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An Arduino - Based Automatic Power Factor Correction Device

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Abstract: When consumers connect inductive loads to the power system, the power factor lags, creating high current demand, thus high active power losses are incurred in the system. In Nigeria, when the power factor goes below 0.8 (lagging), the electric supply company charge penalty to the consumers. This calls for a system control hence power factor correction. Earlier, the power factor correction was done by adjusting the capacitor bank manually. The automated power factor correction using a capacitive bank helps provide the power factor correction, thereby decreasing the time taken to correct the power factor, which also helps to increase the power efficiency. It has been demonstrated in this work that the phase difference between voltage and current can be determined using zero-crossing detectors, optocouplers, XOR gate, and some primary function of the microcontroller (ATmega 328). Voltage and current transformers have been used for transforming load voltage and current respectively to bring them in the desired working range for the zero-crossing detectors. The device reads the time difference between the line voltage and line current, which is now calculated as the phase angle, and the corresponding power factor is then calculated. If the calculated power factor is less than 0.8, the microcontroller calculates the compensation requirement and accordingly switches on the required capacitor with the aid of an electromagnetic relay. The display used was 16×2 liquid crystal display module. In conclusion, according to the test carried out during simulation for three different inductive loads, the power factor was corrected from 0.59 to 0.99, 0.60 to 0.99, and 0.55 to 0.87, respectively, and also, the power factor was adjusted from 0.73 to 0.98 during the hardware test. These results show that the designed and constructed automatic power factor correction device works properly.

Keywords: Power Factor, Power Factor Correction, Zero Crossing Detectors, ATmega 328, Capacitor Bank

I. INTRODUCTION

In contemporary times of revolution in technology, the significant component of cost for domestic, commercial, and industrial utilization is the Electrical Power. Due to the infusion of more reactive power into the power system by inductive loads, the power factor may become deficient in industrial installations. Thus, the net industrial load becomes highly inductive, causing inferior lagging power factors [2]. When consumers connect inductive loads, the power factor lag hence becomes lower. As the power factor of a system becomes smaller, the less economically the system will operate [15].

In Nigeria, if this low power factor goes below 0.8(lagging) and is not corrected, there will be high demand from the electric power utility on the industrial facilities and they will also suffer a stiff penalty for their poor power factor from an economic point of view [2]. This implies that there is a need for this power factor to be corrected.

Power factor correction (PFC) is the process of compensating a lagging current by a leading current by connecting capacitance in parallel to the supply [15]. In most power factor correction systems, the capacitors cause' current to lead voltage, hence producing a leading power factor [13]. The power factor correction device tries to connect a sufficient capacitance to enable the adjustment of the power factor as close to unity as possible. Since the correction is done automatically, the correction device involves the use of programmable devices. Whenever we are thinking about any programmable devices, then the embedded technology comes into the forefront. Currently, this embedded technology is very much accessible, and most of the products are developed with microcontroller based embedded technology [8]. One advantage of using the microcontroller is that it is cost-effective, and the use of so many hardware devices can be avoided.

II. BACKGROUND OF STUDY

A. Power Factor

The power factor is the ratio between the active power (kW) and the apparent power (kVA) drawn by an electrical load.

$$\text{Power factor } = \cos\theta = \frac{P}{S} = \frac{Activepower(KW)}{Apparent\ power(KVA)} \qquad \ldots.(1)$$

Before going into the causes of low power factor, the relationship of these powers (i.e., active, reactive, and apparent) with each other could be understood and developed from the power triangle, as shown in fig. 1.

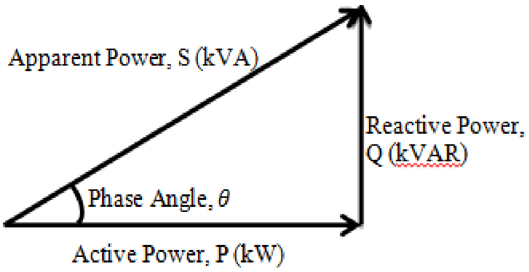

Fig. 1 Power Triangle

$$S = VI \qquad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$
$$P = VI\cos\theta \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$
$$Q = VI\sin\theta \qquad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Active power (kW) is the power that actually powers the equipment and performs useful and productive work. It is also called real power or working power. Reactive power (kVAR) is the power required by some equipment (e.g., transformers, motors, and relays) to produce a magnetic field to enable real work to be done. It is necessary to operate specific equipment, but you do not see any result for its use. The apparent power (kVA) is the vector sum of real power (kW) and reactive power (kVAR) and is the total power supplied through the power mains that are required to produce the appropriate amount of real power for the load. The weak load current is generally the result of an inductive load, such as an induction motor, power transformer, lighting ballasts, and welder or induction furnace [6].

