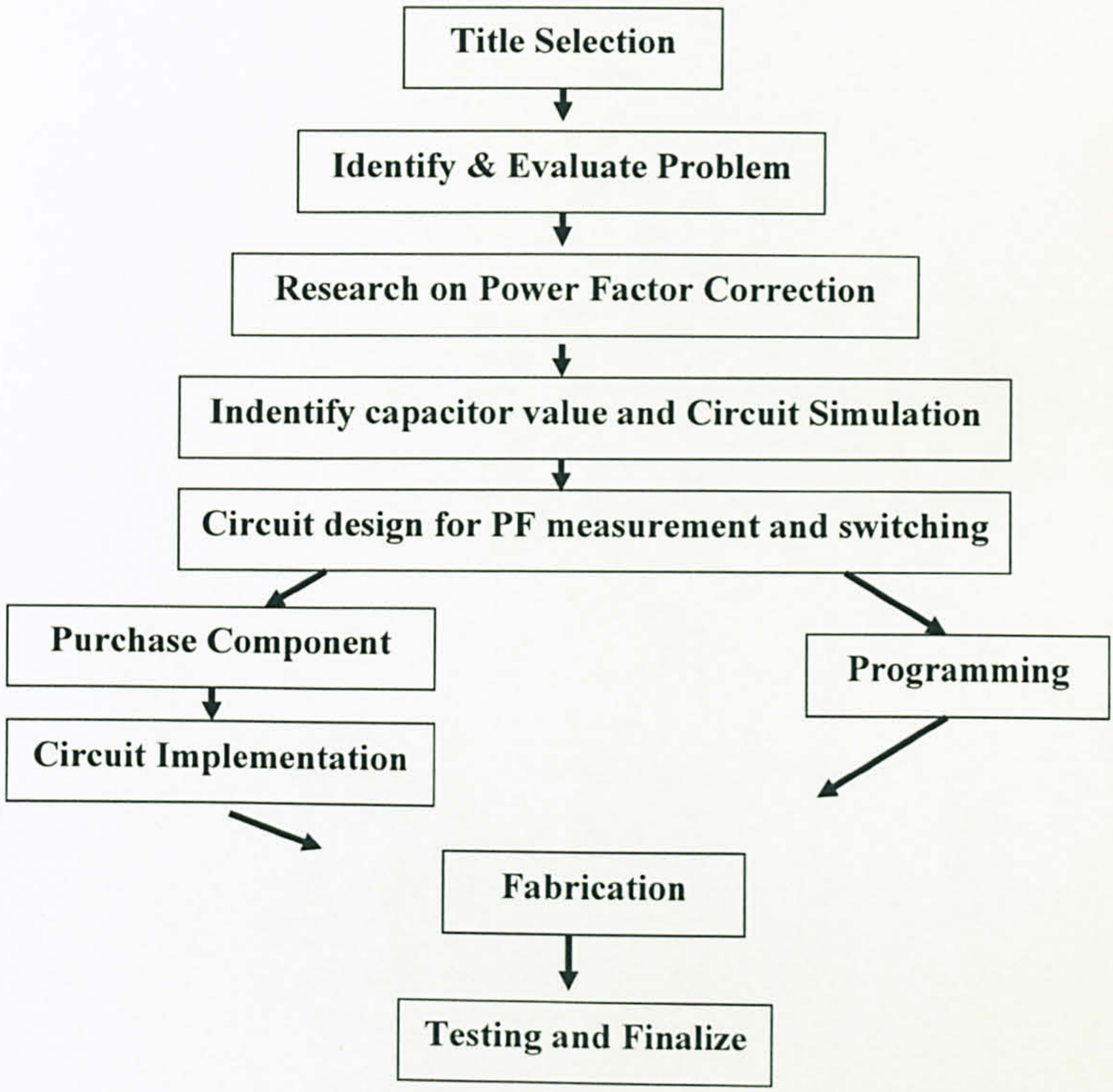

Figure 8 : Methodology for power factor correction device project

At the beginning of semester, few titles are proposed as final year project title. After some initial stage research and consideration, this topic, power factor correction device has been selected. Once the title is finalized, problems regarding this topic is identified and evaluated. With a clear problem statement, objective and scope of study, research on power factor correction were carried out. Research including consulted supervisor and lecturers, read related technical paper from IEEE, browsed through related website and books from Information Resource Center UTP.

Power Factor correction is to compensate the shifted waveform by using appropriate value of capacitor. Hence approach to identify the value of capacitor is crucial. The calculation of this approach for various cases is carried out. Nowadays, electrical appliances come with some simple built in circuit or device to improve the power factor. Hence it is rare that house electrical appliances has significant lower power factor lower than 8.

Referring to Appendix A, generally house electrical appliances where consumes high power will have significant effect on the power factor. This is due to the internal motor or coil that will draw high current for the motor starting and operation. Hence, in this capacitor value, we take 1 HP air conditioner and calculate what value of capacitor needed to compensate the electrical appliances for different power factor.

3.2 Power Factor and Correction Capacitor Value Calculation

Capacitor value is calculated with the equation $C = \frac{\text{VAR}}{2\pi\text{f X } V^2}$.

where, VAR = capacitor unit VAR rating

C = capacitor (farads)

F =frequency (cycles/second)

V = rated voltage

Power factor, $pf = \frac{P}{S}$, where $S^2 = P^2 + Q^2$. Assume in the load of 100W, different power factor will have different value of Q.

Case (a): P=100W, PF=0.9, V=240V

$\frac{P}{S} = 0.9,\ 100\ =\ \frac{P}{0.90}$, P = 90 W

Since $S^2 = P^2 + Q^2$, after rearrange, Q= 43.58 var

$$C = \frac{\text{VAR}}{2\pi f \text{ X } V^2} = \frac{43.58}{2\pi \text{X} 50 \text{ X } 240^2} = 2.67 \text{ uF}$$

Case (b): P=100W, PF=0.8, V=240V

$\frac{P}{S} = 0.8,\ 100\ =\ \frac{P}{0.80}$, P = 80 W

Since $S^2 = P^2 + Q^2$, after rearrange, Q= 60.00 var

$$C = \frac{\text{VAR}}{2\pi f \text{ X } V^2} = \frac{60.00}{2\pi \text{X} 50 \text{ X } 240^2} = 4.10 \text{ uF}$$

,

Case (c): P=100W, PF=0.7, V=240V

$\frac{P}{S} = 0.7,\ 100\ =\ \frac{P}{0.70}$, P = 70 W

Since $S^2 = P^2 + Q^2$, rearrange, Q= 71.41 var

$$C = \frac{\text{VAR}}{2\pi f \text{ X } V^2} = \frac{71.41}{2\pi \text{X} 50 \text{ X } 240^2} = 5.63 \text{ uF}$$

Case (d): P=100W, PF=0.6, V=240V

$\frac{P}{S} = 0.80,\ 100 = \frac{P}{0.6}$, P = 60 W

Since $S^2 = P^2 + Q^2$, rearrange, Q= 80.00 var

$$C = \frac{\text{VAR}}{2\pi f \text{ X } V^2} = \frac{80.00}{2\pi \text{X} 50 \text{ X } 240^2} = 7.37 \text{ uF}$$

Table 2: Summary for power information for electric appliance consumes 100W

Power factor (PF)	Apparent Power (S)	Real power (W)	Reactive power (var)	Capacitor value needed (uF)
0.9	100	90	43.58	2.67
0.8	100	80	60.00	4.10
0.7	100	70	71.41	5.63
0.6	100	60	80.00	7.37

The convention approach of measuring power factor is to produce the PWM and compare the angle between voltage and current. In this project, an alternative approach is proposed. As the equation $pf = \frac{P}{S}$, where P== V_{avg} X I_{avg} while S= V_{rms} X I_{rms}, this project is calculating the average voltage, average current, rms voltage and rms current to calculate the power factor.

To ensure this method is experimentally valid, conceptual circuit is simulated in PSPICE. Two circuits which first is the supply with pure resistive load while second circuit is simulating the supply with inductive load. From comparing the result of simulation and theoretical calculation, the validation of this alternative is verified.

