DEVELOPMENT OF ANALYZER-BASED POWER FACTOR CORRECTION DEVICE

Meddy S. Mangaring[1], Nikko Ardel P. Floretes[2]
[12]*College of Engineering, Samar State University, Philippines*
[1]alon_demz@icloud.com,
[2]nikko.floretes@ssu.edu.ph

Abstract

The ever increasing energy demand nationwide leads to the increase of distribution and transmission losses. Improving the power quality places an important role in suppressing power losses and disturbances in the electrical system. Mostly, electrical loads are inductive that generates reactive power component which causes poor power quality. However, correcting power factor by switching capacitor enhances the power quality profile of an electrical system thereby reducing the current injected into the distribution line. Although there are technologies available in the market capable of correcting power factor, its functionality and application are limited to industrial application only. This paper presented the development of power factor correction (PFC) device through the use of power analyzer as the primary instrument. Data from the analyzer was received and manipulated by microcontroller unit which performs switching capacitor in the electrical system. Application of capacitive power depended on the reactive power drawn by the electrical load and the associated program embedded to the microcontroller. The PFC device automatically improves the power factor of the electrical system up to 95 percent. As a result, the apparent power drawn by the electrical system and the electrical current injected to distribution line decreased. It does not apply capacitive power once the overall power factor of the electrical system is above 95 percent or capacitive. The device was suitable for improving the power efficiency of distribution and transmission system. Its adaptability to power quality monitoring and energy metering equipment is easy since it uses a power analyzer which could serve as the interfacing component between them.

Keywords: Microcontroller, Reactive power, Power quality, Efficiency, Power losses, Power Distribution

I. INTRODUCTION

The world is growing, and energy consumption in 2012 (estimate) is about 19,710,000 kWh/year or about 2807 kWh/year/person (www.world.bymap.org) and is about 21.38 Trillion kWh in 2014 (www.CIA.gov). This has doubled within 30 years drawing some concerns on how to sustain a power-hungry world (Thronton, 2011). There is, therefore, a need for more energy efficient products. Aside from using energy efficient products, there is also need to manage the use of AC circuits like using a power factor corrector. A power factor is a ratio of the true power to apparent power. It defines how efficient the power system is in converting the total supplied power into

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energy demand. Mostly electrical loads are inductive which generates reactive power component. It is estimated that Electric-Motor-Driven Systems (EDMS) account for between 43% and 46% of all global electricity consumption (Waide & Brunner, 2011). This reactive power causes low power factor which triggers inefficient and unreliable power system causing an increase in power cost (Manikandan, 2015). However, their presence is inevitable since it is necessary for other electrical operation aspects. Although it significantly affects the power quality because of high current injection along distribution lines, there are already technologies available to reduce its negative effect.

Recently, there are developed systems dedicated to improving the power factor of the electrical system (Mariya Chithra Mary et.al., 2015; Ali, 2013; Krejcar & Frischer, 2012). In fact, power factor optimum efficiency occurs in transmission and distribution lines only, because energy regulating agency mandatorily imposed to correct power factor drawn by electrical companies. Conversely, an absence of Power Factor Correction (PFC) device among residential and small commercial electrical system is considerable. Therefore, the reactive power drawn by such electrical energy consumers is uncorrected. Consumers cannot afford to buy the device in which its beneficial return is not significant and not directly to them unless reward would be given by utility company.

Lien et. al. (2008) developed a system for power monitoring and control based on power line communication for home power management. Labrador et. al. (2013) designed wireless data transmission to determine the electrical energy consumption, so utility companies find convenience in reading electric bills. In general, the above studies used power measuring module as one component to design systems that read electrical quantities only. This study uses AC power analyzer as power measuring module an instrument to correct the power factor of an electrical system. The project is similar to that of Ali (2013) where he developed a power factor controlling system using programmable interface controller (PIC).

The aim of this study is to develop an automatic PFC device through an analyzer and a reactive compensator (capacitor). Thereby addresses to have an interfacing component between energy monitoring and PFC device. As one component which offers multiple features make it readily available for a utility company or in all types of consumers. Hence, it is desirable to renovate system that also addresses power quality improvement even just in power factor aspects.