Low power factor results in significant copper losses and poor voltage regulation. It also reduces the handling capacity of the system. Equipment rating is not left out as low power factor makes the kVA rating to the equipment to be made more, making the machine larger and expensive [9].

B. Power Factor Correction

The first step recommended to reduce energy costs and improve energy efficiency is power factor correction, and it has been accepted globally. This works by "correcting" an inefficient electrical load or supply. Capacitors are automatically switched into circuits to counteract the effects of an inductive load, which is produced by all motors, pumps, air conditioning systems, refrigeration, and general plant and machinery that use motors in their process or operation. Power users can correct the power factor by balancing the inductive and capacitive elements in their load circuits through the use of power factor correction units, thereby conserving electrical energy [10].

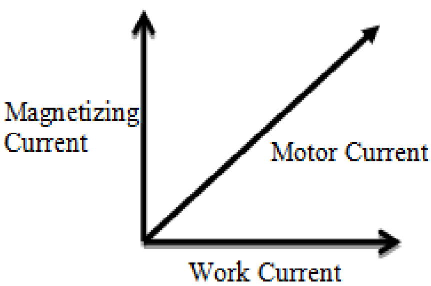

Fig. 2 Inductive Current

Capacitive Power Factor correction is applied to circuits which include induction motors as a means of reducing the inductive component of the current and thereby reduce the losses in the supply. There should be no effect on the operation of the motor itself. An induction motor draws current from the supply that is made up of resistive components and inductive components.

For the benefit of reducing the losses in the distribution system, power factor correction is added to neutralize a portion of the magnetizing current of the motor. Some retailers offer incentives for operating with a power factor of better than 0.8, while others penalize consumers with a poor power factor. There are many ways that this is metered. Still, the net result is that to reduce wasted energy in the distribution system, the consumer will be encouraged to apply power factor correction [8].

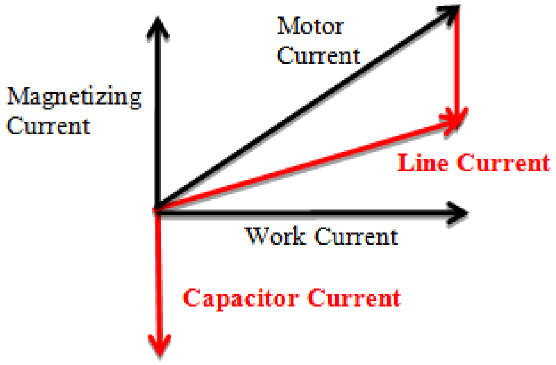

Fig. 3 Current Correction

Power factor correction is achieved by the addition of capacitors in parallel with the connected motor circuits and can be applied at the starter, or applied at the switchboard or distribution panel. Capacitors connected at each starter and controlled by each starter are known as "Static Power Factor Correction." It is dangerous to base correction on the full load characteristics of the motor as in some cases, motors can exhibit a high leakage reactance, and correction to 0.95 at full load will result in over-correction under no load, or disconnected conditions [13].