From the simulation result, the circuit must be able to sample the voltage and current level to calculate the power factor, and choose suitable value of capacitor to compensate the lower power factor. Figure 9 shown a circuit diagram which fulfilled project's requirements.

The voltage supply flow in to device through main source section and supply electrical appliances at output female plug. Voltage at Live line will flow through a voltage divide. The downscaled voltage flowing in PIC ADC pin input. Voltage at Neutral line flow through current sensing resistor before supplying electrical appliances.

The current level is estimated by PIC A/D pin. Opto-isolator placed between the PIC and voltage input to protect the PIC.

PIC microprocessor with A/D pin will sample the level of voltage and current and carry out the calculation and display power factor in LCD. If the power factor is lower than expected, PIC turn on the switching circuit that consist of transistor and power relay to enable capacitor compensate the power factor. This power factor correction circuit will continuously monitor the power flow to ensure high power factor.

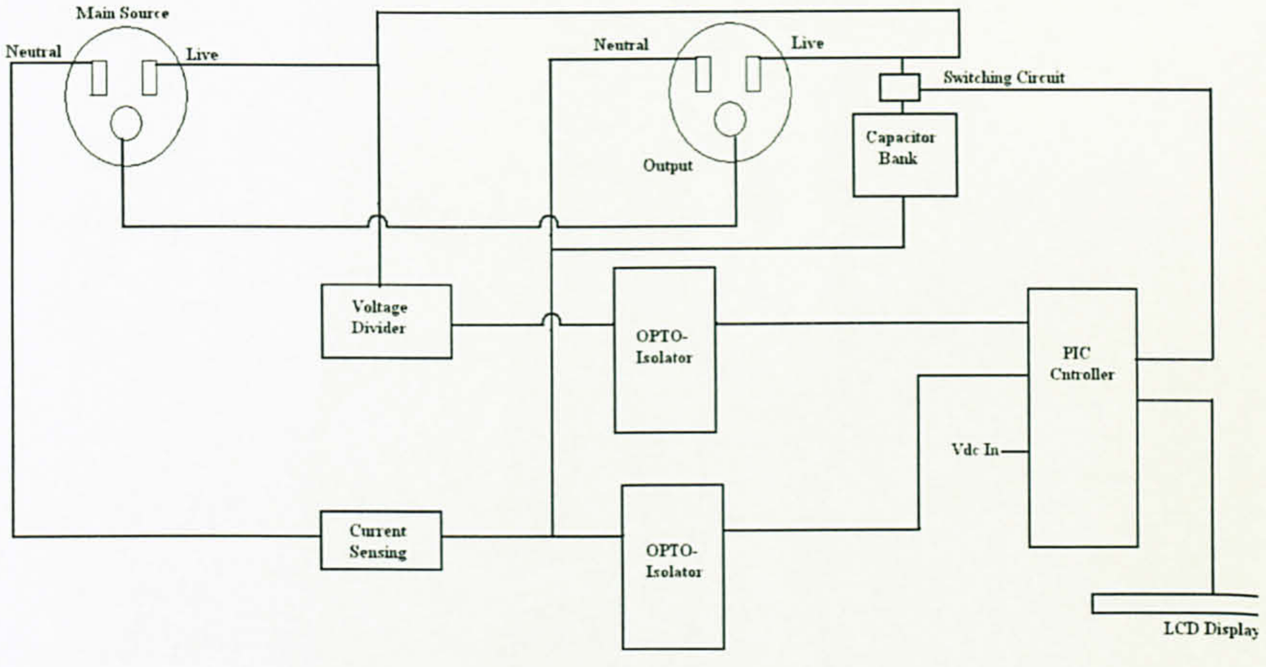

Figure 9: Block diagram for PFC device

After circuit design, purchase component and circuit implementation are carried out. This is to experimentally construct the circuit on bread board to ease the modification. Programming on PIC also started at the same time to program the PIC to do the calculation for power factor measurement.

Next is the fabrication stage. In this stage, the circuit is transferred to veroboard and all the components and wiring located in the housing. This is to ensure the prototype looks tidy and presentable. After the fabrication process, final testing is carried out. If the prototype is working, finalize the project including prepare the documentation, marketing consideration and presentation.

3.3 PIC Programming

The PIC is programmed in order to senses the voltage and current level, calculate and display power factor, and give command to output pin to trigger capacitor to be connected parallel with load. The algorithm of the programmed is shown in figure 10 Figure 11 shown the interface of PIC C Compiler.