II. METHODOLOGY

2.1 System Operation

The development of Analyzer Based Power Factor Correction device started on defining how the system operates. In most cases, the electrical load is an inductive form which creates a lagging power factor. In negative effect, a capacitor will provide a leading power factor to compensate the inductive power injected to the electrical system. As it appears in figure 1, the analyzer constantly monitors the electrical power quantities drawn by the electrical load. The Arduino Uno Microcontroller Unit (MCU) will continuously read the data fed to the analyzer. A set of programs or instructions would be loaded to the MCU to perform the task such as switching on or switching off capacitors banks in the power circuit. The MCU will also perform certain calculations before switching operation. The application and removal of a capacitor in the power circuit took place at specified power factor limit. Liquid Crystal Display (LCD) was provided to display electrical quantities information of the electrical load.

2.2 Hardware Design

All of the components in the system are powered up by 5 volts regulated power supply. The power supply was designed using the theoretical concepts in Electronic Devices, Electron Flow Version by Floyd (2012). AC Power Analyzer 2 kit module is interfaced with Arduino Uno MCU to transmit data through Rx and Tx provided by both components. Circuit configuration and program development for data streaming will be implemented using the Power Analyzer 2 Hardware Manual by e-Gizmo Mechatronix Central. The program was loaded to the MCU to manipulate data and perform switching functions. The switching module comprises an opto-coupled relays to protect the MCU during switching action. Relays would provide connection of capacitors to the power circuit. The MCU was interfaced with 4X20 Serial Liquid Crystal Display for displaying electrical quantities.

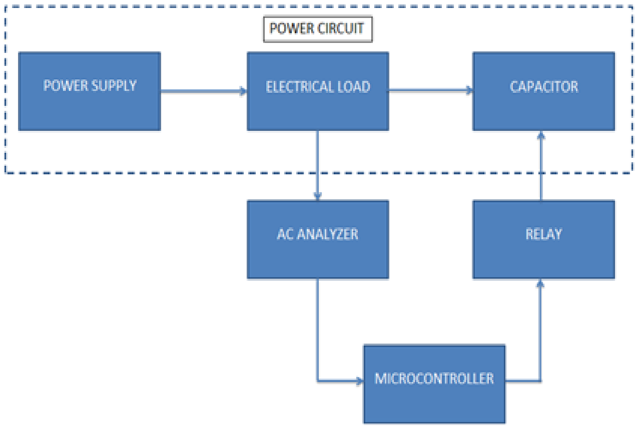

Figure 1: System Operation Process

2.3 Software Design

The embedded software design included manipulating and displaying data obtained from the analyzer and switching function operation. Figure 2 shows a program flow chart on how the program of MCU is developed. The program starts with reading the reactive power and power factor drawn by the electrical loads connected. In this design, the device would correct the power factor up to 0.95 lagging. Although electrical loads are predominantly inductive, it would be sometimes capacitive.

The analyzer reads reactive power (VAR) in which it indicates a positive (+) value for inductive and negative (-) value for capacitive. In the first decision stage, when the analyzer reads a negative value for reactive power the system must switch off capacitors disconnecting it from the power circuit. On the other hand, the MCU reads the second decision stage checking for the power factor drawn by the electrical load. If the power factor reading is above 0.95, the system must switch off also capacitors. When the condition is met, the MCU will perform the calculation for the net reactive power that will draw once the capacitor is turned on, and pass it to the third decision stage. A negative net result would cause a leading power factor, therefore, no switching that will happen. For the positive net result, the MCU will calculate the expected power factor before applying capacitors to ensure that power factor will not exceed the 95 percent limit. Presented below is the formula for calculating the expected power factor after applying the capacitor.

Calculated Power Factor

$$= \text{Cos}\left[\text{ArcTan}\,\frac{Qr-Qc}{Pr}\right]$$

Where Pr = real power reading of the analyzer
Qr = reactive power reading of the analyzer
Qc = calculated reactive power of single unit capacitor

$$Qc = \frac{Vrms}{Xc}$$

Where; Vrms = root means square voltage reading of the analyzer
Xc = calculated capacitive reactance of the capacitor (2πfC)

After calculating the power factor, it passes the last decision stage. If the condition is true the MCU will initiate to

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switch on the additional capacitor in the power circuit. Otherwise, it will continue reading the power quantities from the analyzer. Capacitive reactance and frequency are determined first as constants in the program.