III. CIRCUIT ANALYSIS

C. Block Diagram

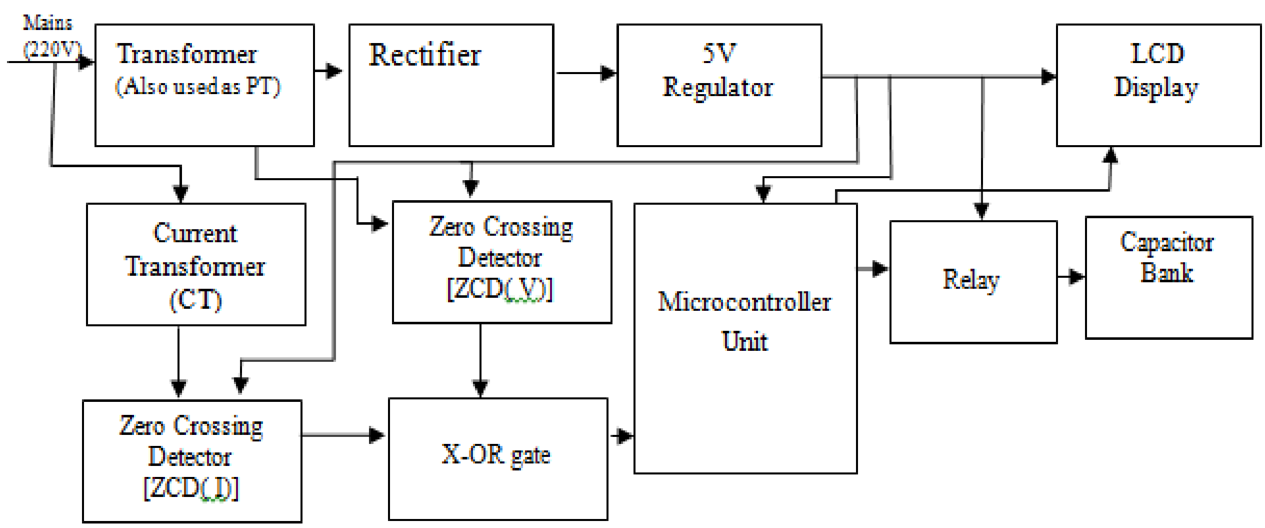

Fig. 4 Block Diagram

The supply signal voltage and current are given by the mains and stepped down by the CT and PT and fed to the rectifier unit, which converts these AC signal to DC signal. Then this DC supply is given to the regulator as it can be seen in Fig. 4. The regulator used is 7805. +ve 5V supply is given to ZCD (V), ZCD (I), LCD, and microcontroller. Two operational amplifiers act as comparators with their output fed into two separate optocouplers, which generate dual pulses that are then fed into an X-OR gate. The output of the X-OR is given to a digital pin (i.e., pin 10) of the microcontroller. The microcontroller has an internal timer circuit that calculates time in ms, which then converts into phase angle, and the power factor will display on LCD. If the power factor is low, then the microcontroller actuates relay, and the shunt capacitor will come in contact with a device that provides leading current. Thus power factor will be improved and shown on LCD [14].