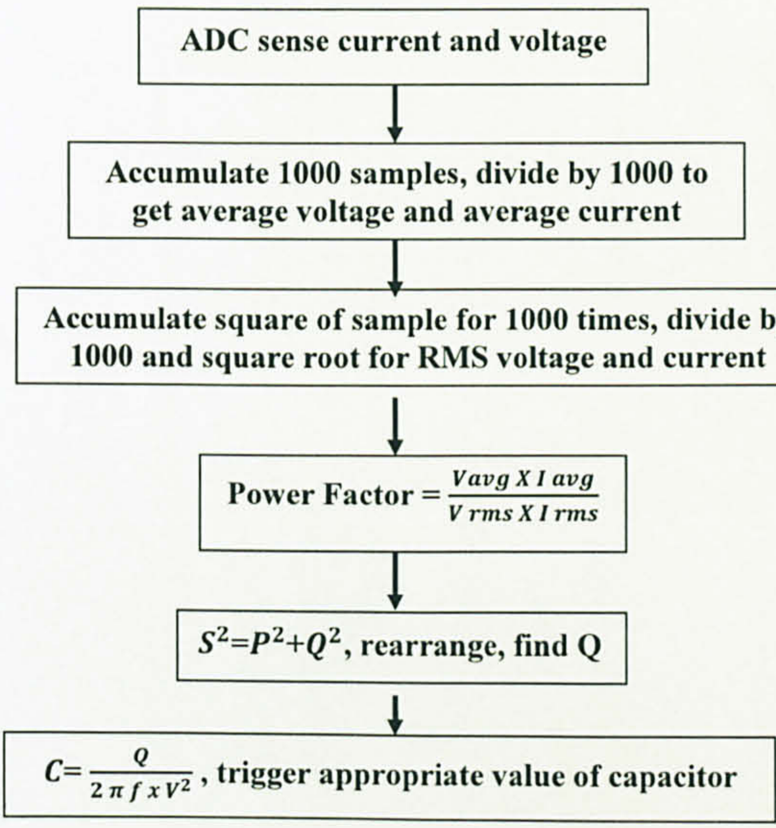

Figure 10 : Algorithm for programming

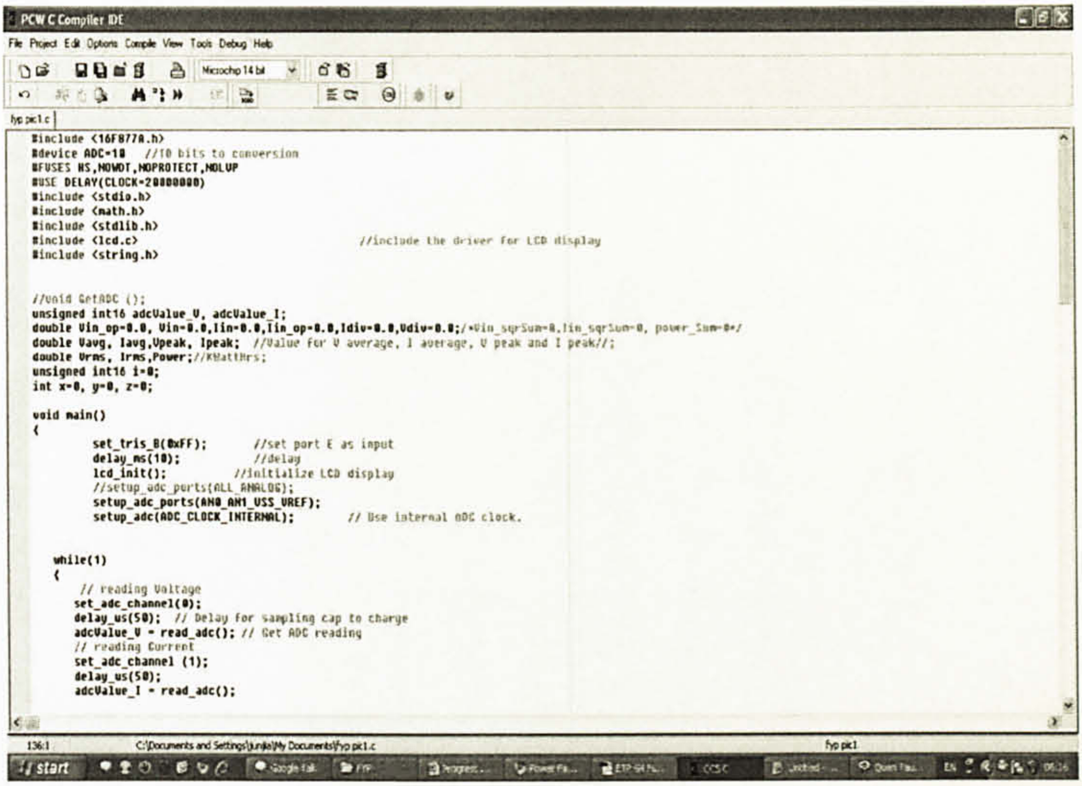

Figure 11: Print Screen of programming interface

The programming loaded to PIC microcontroller by using the USB PIC programmer that displayed in figure 12.

Figure 12 : USB PIC programmer

3.4 Hardware and Software Used

This project will involved few software and hardware as listed in table 3:

Table 3: Hardware and software used

Software	
PSPICE	Circuit Simulation for measuring device
PIC C Compiler (PCW)	PIC programming for calculate the power input
Microsoft Office	Word processing software for report preparation
LVDAM-EMS	Monitor voltage, current and power in experiment
Hardware/ Component	
PIC	To receive input, calculate the power factor and initiate capacitor for power factor correction
LCD Display	Display the calculated power factor
Opto-isolator	To isolate the input voltage with the PIC
Capacitor Bank	To compensate the lagging power factor
Current sensing resistor	To measure the current pass through Neutral line
Power Relay	To control and On/Off status of Capacitor Bank
LabVolt modules (Data Acquisition Interface, Resistive load, Inductive load and Capacitive load)	To conduct experiment on power factor and power factor correction

CHAPTER 4

RESULT AND DISCUSSION

4.1 Circuit Simulation Result

Conceptual circuits have been simulated in PSPICE. This is to validate the power factor measurement approach is works and efficient. The general approach of measuring power factor without devices such as Power Quality Analyzer or Power Meter is to calculate the phase angle between voltage and current. In this project, alternative approach which is measuring the consumption of Real Power (W) and Apparent Power (S).

By definition, Real Power = V_{avg} X I_{avg} while the Apparent Power = V_{rms} X I_{rms}. For the pure resistive load, a circuit with 240Vrms voltage source, 57.507 ohm load shown in figure 13 is simulated:

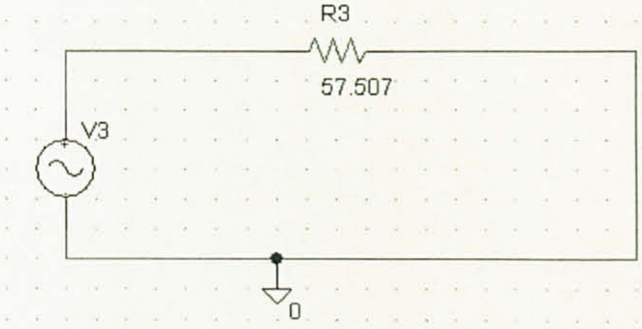

Figure 13: Conceptual circuit with pure resistive load

From the simulation result in Figure 14, real power, P=996.5W

Apparent power, S= V_{rms} X I_{rms}, where $Vrms = \frac{\text{Vpeak}}{\sqrt{2}}$ and $Irms = \frac{\text{Ipeak}}{\sqrt{2}}$.

From the graph, $Vrms = \frac{338.825}{\sqrt{2}}$ =239.58V while $Irms = \frac{117.838}{20 \times \sqrt{2}} = \frac{5.89}{\sqrt{2}}$= 4.17A.

I_{rms} is divided by 20 because in the graph I_{rms} is multiplied by 20 to make the graph obvious.

Apparent power, S= V_{rms} X I_{rms} =239.58 X 4.17 =999.049

And calculated power factor, $pf = \frac{996.5}{999.049}$ =0.9974

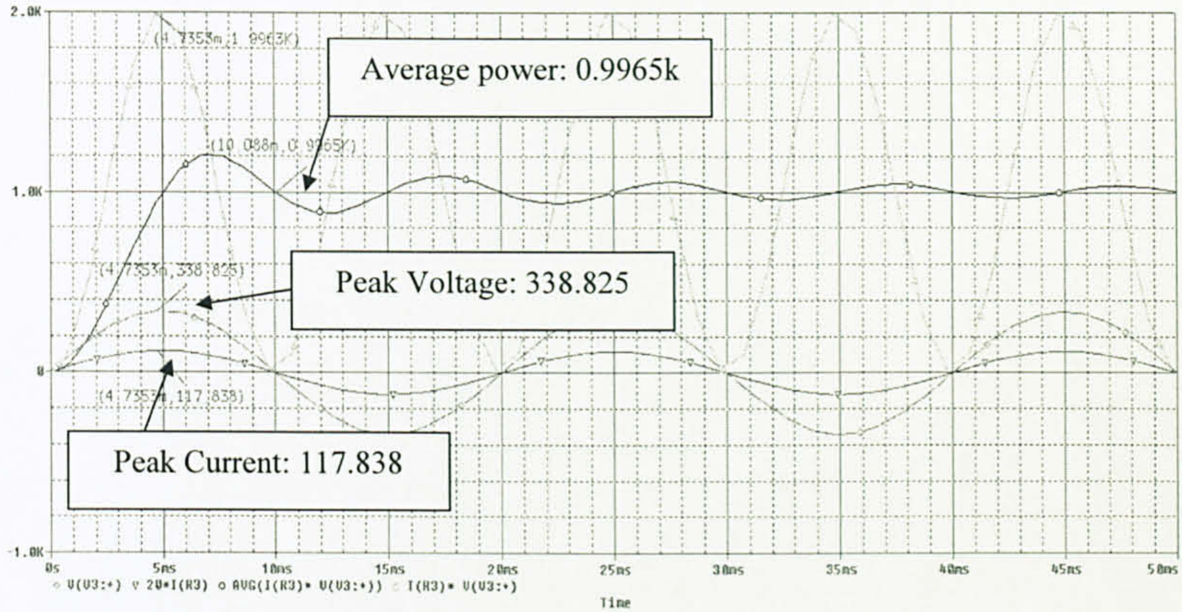

Figure 14: Simulation result for pure resistive load

For the inductive load, a circuit with 240Vrms voltage source, 57.507 ohm loads with shifted angle 31.78 degree shown in figure 15:

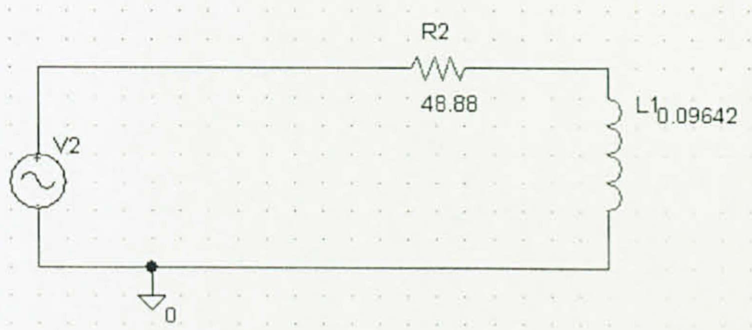

Figure 15: Conceptual circuit with inductive load

From the simulation result in Figure 16, real power, P=848.726W

Apparent power, S= V_{rms} X I_{rms}, where $Vrms = \frac{\text{Vpeak}}{\sqrt{2}}$ and $Irms = \frac{\text{Ipeak}}{\sqrt{2}}$.