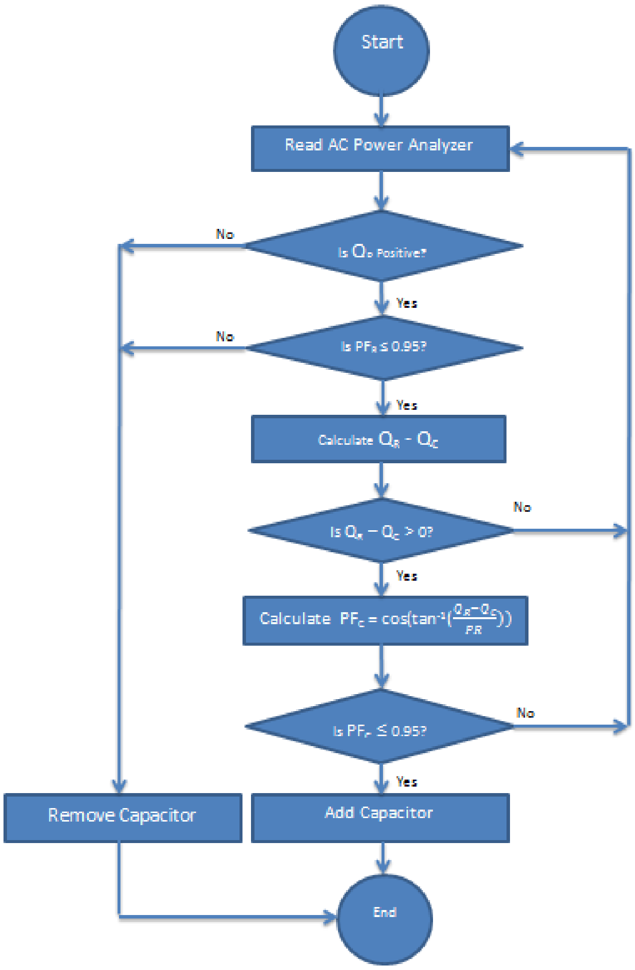

Figure 2: Program Flow Chart

III. RESULTS AND DISCUSSIONS

The following are the results of the evaluation of the developed Automatic PCF device through an analyzer and a reactive compensator (capacitor) for various types of clients/consumers.

3.1 Hardware Design

As expected the PFC device is comprised of five different modules. Figure 3 shows the Integrated Power Supply and Switching module, AC Power Analyzer 2 Kit, Arduino Uno MCU, 4 x 20 Serial LCD and 4-7microfarad Capacitor Bank. The power supply has 5V regulated dc voltage which delivers power to the rest of the components. Figure 4 schematically illustrates the circuit configuration of interfacing components of the MCU and designates I/O pins for different modules. The AC power analyzer streamed out electrical quantities of the electrical load through UART port provided and displays the measured values to the LCD. The LCD displays voltage, current, real power and volt-ampere on the first flash while volt-ampere reactive, harmonic, chip temperature and power factor appear on the second flash as shown in Figure 5. The four I/O pins are reserved to switch the state of the relays through an opto-coupler (4N25).

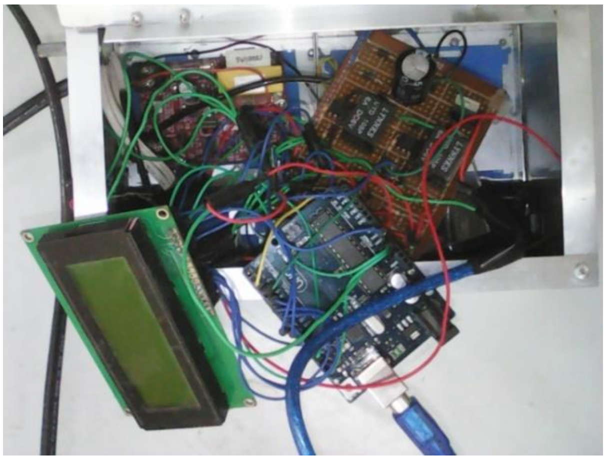

Figure 3: Power Factor Correction Device

In series with relays are capacitors having an average reactive power of 140 VAR each at 230 V and 60 Hz frequency. The average volt-ampere reactive drawn by each capacitor has been declared as constants in the program development. Arduino IDE was used to develop the program for the microcontroller. The system successfully corrects the power factor base on the analyzer streamed out data, and the instruction commands loaded to the MCU.