D. Flow Chart

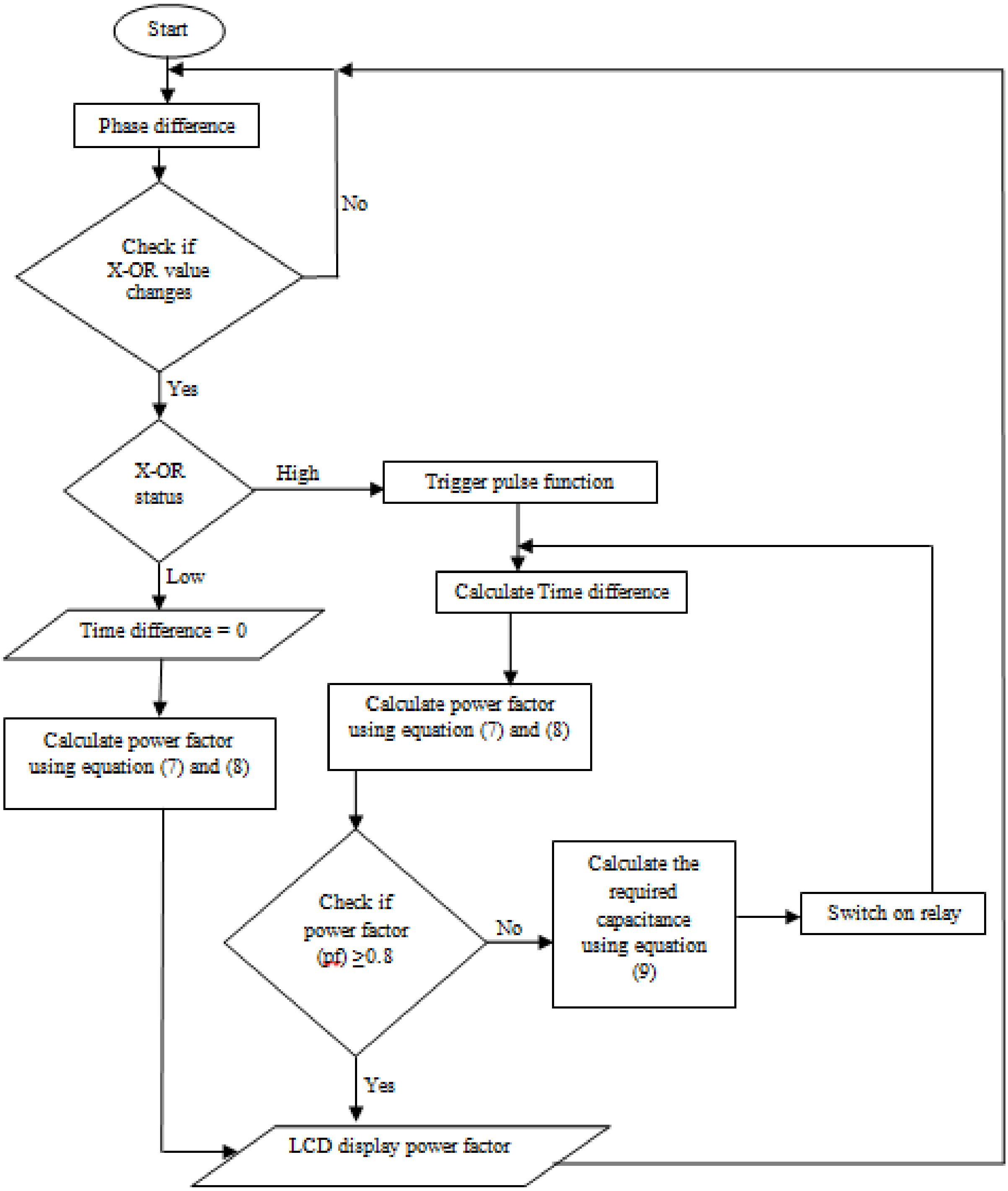

Fig. 5 Flow Chart

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E. Circuit Diagram

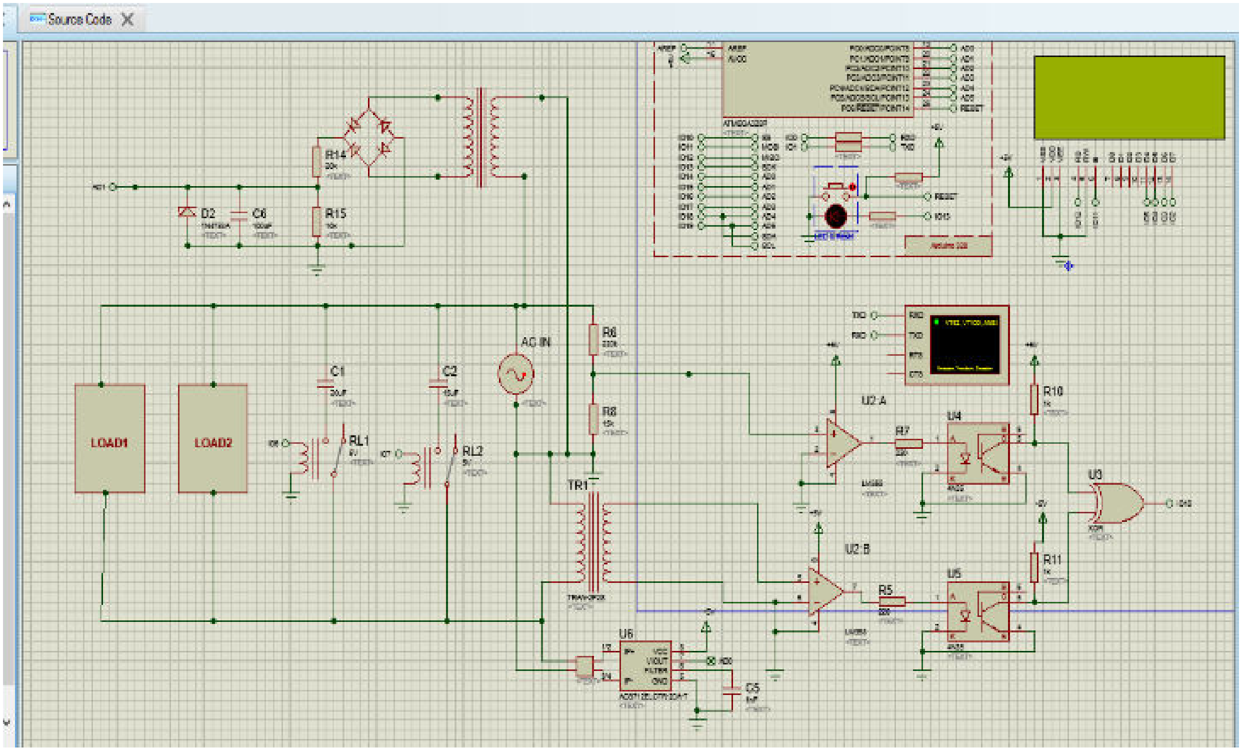

Fig. 6 Circuit Diagram

Automatic Power Factor Correction system is based on the Arduino ATmega 328. The circuit operates on the principle of constantly monitoring the power factor of the system and to initiate the required correction in case the power factor is less than the set value of which is 0.8. The voltage and current in the circuit are stepped down using a potential transformer and a current transformer, respectively. These transformed A.C signals are next fed to a Zero Crossing Detector (ZCD) circuit. The output of the Zero Crossing Detector (ZCD) is a square wave, in which each change of state represents a zero crossing of the A.C waveform. The signal goes high on the first zero-crossing of the current or voltage waveform and then goes low on the next zero-crossing of the signal, thereby generating a square wave. Two separate Zero Crossing Detector (ZCD) circuits are used for voltage and current waveform. The two square waves are then summed using an Exclusive OR (X-OR) gate. The output of the summer gives the phase angle difference, which is given to the Arduino microcontroller through pin 10.

The value on the pin is read using the function pulseIn(pin, value, timeout), where the parameters pin depicts the number of the pin on which you want to read the pulse. (*int*), value depicts the type of pulse to read, i.e., either HIGH or LOW (*int*), and timeout (optional) depicts the number of microseconds to wait for the pulse to start, default is one second (*unsigned long*). The function reads a pulse (either HIGH or LOW) on a pin. For example, if the value is HIGH, pulseIn() waits for the pin to go HIGH, starts timing, then waits for the pin to go LOW and stops timing. It finally returns the length of the pulse in microseconds or gives up and returns 0 if no pulse starts within a specified time out. This time value obtained is in microseconds (μs), and is then calibrated as phase angle φ using the relation:

$$\varphi = t \times f \times 360 \times 10^{-6} \qquad \text{................}(7)$$

Where, φ= difference in phase angle
t = time difference;
f = frequency