From the graph, $Vrms = \frac{338.825}{\sqrt{2}}$ =239.58V while $Irms = \frac{119.965}{20 \times \sqrt{2}} = \frac{5.99}{\sqrt{2}}$ = 4.23A.

I_{rms} is divided by 20 because in the graph I_{rms} is multiplied by 20 to make the graph obvious.

Apparent power, S= V_{rms} X I_{rms} =239.58 X 4.23 =1015.67W

And calculated power factor, $pf = \frac{848.726}{1015.67}$ =0.8356

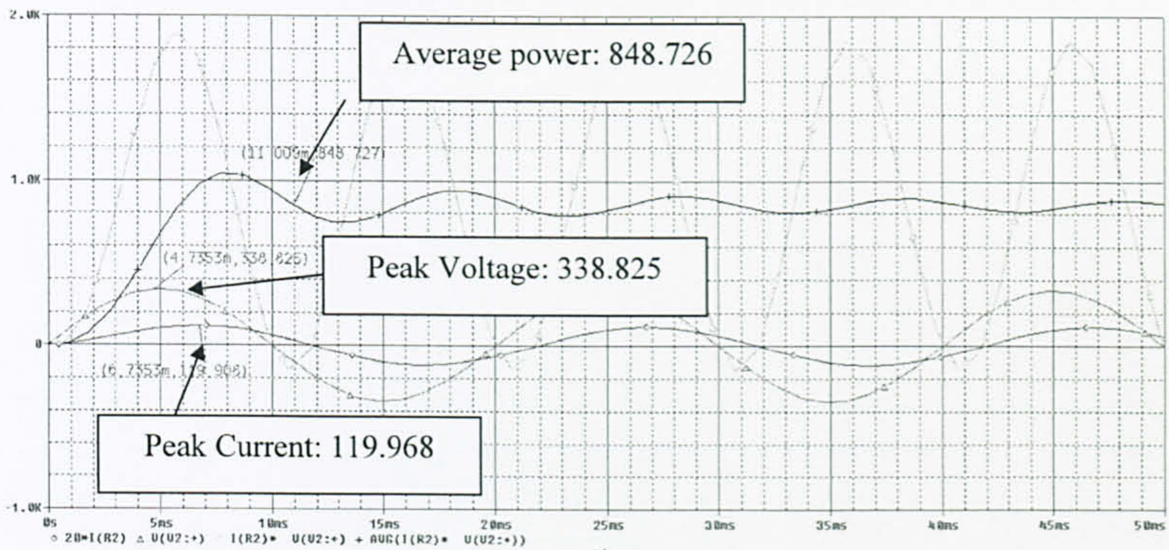

Figure 16: Simulation result for inductive load

Table 4: Comparison of theoretical and experimental result

	Angle Difference, θ	Theoretical pf, Cos θ	Simulated pf, $\frac{P}{S}$	Error Percentage
Resistive Load	0	1	0.9974	0.26%
Inductive Load	31.78	0.85	0.8356	1.69%

This simulation result theoretically proved that the power factor can be measured by the proposed approach.

4.2 Experiment on Power Factor

Experiment on power factor of the power system in different load has been carried out in Power Electronics Lab by using LabVolt LVDAM-EMS System. The lab equipments involved are:

- LabVolt Data Acquisition Interface 9062-15
- LabVolt Power Supply 8821-2A
- LabVolt Resistive Load, 8311-0A
- LabVolt Inductive Load, 8321-05
- LobVolt Capacitive Load, 8331-0A

Figure 17 shows the computer interface of LVDAM-EMS. Figure 18 and 19 show the resistive and inductive module by LabVolt. Figure 20 shows the workstation of experiment on power factor and power factor correction.

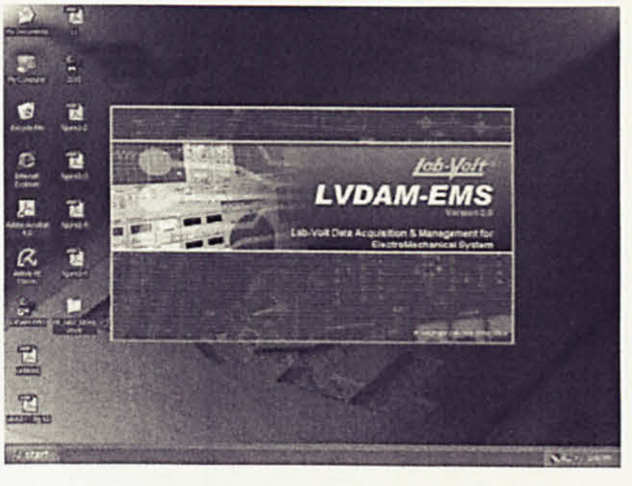

Figure 17: Interface of LVDAM- EMS

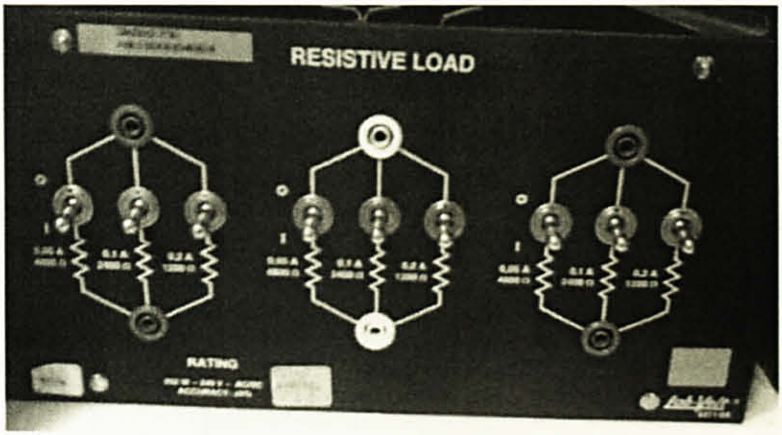

Figure 18: Resistive module of LabVolt

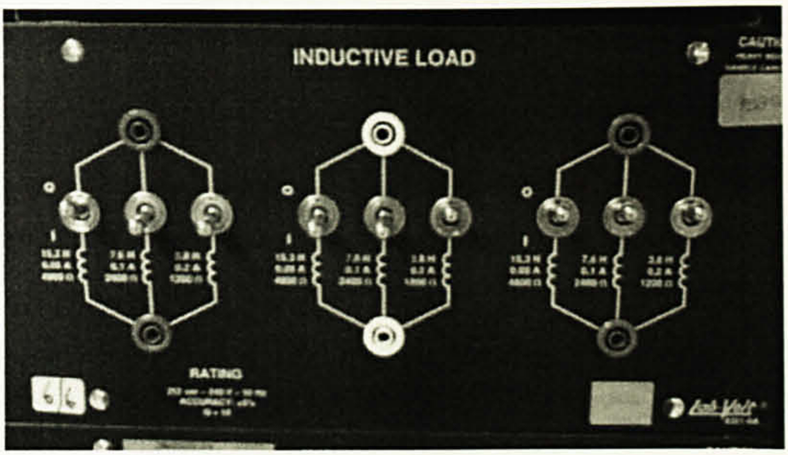

Figure 19: Inductive module of LabVolt

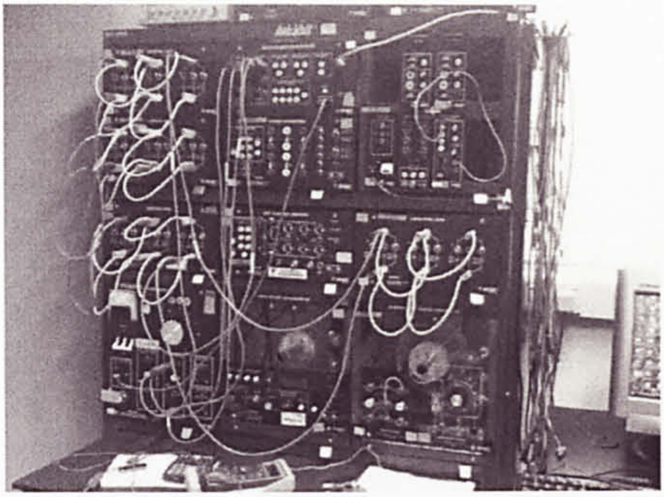

Figure 20: Workstation for power factor experiment

4.2.1 Experiment Result without Capacitor

When different loads consist of different value of resistance and inductance are connected to the system, the system response to the load and reflected different power factor. The results of the experiment are attached in appendix D and the summary of result is as shown in Table 5

Table 5: Experiment result without capacitor

	1.0	0.9	0.8	0.7	0.6
V average, V	240.9	240.91	240.42	240.70	241.08
I average, A	0.414	0.385	0.386	0.366	0.358
Real Power, W	99.67	83.16	75.42	61.16	51.49
Reactive Power, Var	0.34	40.86	54.10	63.64	69.25
Apparent Power, VA	99.67	92.66	92.72	88.10	86.17
Phase Shift, degree	0.1	25.3	33.9	45.0	52.1
PF	1.00	0.90	0.81	0.69	0.60

The experimental results are compared with the theoretical calculation result. From the comparison, the system responses as expected with a acceptable range or error percentage. The result of comparison is shown in Table 6.

