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ORIGINAL RESEARCH ARTICLE

Implementation of IoT-based energy monitoring and automatic power factor correction system

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ABSTRACT

Energy monitoring facilitates quick access and helps to know the power utilization and normal and abnormal conditions. Nowadays, many applications and majorly industries face problems regarding power quality. In the power system, the power factor plays a vital role in power quality. The addition of capacitance overcomes the decay of the power factor and reduces the power loss. This paper aims to build an automatic power factor correction (APFC) system, which can monitor the energy consumption of a system and automatically improve its power factor. In the design, an open-source energy monitoring library has been implemented for accurate power calculations. This paper carried out the work of hardware experimentation of energy monitoring and automatic power factor correction using a capacitor bank with the association of Internet of Things (IoT) technology. Build a mobile application to more simply and comfortablely monitor power and correct automatically. The developed hardware model's performance is validated with and without load conditions. The result proves that the designed Raspberry Pi-based energy monitoring and automatic power factor correction system outperforms to improve the power factor without human interaction by properly switching the capacitor bank. Hence, the power loss, penalty, and power quality-related problems were resolved based on the proposed approach. The proposed design is compact, simple, and easy to implement and aids in power system advancement.

Keywords: Power System; Automatic Power Factor Correction; Capacitor Bank; IoT; Raspberry Pi; Energy Monitoring

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1. Introduction

In modern electrical distribution systems, most of the loads are inductive, and there is an ongoing interest in improving the power factor (PF).

Monitoring generally means to be the state of a system using a monitoring or measuring device that may refer to observing a situation for any changes which may occur during the time. The power factor is the ratio between real and apparent power, and the efficiency is high for the unity power factor. Low-cost installation and less maintenance are the two significant advantages of the capacitor method, so it is most preferred for power factor correction.

1.1 Objective

The objectives achieved by the proposed model are as follows:

- To reduce emissions and global warming and safeguard the environment.
- To improve the quality of power.
- To achieve an economic performance of the power system.
- To enhance efficiency by minimizing the loss.
- To achieve higher load-carrying capacity.

The contributions of this paper are as follows:

1) IoT-based energy monitoring and automatic power factor

correction (APFC) using Raspberry Pi.

2) Automatic power factor correction using a capacitor bank.

3) Development of a mobile application to ease usage.

The novelty of the carried-out model is to correct the power factor automatically and monitor energy efficiently with the use of IoT. Therefore, it is used to reduce the burden on the industry and power system engineers.

The rest of the paper is organized as the following sections: Section 2 discusses the automatic power factor correction and related work studied in Section 3. Section 4 explains the hardware implementation of the proposed model, flowchart, and IoT for energy monitoring. Section 5 describes the result and discussion of the proposed model. Finally, Section 6 presents the conclusion.

2. Automatic power factor correction

Power wastage due to the poor power factor issue was resolved by the automatic power factor correction approach.

2.1 Need for automatic power factor correction

The inductive load generated excessive reactive power that was corrected by automatic power factor correction. The automatic power factor correction must be due to the following reasons.

- Varying power demand on the supply system. The power factor varies as a function of the load requirements.
- Difficult to maintain a consistent power factor by use of Fixed Compensation.
- Electrical distribution system load burden minimization.
- Automatic variation, without manual intervention, and compensation to suit the load requirements.
- To reduce electricity bills and penalties.
- To minimize the failure of the equipment and instability.
- To improve efficiency.

2.2 Advantages of automatic power factor correction

The automatic power factor correction possesses the following advantages:

- Consistent high power factor under fluctuating loads.
- Prevention of lagging/leading power factor.
- Ensuring an easy user interface.
- Avoiding the power factor penalty.
- Reducing losses.
- Continuously sensing and monitoring load.
- Automatically switching on/off the relevant capacitor's steps for consistent power factor.
- Consuming low energy.

2.3 Methods for improving power factor

The following methods are generally used to improve the power factor.

Static capacitors: to connect the capacitor in parallel to the circuits to improve the power factor and efficiency.

Synchronous condensers: the reactive components are partially removed to improve the power factor.

Phase advancers: in industry, the induction motor power factor is improved by phase advancers.