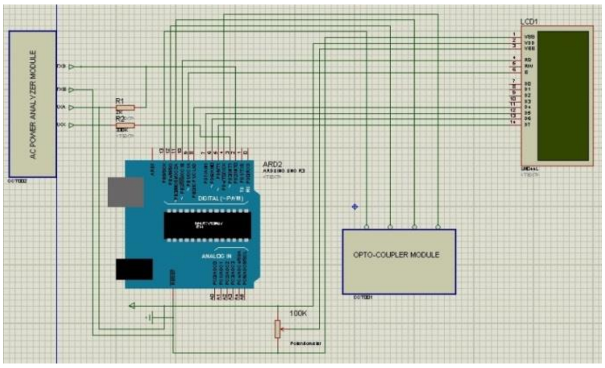

Figure 4: Circuit Configuration

Figure 5: Liquid Crystal Display Output

3.2 Power Factor Correction Results

Actual testing of the system was done by using the following load's listed in Table 1 together with its corresponding electrical ratings. The system was tested through inductive, capacitive and unity power factor loading setup. All measured electrical quantities were taken from the displayed values of the LCD.

3.2.1 Inductive Loading

The result shown in Table 2 reflects the performance of the developed system's hardware and software. In the first load setup in which only one fluorescent lamp was energized, the system did not apply capacitive power. Although the resulting reactive power (VAR) reading is inductive, the MCU prematurely detected that capacitive loading would take place if a capacitor would be switched on. Note that the resulting VAR reading is 85.89 which would result to a negative value if a 7-uF capacitor with 140 VAR would turn on. That makes the third decision stage in the program flow chart falsely.

In the next loading in which two fluorescent lamps energized, generates a VAR reading that was twice of the previous loading. This makes all of the decision stages in the program flow chart truly. The resulting inductive (VAR) had been compensated by adding a single unit capacitor, thereby raising the power factor to 0.91 lagging. In the third loading, no additional capacitor had been switched on as the same case in the first loading. The fourth and the fifth loading had the same case in the second loading initiating the application of 2 and 4 capacitor units respectively. The last loading caused a negative VAR reading because of removing two fluorescent lamps from the power circuit. The MCU detected capacitive circuit loading, in that case, a single unit capacitor had been removed from the power circuit.

The result showed that the developed device automatically corrected the power factor during loading operation. Corresponding to the improvement of power factor was the decrease of current (Irms) and apparent power (VA) drawn by the electrical system as it appears in the table. During capacitor switching, the real power (Preal) was not affected hence its reading was cumulatively added or subtractive depending on the loading condition.

3.2.2 Leading and Unity Power Factor Loading

In Table 3 showed the electrical quantity reading obtained from loading set-up of the following appliances and

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Table 1. Electrical Load Specifications

Electrical load	Electrical Rating	Power Factor Characteristics
1. Magnetic Ballast Fluorescent lamp	18/20W, 0.37 A, 220 V, Cos Ø = 0.35	Lagging
2. Electric Fan	60 W, 220 V	Leading
3. Trinitron Color TV	108 W, 240 V	Leading
4. Incandescent Bulb	18 W, 230 V	Unity

Table 2. Inductive Loading Power Factor Correction Results

Electrical Quantity	No of Fluorescent (F) lamp and Capacitor (C)					
	1F without C	2F with 1-7uF C	3F with 1-7uF C	4F with 1-7uF C	8F with 4-7uF C	6F with 3-7uF C
Vrms	236.46	236.21	235.82	236.04	235.27	235.79
Irms	0.38	0.25	0.57	0.51	0.97	0.73
Real Power (Preal)	25.82	52.75	77.08	110.28	206.91	155.18
Aparent Power (VA)	89.71	58.18	135.04	121.12	228.73	171.22
Reactive Power (VAR)	85.89	24.56	111.45	50.34	97.28	72.41
Power Factor	0.29	0.91	0.57	0.9	0.9	0.91