Table 6: Comparison between experiment and theoretical result

	Result Comparison For Phase Shift			Result Comparison For PF		
	Experimental Result	Theoretical Result	Error Percentage	Experimental Result	Theoretical Result	Error Percentage
1	0.1	0.0	0	1.0	1.0	0
2	25.3	25.84	2.89	0.90	0.90	0
3	33.9	36.86	8.03	0.81	0.80	1.25
4	45.0	45.57	1.25	0.69	0.70	1.43
5	52.1	53.13	1.93	0.60	0.60	0

4.2.1 Experiment Result with Capacitor

After verified the effect of loads in the power system, next capacitors are connected to the system accordingly to correct the power factor in the system. As discussed in previous session, the value of capacitance to correct the power factor is shown in Table 2.

When different load is connected to the power system, the capacitive loads are connected parallel with the load to compensate low power factor. The result of the experiment is attached in appendix E and the summary of the results is shown in Table 7.

Table 7: Experiment result with capacitor

	0.9	0.8	0.7	0.6
V average, V	237.80	237.96	238.36	238.52
I average, A	0.349	0.319	0.264	0.228
Real Power, W	81.82	74.32	60.49	50.24
Reactive Power, Var	1.18	6.75	8.88	2.96
Apparent Power, VA	83.09	75.97	62.90	54.43
Phase Shift, degree	0.9	0.1	6.6	5.8
PF	1.0	1.0	0.99	1.0

The experimental results are compared with the theoretical calculation result. From the comparison, the system responses as expected with a acceptable range or error percentage. The result of comparison is shown in Table 8

Table 8: Comparison between experiment and theoretical result

	Result Comparison For Phase Shift		Result Comparison For PF	
	Experimental Result	Theoretical Result	Experimental Result	Theoretical Result
0.9	0.9	0.0	1.0	1.0
0.8	0.1	0.0	1.0	1.0
0.7	6.6	0.0	0.99	1.0
0.6	5.8	0.0	1.0	1.0

From the results shown, the formula to calculate value of capacitance is verified. All the values of capacitor calculated in Table 2 corrected the power factor to almost unity with a small value of error percentage.

4.3 Circuit Configuration

The circuit of this project has two parts which are measuring circuit and switching circuit. Measuring circuit is the circuit that read the input, carries out calculation display output and gives instruction to switching circuit. While switching circuit is depending on the command of measuring circuit to connect the correction capacitor to the load. The schematic diagram is shown in figure 21.

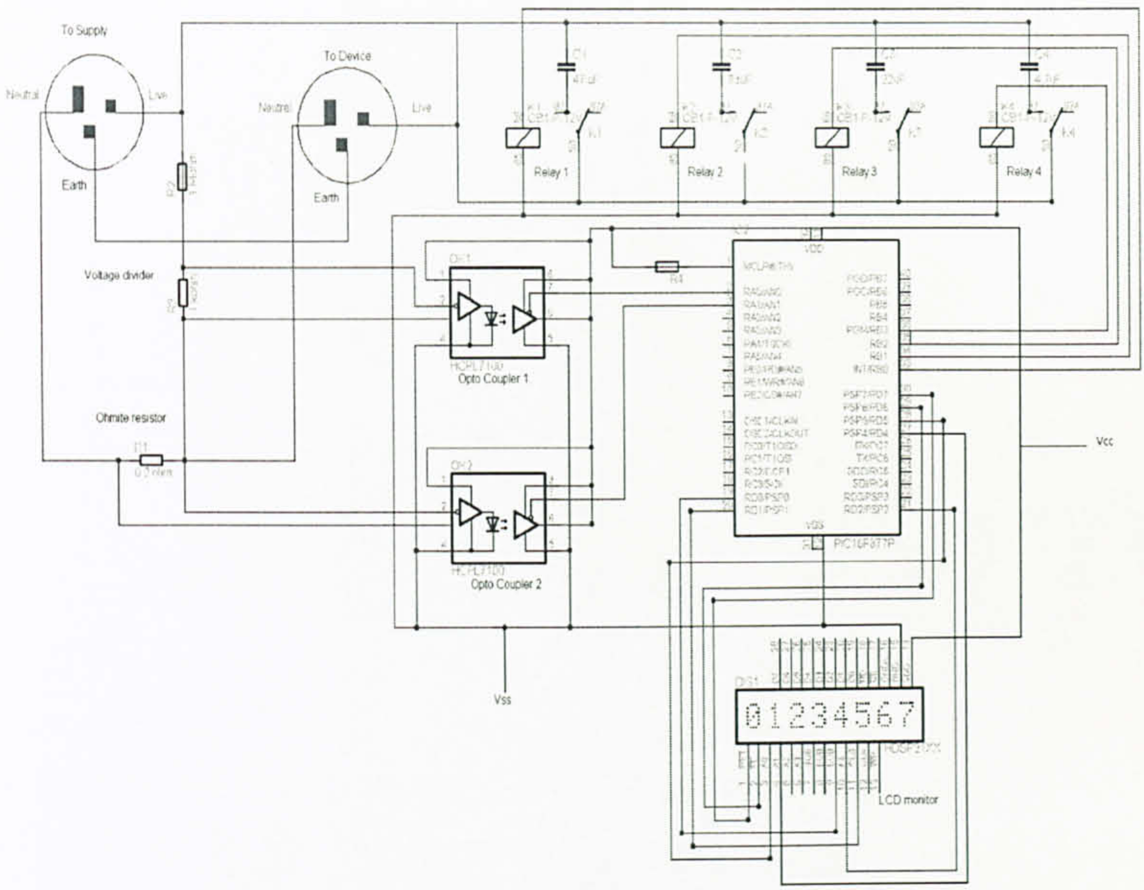

Figure 21: Schematic diagram for circuit

4.3.1 Measuring Circuit

Measuring circuit is contrasted based on schematic diagram in figure 21. Voltage flowing in through LIVE and then is step downed by the voltage divider. The Step downed voltage feed the input pins of the opto-isolator, which give the output according to intensity of LED in the opto-isolator and isolating the voltage and the PIC. The output of opto-isolator sensed by the ADC pin of PIC and used for calculation for average voltage and RMS voltage. While in the Neutral, the current sense resistor measure the voltage flowing through, and reflect in second ADC pin. This value used for calculation for average current and RMS current.