3. Related work

Most industries use various types of induction motors and inductive loads, which may cause the reduction of power factor. The power factor is below the specified standard; the power factor of 0.92 is generally fixed as the standard value because of inductive load. If the power factor is reduced below the standard value, it will create a burden on the power system and industry. It affects the quality of power. Therefore, power factor correction is required to minimize the power loss and eliminate the penalty imposed by the electricity board. Biswas and Mal[1] suggested microcontroller-based automatic power factor correction. The limitation is a concern for accuracy, and performance improvement is required. Kabir *et al*.[2] carried out automatic power factor correction and energy monitoring. The limitation is that the serial communication technology is used, and the interface with a real-time environment is challenging. Chooruang and Meekul[3] presented an energy monitoring system using IoT. The limitation is suitable for low-cost energy meters and cannot detect the usage of appliance power consumption. Luqman[4] pointed out a fuzzy logic-based automatic VAR compensator for power factor improvement. The limitation is the framing of the optimal fuzzy rule.

Bhagavathy *et al*.[5] conducted microcontroller-based automatic power factor correction. The prototype model developed based on Pic microcontroller has a limitation like lengthy programs, and access to program memory is not possible. Jawaduddin *et al*.[6] suggested the ATmega328 microcontroller-based automatic energy monitoring system. A Hall effect sensor is used to acquire the current with 99% efficiency. Real-time implantation needs an advanced technique to enhance feasibility. Mane *et al*.[7] performed automatic power factor correction using an Arduino microcontroller. The limitation is that authors cannot carry out hardware-based implementation. Praveen *et al*.[8] presented an IoT-based power factor penalty charge calculated and intimated to the consumer. The proposed model is suitable for nonlinear domestic loads.

Some researchers performed work related to automatic power factor correction using a microcontroller to address these literature issues. However, it still required an advanced and compact model. This paper attempts a Raspberry Pi-based APFC and an energy monitoring system. The Raspberry Pi has many features, like supporting all program languages, having many interfaces, being cost-effective, with compact size, and high processing power.

4. Proposed model hardware design

The proposed model hardware design comprises modules as follows:

- Power supply
- Raspberry Pi
- Inductive load network
- Relay driver
- Display
- Capacitor bank

A 230 V 50 Hz AC power supply is used in the circuit. The 230 V AC power is stepped down to 12 V AC by the step-down transformer. The bridge converter processes the 12 V AC and converts the AC supply into a DC supply.

Placing a capacitor between the rectifier and voltage regulator capacitors aids in filtering the voltage harmonics. The 5 V output got from the voltage regulator. All components in the circuit work in 5 V only. RPS is used to feed the components. The voltage and current are measured using the current transformer (CT) and potential transformer (PT), respectively.

The conversation of analog CT and PT data into digital data using the analog-to-digital converter (ADC). This digital data feeds to the Raspberry Pi through GPIO pins. By connecting to electronic circuits, GPIO pins enable the Raspberry Pi to regulate and monitor the surrounding environment. Raspberry Pi is a compact single-board computer that is used for energy monitoring and automated power factor management. The processor calculates the time lag between the voltage and current. According to the coded program in the processor, it gives the commands to the relay driver circuit. If the power factor value is less than the set value, then the Raspberry Pi will give the commands to the relay circuit to operate. Then the relay circuit takes appropriate action to add the capacitor banks to the load. The capacitor banks give the reactive power to the load until the power factor reaches unity through the capacitor bank switching.

Figure 1 shows the block diagram of the proposed system. Using IoT technology, continuously monitor and send the load data to the web server. With the acquired data, monitor the load condition from anywhere. Let an LCD interface with the Raspberry Pi display the load condition, and the same result can be visualized in the mobile application and the web server. The power factor is calculated. It requires correction, and the proper capacitor switching operation is performed automatically. The Blink app is a low-cost wireless security monitoring system that allows you to monitor from your smartphone. This proposed approach makes it less difficult for the user to determine the state of the circuit by utilizing the Blink app. By using IoT, the measured power factor values are passed to the web link over the Internet. Furthermore, the data was retrieved for future analysis and operation.

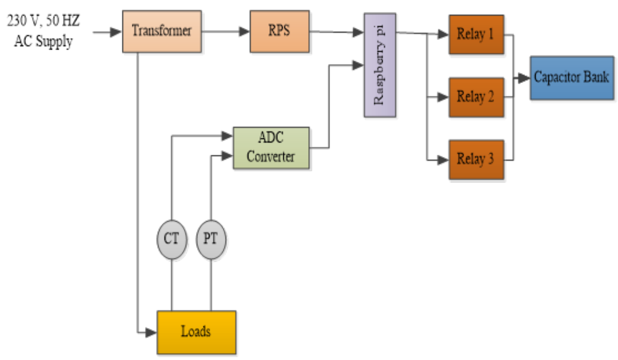

Figure 1. The proposed model block diagram.