The corresponding power factor is calculated by taking the cosine of the phase angle obtained above (i.e., cosφ). If the calculated power factor is less than 0.8, the microcontroller then, based on the algorithm, switches on the capacitor by operating the electromagnetic relay until the power factor is normalized to the set limit (i.e., ≥0.8). The output is then displayed on an LCD.

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IV. RESULTS AND DISCUSSION

F. Simulation Results

CASE I

Table I Modelled Induction Motor Result

Measured Quantities	Before Correction	After Correction
Phase	54.22^0	9.79^0
Power factor (pf)	0.59	0.98
Voltage (V)	220.75	220.75
Current (I)	1.33A	0.78A
Apparent power (S)	292.82VA	172.2VA
Real power (P)	171.3W	169.6W
Reactive power (Q)	237.4VAR	29.25VAR

CASE II

Table II Modelled Induction Fan Result

Measured Quantities	Before Correction	After Correction
Phase	53.2^0	6.15^0
Power factor (pf)	0.6	0.99
Voltage (V)	220.75	220.75
Current (I)	1.1A	0.69A
Apparent power (S)	243.42VA	151.35VA
Real power (P)	149.8W	150.4W
Reactive power (Q)	195.1VAR	16.21VAR

CASE III

Table III Modelled Induction Motor and Fan Result

Measured Quantities	Before Correction	After Correction
Phase	56.52^0	29.54^0
Power factor (pf)	0.55	0.87
Voltage (V)	220.75	220.75
Current (I)	2.2A	1.33A
Apparent power (S)	486.37VA	293.6VA
Real power (P)	268.2W	255.43W
Reactive power (Q)	405.6VAR	144.75VAR

G. Hardware Results

Fig. 7 Experimental Setup

(a) Before Correction

(b) After Correction

Fig. 8 Result using an AC Blower as Load

H. Discussion

From the simulation result of *CASE I*, where the modelled induction motor was used as load, the power factor decreased to 0.59; however, when the capacitor was connected in parallel, it improves the power factor to 0.98.
Similarly, in *CASE II*, where the modelled induction fan was used as a load, the power factor obtained was 0.60. When the capacitor was put online, the power factor was corrected to 0.99.
The case is not different in *CASE III*, where both the modelled induction motor and fan were applied, the measured power factor was found to be 0.55 lagging, but when the capacitor was put online; the power factor improves to 0.87.
From the hardware result where an Ac blower was used as load, the power factor obtained was 0.73, however, when the capacitor was brought into the circuit by the correction device, the power factor was corrected to 0.98.
These results thus verify the idea that static power factor correction can be achieved by using capacitors.