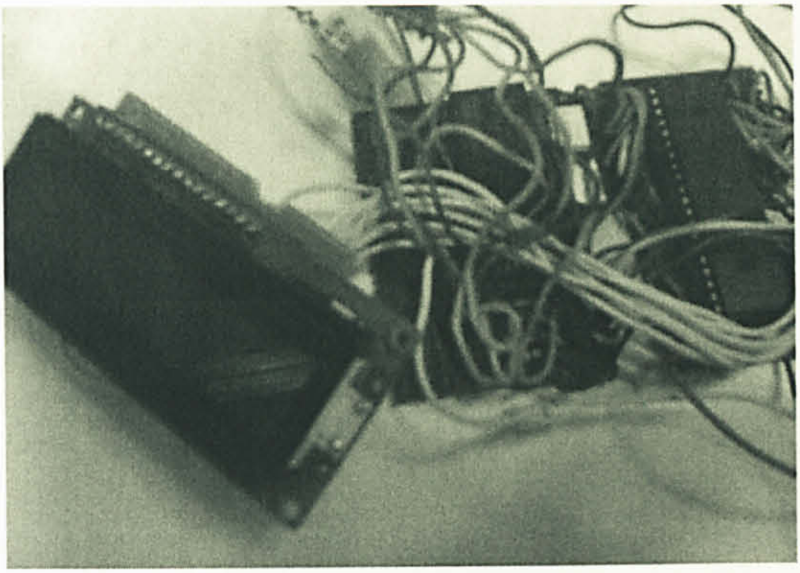

Figure 22: Measuring Circuit

4.3.2 Switching Circuit

Switching circuit is the important part of this project as it receives the output from PIC, which has been programmed and calculated the Power Factor. The switching circuit is consists 4 6V relay and 4 correcting capacitors with different value.

In the circuit, 4 pins from PIC are designated as the output. When one of the pin is high, it is flowing from the base to emitter in respective transistor. This will allow relay's coil being charged and hence the capacitor is connected to the LIVE and NEUTRAL line in parallel. The switching circuit is shown in figure 23.

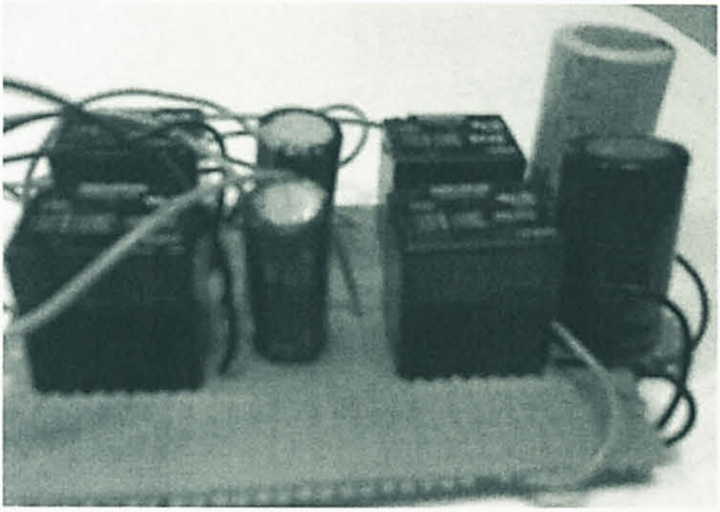

Figure 23: Switching Circuit

4.4 Circuitry Result

Testing on the measuring circuit and switching circuit has been done. The LED is successfully displayed the calculated result based on the input that read at the ADC pin in PIC. The circuit has shown the reading for average voltage, average current and power factor. The switching circuit are triggered and connected parallel to the load when the command is given by the PIC based on the calculation.

4.4.1Result for switching circuit

The switching circuit is constructed as shown in figure 23. As the objective of the switching circuit is to connect the appropriate value of capacitor to the system, the testing on switching circuit is to measure the capacitance value in the load when the relay is triggered.

When 5V output is provided by the PIC pin, the coil in respective relay is energized and relay connects the capacitor to the system. Table 9 shown the capacitance in the system when 5 V is present in respective pin of PIC.

Table 9: Triggered capacitance in system

PIC Pin	Voltage at the PIC pin	Relay	Capacitance
C0	5V	1	2.2 uF
C1	5V	2	3.3 uF
C2	5V	3	4.7 uF
C3	5V	4	10.0 uF

4.4.2 Result for Measuring Circuit

The measuring circuit first tested by supplying voltage by the power supply without load. The result of the measuring device is displayed by the LED as shown in figure 24. When there is no load, the current will always be constant and the voltage reading varies according to the level of input voltage.

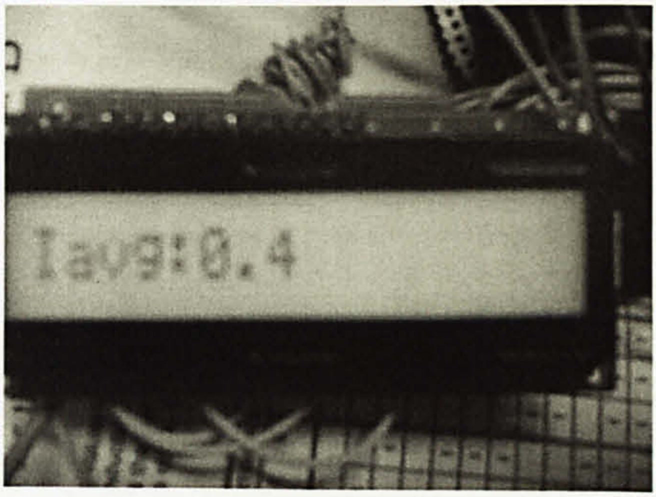

Figure 24: Reading displayed by LED

The summary of the value displayed in the LED is recorded and as shown in Table 10.

Table 10: Summary of voltage displayed by LCD

	Voltage Supplied (V)	Voltage Measured (V)	Error Percentage
1	60	64	6.67
2	120	108	10.00
3	180	163	9.44
4	240	227	5.4

The result of the experiment has shown that the measuring device able to display the voltage in the system with a range of error percentage. Figure 25 shows the comparison between the actual values of voltage with the measured voltage.

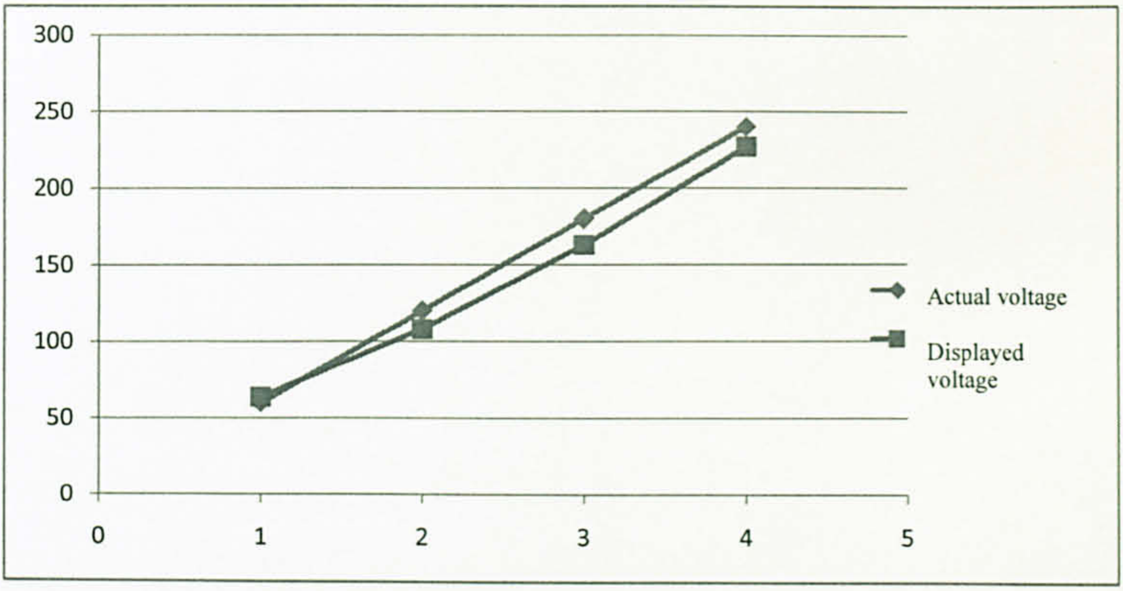

Figure 25: Comparison between actual voltage and displayed voltage

The loads are connected to measuring device in the second stage testing. When the loads vary, the displayed power factor is adjusted according to input voltage. However, as the power factor involved several steps of calculation depending on the input, a small deviation in the PIC ADC pin gave a big impact in the value of average voltage, average current, RMS voltage and RMS current. As the result displayed in Table 10 shown the certain error percentage in the reading, the result of power factor displayed gave a large error percentage. The result of power factor is shown in table 11

Table 11: Comparison between PF measured by system and measuring circuit

	Power Factor Measure by LVDAM-EMS	Power Factor Measured by measuring circuit
1	0.9	0.70
2	0.81	0.94
3	0.69	0.82
4	0.6	0.80

The reading measuring device for power factor has a range of variation. The next testing is to test the effect of capacitor when it is connected to the system according to the command of PIC. The result of the experiment is recorded and shown in table 12,

Table 12: PF after capacitor connected

	PF before capacitor connected	PF after capacitor connected
1	0.70	0.78
2	0.94	0.96
3	0.82	0.89
4	0.80	0.86

The graphical comparison between the power factor measured by system, power factor measured by measuring circuit before and after the capacitors are connected to the measuring circuit is shown in figure 26. From the graph, the deviation for the power factor measured by the measuring circuit is quite obvious. When the capacitor is connected parallel to the load, the result has shown the capacitor give positive impact on the power factor.