Vrms - root means square voltage reading of the analyzer

Table 3. Capacitive and Unity Power Factor Loading Results

Electrical Qty	Electric fan without capacitor	Television without capacitor	Incandescent bulb without capacitor
Vrms	229.63	231.96	233.44
Irms	0.26	0.39	0.07
Real Power (Preal)	56.46	104.44	17.37
Aparent Power (VA)	59.80	104.49	17.06
Reactive Power (VAR)	-21.05	-3.37	0.09
Power Factor	0.94	1.0	1.0

incandescent bulb. In the first and second loading, the resulting reactive power was already capacitive which indicate a negative value for VAR and in the last loading an incandescent bulb reads a power factor of 1.0 or unity. As expected in the results, the device did not switch on a capacitor in the power circuit. The addition of capacitive power would cause a higher value of reactive power resulting to an increase current injection and greater apparent power requirement of the electrical system.

IV. CONCLUSIONS

This study presented the used of an analyzer to improve the power factor drawn by the electrical system. It had undergone data acquisition process to attain its intended function through hardware and software development. The correction process depends on primarily on the data streamed out by the analyzer and the associated program loaded to the microcontroller. The device automatically adjusted the electrical system reactive power based on the required limit. With this, the apparent power and the current injected to the distribution line was decrease. It is also suitable for improving the power efficiency of distribution and transmission system. Its adaptability to power quality monitoring and energy metering equipment is easy since it uses power analyzer which could serve as the interfacing component between them.

REFERENCES

Ali, M. (2013) Design and Implementation of Microcontroller-Based Controlling of Power Factor Using Capacitor Banks with Load Monitoring, Global Journal of Researches in Engineering, Electrical and Electronics Engineering. Volume 13 Issue 2 Version 1.0 Year 2013

Cental Intelligence Agency, The World Factbook, Energy: World. (Accessed: November 12, 2016)

Krejcar, O. & Frischer, R. (2012) Real Time Voltage and Current Phase Shift Analyzer for Power Saving Applications, Sensors. www.mdpi.com/journal/sensors. (Accessed: September 3, 2016)

Kumar, S., Govinathan, M. (2015) Microcontroller Based Automatic Power Factor Correction, International Journal of Innovative Research in Science, Engineering, and Technology. Volume 4, Special Issue 4, April 2015.

Manikandan P., et.al. A Review on Importance of Power Factor. Journal Club for Electrical Engineering, 2(1), 72-78

Labrador, M., Tabon, M.L., & Sahhibal, A. (2013) Design and Development of GSM-Controlled Electric Consumption and Monitoring System, International Journal of Electrical, Electronics and Computer Systems. Vol: 16 Issue: 02, October 2013.

Lien, C.H., Chen, H.C., Bai, Y.W., & Lin, M.B. (2008) Power Monitoring and Control for Electric Home Appliances Based on Power Line Communication, I^2MTC 2008 – IEEE International Instrumentation and Measurement Technology Conference Victoria, Vancouver Island, Canada, 2008 IEEE.

Z. Kokolanski, M. Srbinovska, A. Simevski, C. Gavrovski & V. Dimcev (2009) Power Quality Monitoring Mariya Chithra Mary, A., BeninManoRaja, D.R., Sathish and Power Measurements by Using Virtual Instrumentation, Electronics, Vol. 13, No. 1, June 2009

Thornton, M. (2011). Power Factor Correction – why is it important? ME Site, Buildings, Energy & Works Management (Energy Management). http://www.maintenanceonline.org/maintenanceonline/content_images/Page%2053-20110527-150121.pdf (Accessed: October 3, 2016)

Waide, P. & Brunner CU., (2011). Energy-Efficiency Policy Opportunities for Electric Motor-Driven Systems. International Energy Agency. https://www.iea.org/publications/freepublications/publication/EE_for_ElectricSystems.pdf (Accessed: June 3, 2016)

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