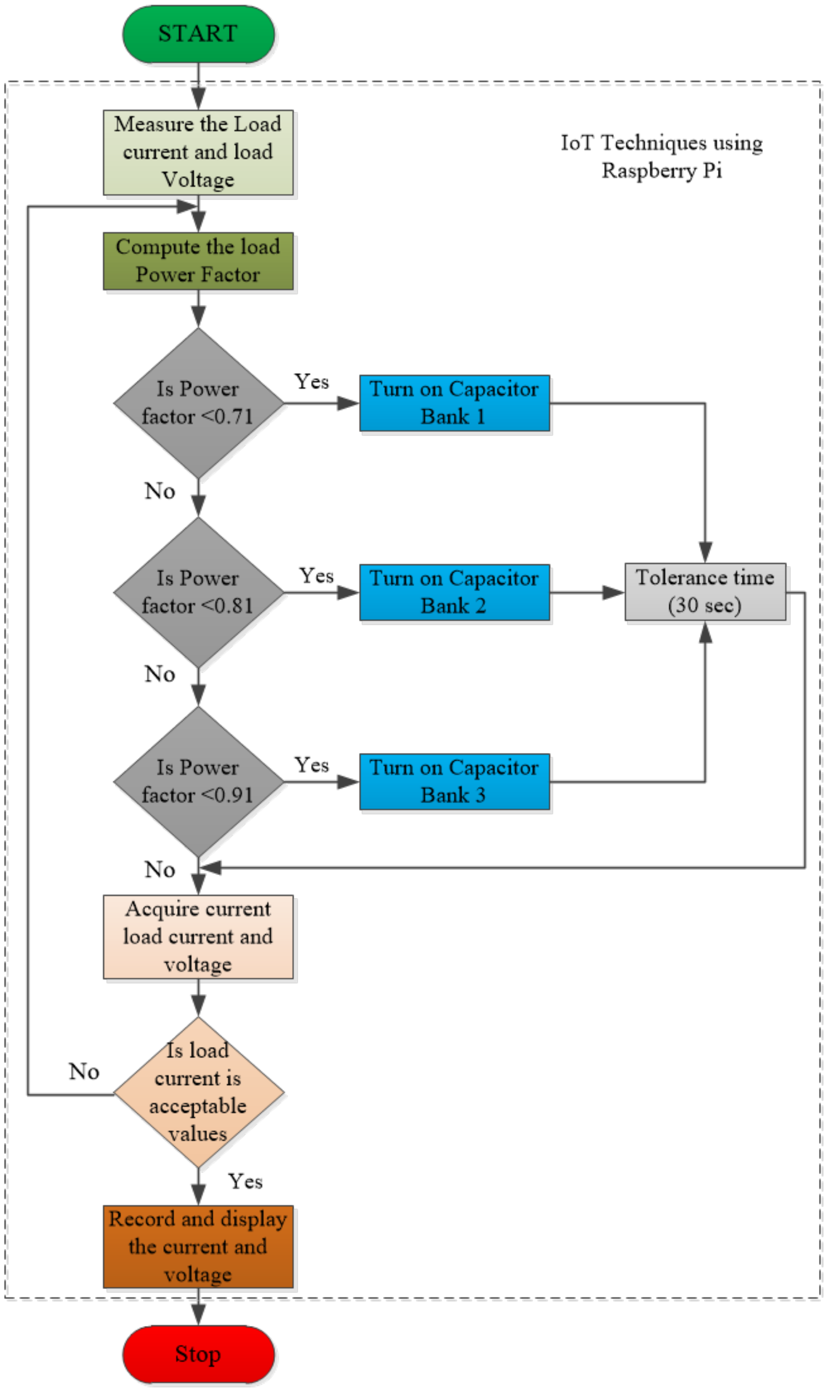

Figure 2. Proposed model flow chart.

4.1 Procedural steps

The procedural steps of the proposed model are illustrated in **Figure 2** as well as described as follows.

Step 1: For the considered system, measure the load current and voltage, calculate the load power factor, and send it to the web server.

Step 2: Perform the decision-making of capacitor insertion based on the power factor values. Suppose the power factor is less than 0.71, switch on capacitor bank 1; else, move to the next step.

Step 3: Check if the power factor is less than 0.81. If it is yes, switch on capacitor bank 2; or else, move to the next step.

Step 4: Again, check if the power factor is less than 0.91; if it is yes, switch on the capacitor bank 3, then wait for 30 sec as a tolerance time.

Step 5: Again, measure the load current and voltage. Check whether load current values are acceptable or not. If yes, move to the next step; else, proceed to step 1.

Step 6: Record the data sent to the web server, mobile app, and display.