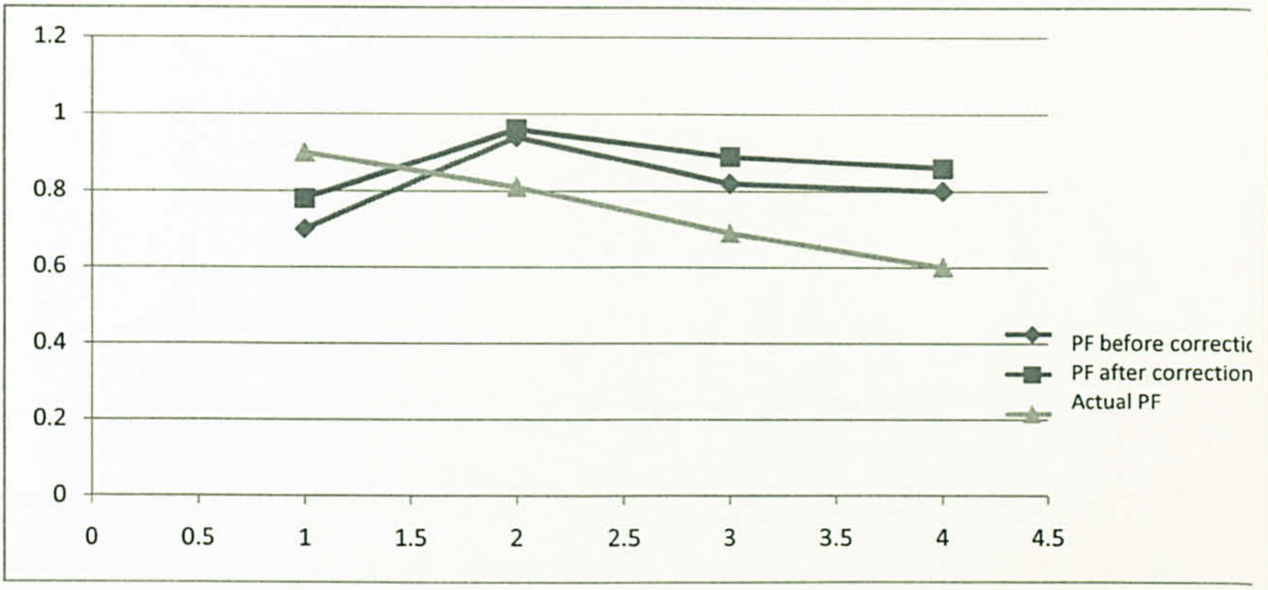

Figure 26: Result of actual PF, measured PF before and after capacitor connected

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The research done so far shown that power factor correction devices are widely used in commercial and industrial fields. However for the residential power users, they are not very familiar with this PFC device and rarely use it. This is mainly because in the commercial and industrial user the power utilities will charge them on the low power factor while residential users are not being charged on the low power factor.

From the research, with installation of good PFC device will reduce the line loss and save the money in bill. This is due to corrected power factor give higher electrical efficiency in the electrical system. From the experiment conducted, power factor increased with appropriate value of capacitor connected. The research on this project had given the exposure of understanding of power factor and power factor correction device.

5.2 Recommendations

From the result of the measuring circuit, it can be conclude that modifications on the measuring device have to be done. One of the recommendations is to look for alternative component that give a more linear input and out characteristic. This can effectively increase the accuracy of the measuring circuit.

The ratio of voltage divider in the circuit can be reduced. The input voltage and input current in ADC pin of PIC is only certain ratio of the actual current and voltage due to the voltage divider in the measuring circuit. When the ratio of voltage divider is big, a small error in the ADC of PIC will give a great impact on the calculated value, and very much affect the accuracy of calculated result.

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[10] http://en.wikipedia.org/wiki/PIC_microcontroller

APPENDICES

Appendix A

No	Electrical Appliances	Watt	Amp	Consumption (RM/Hour)
1	Air Conditional (1 HP)	1000	4.17	0.218
2	Fan	84	0.35	0.018
3	Fluorescent Light	40	0.17	0.009
4	Television 29''	100	0.42	0.022
5	Refrigerator	140	0.58	0.031
6	Washing Machine	330	1.38	0.072
7	Vacuum Cleaner	1200	5.00	0.262
8	Computer	400	1.67	0.087
9	Water Heater	2000	8.33	0.436
10	Iron	1000	4.16	0.218
11	Microwave	1300	5.42	0.283
12	Rice Cooker	1000	4.17	0.218
13	Cloth Dryer	3000	12.5	0.654
14	Dish Washer	2700	11.25	0.589

Appendix B

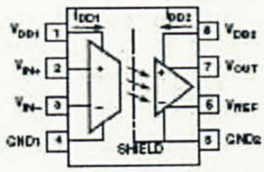
Agilent HCPL-7520 Isolated Linear Sensing IC
Data Sheet

Description

The HCPL-7520 isolated linear current sensing IC family is designed for current sensing in low-power electronic motor drives. In a typical implementation, motor current flows through an external resistor and the resulting analog voltage drop is sensed by the HCPL-7520. An output voltage is created on the other side of the HCPL-7520 optical isolation barrier. This single-ended output voltage is proportional to the motor current. Since common-mode voltage swings of several hundred volts in tens of nanoseconds are common in modern switching inverter motor drives, the HCPL-7520 was designed to ignore very high common-mode transient slew rates (of at least 10 kV/µs).

The high CMR capability of the HCPL-7520 isolation amplifier provides the precision and stability needed to accurately monitor motor current in high noise motor control environments, providing for smoother control (less "torque ripple") in various types of motor control applications.

Functional Diagram



The product can also be used for general analog signal isolation applications. For general applications, we recommend the HCPL-7520 (gain tolerance of ±5%). The HCPL-7520 utilizes sigma delta (Σ-Δ) analog-to-digital converter technology to delivery offset and gain accuracy and stability over time and temperature. This performance is delivered in a compact, auto-insert, 8-pin DIP package that meets worldwide regulatory safety standards. (A gull-wing surface mount option #300 is also available).

Features

- 15 kV/µs common-mode rejection at Vcm = 1000 V
- Compact, auto-insertable 8-pin DIP package
- 60 ppm/°C gain drift vs. temperature
- –0.6 mV input offset voltage
- 8 µV/°C input offset voltage vs. temperature
- 100 kHz bandwidth
- 0.06% nonlinearity, single-ended amplifer oon
- Worldwide safety approval: UL 1577 (3750 Vrms/1 min.) and CSA (pending), DIN EN 60747-5-2 (Option #060 only pending)
- Advanced sigma-delta (Σ-Δ) A/D converter technology

Applications

- Low-power inverter current sensing
- Motor phase and rail current sensing
- Switched mode power supply signal isolation
- General purpose low-power current sensing and monitoring
- General purpose analog signal isolation

CAUTION: It is advised that normal static precautions be taken in handling and assembly of this component to prevent damage and /or degradation which may be induced by ESD.