V. CONCLUSION

The low power factor in a power system is a highly undesirable condition as it places an unnecessarily high current demand, thus high active power losses are incurred in the system. This results in a penalty charge on customers by utility companies. Power factor correction techniques can be applied to industries, power systems, and also households to make them stable. By installing suitably sized power capacitors into the circuit, the power factor can be improved to a value close to unity. Care should be taken to avoid overcorrection. Otherwise, the voltage and current go out of phase, then the power system becomes unstable, the life of the capacitor bank reduces, and the aim of the device becomes defeated.

REFERENCES

[1]. Arduino ICSP Programming Header Pinout, (2013), Retrieved from, http://www.enchantedage.com/node/244.
[2]. Adesina, L. M., and Ebere I. (2016). Practical Approach to Power Factor Correction for a Commercial Electricity Consumer in Nigeria. International Journal of Engineering Research & Technology, 5 (12): 519-524.
[3]. Etisosa, U., Matthew, A., Agharese, E., Ogbemudia, O. G., Osaze, P. U. and Ose, G.O (2009): Energy Efficiency Survey in Nigeria-A Guide for Developing Policy and Legislation. Community Research and Development Centre. 37pp.
[4]. Fonstad, G. C. (2006). Microelectronic Devices and Circuits. Retrieved from http://creativecommons.org/licenses/by-nc-nd/2.5/.
[5]. Jaeger, R. C., and Ballock T. N. (2004), Microelectronic circuit design. 2nd Edition, New York, McGraw-Hill, 1820pp.
[6]. Khan, M. B., and Owais, M. (2016). Automatic Power Factor Correction Unit. Department of Electronic Engineering, Faculty of Engineering Sciences & Technology, Hamdard Institute of Engineering & Technology, Hamdard University Karachi, Pakistan. 6pp.
[7]. Machado, P.P. Jr., and Abud T. P. (2017). Power Factor Metering System Using Arduino. Fluminense Federal University, Electric and Telecommunications Engineering Master Program – PPGEET Niterói, Rio de Janeiro, Brazil. 6pp.
[8]. Satyasuranjeet, B. Sibasis, M., and Monalisa, B. (2007). Automatic Power Factor Correction by Microcontroller 8051. B.Tech. Project. Department of Electrical Engineering, National Institute of Technology, Rourkela. 49pp.
[9]. Shohel, M. R., Miah, M. N., and Rahman H. (2013). Automatic Power Factor Improvement by using Microcontroller. Global Journal of Researches in Engineering Electrical and Electronics Engineering, 13(6): 29-34.
[10]. Sodikpo, K. B., Oluwale, B. A., and Jubril, A. M. (2015): Energy Conservation: Utilization of Power Factor Correction in selected manufacturing companies in Nigeria. African Institute for Science Policy and Innovation, Obafemi Awolowo University, Ile-Ife, Electronic, and Electrical Engineering Department. 9pp.
[11]. Taye, A. (2018). Design and Simulation of Automatic Power Factor Correction for Industry Application. International Journal of Engineering Technologies and Management Research, 5 (2): 10-21.
[12]. Theraja, B. L., and Theraja A. K. (2013). A Textbook of Electrical Technology. 25th Edition, India, S. Chand and Company Ltd, 2750pp.
[13]. Tiwari K., Sharma D., and Sharma V. (2014), Automatic Power Factor Correction Using Capacitor Bank, International Journal of Engineering Research and Applications, 4 (2): 393-395.
[14]. Yadav, A. R., Waghmode, S.S., Gawade, G. B., Zinjade, S. S. and Patil, P. T. (2016): A review on Microcontroller Based Automatic Power Factor Correction. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, 5 (3): 1517-1520.
[15]. Yasin K., Yusuf M. M., and Mohammad M. K. (2017). Automated Power Factor Correction and Energy Monitoring System. Department of Electrical and Computer Engineering, North South University Bashundhara R/A, Dhaka-1229, Bangladesh, 6pp.