Agilent Technologies

Appendix C

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Circuit Construction	x	x												
PIC Programming			x	x										
Refine Circuit					x	x								
Troubleshooting							x	x	x					
Transform into Prototype										x				
Finalize Project											x			
EDX												x		
Dissertation Preparation													x	
Presentation Preparation														X

Appendix D-1

Metering

Meter	Description	Mode	Scale/Unit	Value
E1	E1	AC	V	240.90
E2	E2	AC	V	---
E3	E3	AC	V	---
I1	I1	AC	A	0.414
I2	I2	AC	A	---
I3	I3	AC	A	---
PQS1	PQS1 (E1,I1)	P1	W	---
PQS2	PQS2 (E2,I2)	Q2	var	---
PQS3	PQS3 (E3,I3)	P3	W	---
T	T	NC	N·m	---
N	N	---	r/min	---
Pm	Pm (T,N)	C	W	---
A	PQS1 (E1,I1)	P	W	99.67
B	PQS1 (E1,I1)	Q	var	0.34
C	PQS1 (E1,I1)	S	VA	99.67
D	PQS1 (E1,I1)	Q	var	---
E	PS (E1,I1)	---	°	0.1
F	PF (E1,I1)	True		-1.00

Appendix D-2

Metering

Meter	Description	Mode	Scale/Unit	Value
E1	E1	AC	V	240.91
E2	E2	AC	V	---
E3	E3	AC	V	---
I1	I1	AC	A	0.385
I2	I2	AC	A	---
I3	I3	AC	A	---
PQS1	PQS1 (E1,I1)	P1	W	---
PQS2	PQS2 (E2,I2)	Q2	var	---
PQS3	PQS3 (E3,I3)	P3	W	---
T	T	NC	N·m	---
N	N	---	r/min	---
Pm	Pm (T,N)	C	W	---
A	PQS1 (E1,I1)	P	W	83.16
B	PQS1 (E1,I1)	Q	var	40.86
C	PQS1 (E1,I1)	S	VA	92.66
D	PQS1 (E1,I1)	Q	var	---
E	PS (E1,I1)	---	°	25.3
F	PF (E1,I1)	True		-0.90

Appendix D-3

Metering

Meter	Description	Mode	Scale/Unit	Value
E1	E1	AC	V	240.42
E2	E2	AC	V	---
E3	E3	AC	V	---
I1	I1	AC	A	0.386
I2	I2	AC	A	---
I3	I3	AC	A	---
PQS1	PQS1 (E1,I1)	P1	W	---
PQS2	PQS2 (E2,I2)	Q2	var	---
PQS3	PQS3 (E3,I3)	P3	W	---
T	T	NC	N·m	---
N	N	---	r/min	---
Pm	Pm (T,N)	C	W	---
A	PQS1 (E1,I1)	P	W	75.42
B	PQS1 (E1,I1)	Q	var	54.10
C	PQS1 (E1,I1)	S	VA	92.72
D	PQS1 (E1,I1)	Q	var	---
E	PS (E1,I1)	---	°	33.9
F	PF (E1,I1)	True		-0.81

Appendix D-4

<u>Metering</u>

Meter	Description	Mode	Scale/Unit	Value
E1	E1	AC	V	240.70
E2	E2	AC	V	---
E3	E3	AC	V	---
I1	I1	AC	A	0.366
I2	I2	AC	A	---
I3	I3	AC	A	---
PQS1	PQS1 (E1,I1)	P1	W	---
PQS2	PQS2 (E2,I2)	Q2	var	---
PQS3	PQS3 (E3,I3)	P3	W	---
T	T	NC	N·m	---
N	N	---	r/min	---
Pm	Pm (T,N)	C	W	---
A	PQS1 (E1,I1)	P	W	61.14
B	PQS1 (E1,I1)	Q	var	63.64
C	PQS1 (E1,I1)	S	VA	88.10
D	PQS1 (E1,I1)	Q	var	---
E	PS (E1,I1)	---	°	45.0
F	PF (E1,I1)	True		-0.69

Appendix D-5

Metering

Meter	Description	Mode	Scale/Unit	Value
E1	E1	AC	V	241.02
E2	E2	AC	V	---
E3	E3	AC	V	---
I1	I1	AC	A	0.358
I2	I2	AC	A	---
I3	I3	AC	A	---
PQS1	PQS1 (E1,I1)	P1	W	---
PQS2	PQS2 (E2,I2)	Q2	var	---
PQS3	PQS3 (E3,I3)	P3	W	---
T	T	NC	N·m	---
N	N	---	r/min	---
Pm	Pm (T,N)	C	W	---
A	PQS1 (E1,I1)	P	W	51.49
B	PQS1 (E1,I1)	Q	var	69.25
C	PQS1 (E1,I1)	S	VA	86.17
D	PQS1 (E1,I1)	Q	var	69.25
E	PS (E1,I1)	---	°	52.1
F	PF (E1,I1)	True		-0.60

Appendix E-1

Metering

Meter	Description	Mode	Scale/Unit	Value
E1	E1	AC	V	237.80
E2	E2	AC	V	---
E3	E3	AC	V	---
I1	I1	AC	A	0.349
I2	I2	AC	A	---
I3	I3	AC	A	---
PQS1	PQS1 (E1,I1)	P1	W	---
PQS2	PQS2 (E2,I2)	P2	W	---
PQS3	PQS3 (E3,I3)	P3	W	---
T	T	NC	N·m	---
N	N	---	r/min	---
Pm	Pm (T,N)	NC	W	---
A	PQS1 (E1,I1)	P	W	81.82
B	PQS1 (E1,I1)	Q	var	1.18
C	PQS1 (E1,I1)	S	VA	83.09
D	PS (E1,I1)	---	°	0.9
E	PF (E1,I1)	True		-1.00
F	None	---	---	---

Appendix E-2

<u>Metering</u>

Meter	Description	Mode	Scale/Unit	Value
E1	E1	AC	V	237.96
E2	E2	AC	V	---
E3	E3	AC	V	---
I1	I1	AC	A	0.319
I2	I2	AC	A	---
I3	I3	AC	A	---
PQS1	PQS1 (E1,I1)	P1	W	---
PQS2	PQS2 (E2,I2)	P2	W	---
PQS3	PQS3 (E3,I3)	P3	W	---
T	T	NC	N·m	---
N	N	---	r/min	---
Pm	Pm (T,N)	NC	W	---
A	PQS1 (E1,I1)	P	W	74.32
B	PQS1 (E1,I1)	Q	var	6.75
C	PQS1 (E1,I1)	S	VA	75.97
D	PS (E1,I1)	---	°	-0.1
E	PF (E1,I1)	True		-1.00
F	None	---	---	---

Appendix E-3

Metering

Meter	Description	Mode	Scale/Unit	Value
E1	E1	AC	V	238.36
E2	E2	AC	V	---
E3	E3	AC	V	---
I1	I1	AC	A	0.264
I2	I2	AC	A	---
I3	I3	AC	A	---
PQS1	PQS1 (E1,I1)	P1	W	---
PQS2	PQS2 (E2,I2)	P2	W	---
PQS3	PQS3 (E3,I3)	P3	W	---
T	T	NC	N·m	---
N	N	---	r/min	---
Pm	Pm (T,N)	NC	W	---
A	PQS1 (E1,I1)	P	W	60.49
B	PQS1 (E1,I1)	Q	var	8.88
C	PQS1 (E1,I1)	S	VA	62.90
D	PS (E1,I1)	---	°	6.6
E	PF (E1,I1)	True		-0.99
F	None	---	---	---

Appendix E-4

Metering

Meter	Description	Mode	Scale/Unit	Value
E1	E1	AC	V	238.52
E2	E2	AC	V	---
E3	E3	AC	V	---
I1	I1	AC	A	0.228
I2	I2	AC	A	---
I3	I3	AC	A	---
PQS1	PQS1 (E1,I1)	P1	W	---
PQS2	PQS2 (E2,I2)	P2	W	---
PQS3	PQS3 (E3,I3)	P3	W	---
T	T	NC	N·m	---
N	N	---	r/min	---
Pm	Pm (T,N)	NC	W	---
A	PQS1 (E1,I1)	P	W	50.24
B	PQS1 (E1,I1)	Q	var	-2.96
C	PQS1 (E1,I1)	S	VA	54.43
D	PS (E1,I1)	---	°	5.8
E	PF (E1,I1)	True		1.00
F	None	---	---	---