4.2 IoT for energy monitoring

The system's energy or power consumption is monitored continuously based on the current and voltage sensor measurement. Based on the varying load, the current, voltage, power, and power factor are getting varied. The power factor of the proposed model is automatically improved by triggering the appropriate capacitor bank. The IoT gives continuous monitoring of the power factor over Wi-Fi. Because of its special features, IoT technology has been widely used for various applications like transmission line protection and control[9], and military application[10]. Moreover, a user or consumer can receive SMS alerts about electricity usage. Hence, power wastage was reduced, and improved the economy.

5. Results and discussion of the proposed model

Figure 3 depicts the implementation of the hardware prototype model. The capacitor bank is one of the methods to improve the power factor by compensating the demand with respect to the reactive power, therefore, avoiding the supply voltage-based energy crisis. In this analysis, R and L loads are used for experimentation. The R load results in the power factor being near unity. In the R load condition, the current and voltage are in phase with each other. When L load is connected to the circuit, the current lags the voltage and slight change in the light intensity of the bulb, which shows the power quality problem. Then the shunt capacitor bank is switched onto the circuit to improve the power factor. **Figures 4** and **5** depict the working of the proposed model and the result in the developed mobile application, respectively. The Blink app-based monitored results are represented in **Figure 5.**

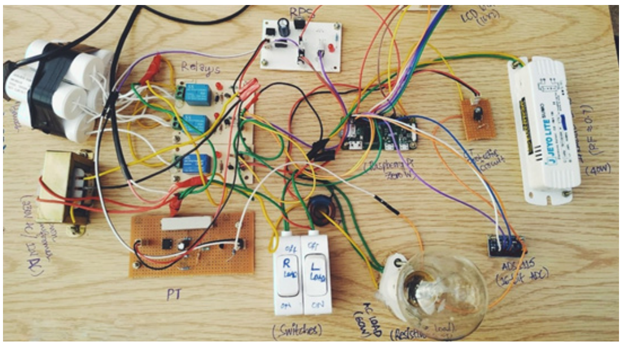

Figure 3. The prototype of the proposed hardware model.

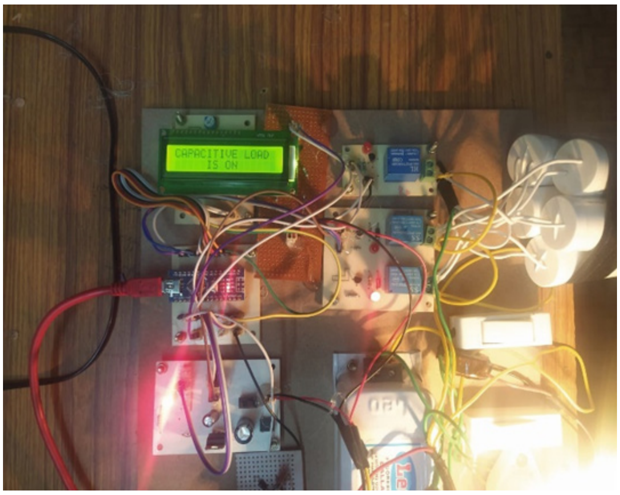

Figure 4. Working of the proposed model.

Figure 5. Results in the mobile application.

The excessive reactive power required to achieve the unity power factor is obtained by switching the appropriate capacitor bank. The power factor is corrected automatically based on the proper switching of the capacitor with respect to the acquired information from the load and continuously monitoring the energy by IoT. The capacitor compensates for the poor power factor (reactive power); therefore, the undesirable impact of the load is reduced, and the voltage stability is improved.

5.1 Experimentation with resistive load

For resistive load, power factor correction is not required because both voltage and current are in phase. Therefore, there is no need for a capacitor bank. For resistive and inductive (RL) loads, as the inductance power factor reduces, power factor improvement is required. **Table 1** depicts the results achieved by the proposed system with respect to R and RL load.

Table 1. Experimental results of R and RL loads

S. NO	Load type	Vs (Volts)	IL (mA)	P drawn (Watts)	Freq (Hz)	P. F	Remarks
1	Pure R load	234	437	101.2	49.87	0.99	No correction required
2	R-L	235	730	129.1	49.89	0.72	Correction required

Table 2. Experimental results of power factor correction

S. NO	Load type	Vs (Volts)	IL (mA)	P drawn (Watts)	Freq (Hz)	P. F	Remarks
1	Pure R load	230	424	96.6	50.02	0.99	No improvement in PF
2	R-L	232	602	130.2	50.06	0.99	PF increases from 0.76 to 0.99

5.2 Experimentation with inductive load automatic power factor correction

For inductive load, current and voltage have a phase delay because the phase delay power factor weakens. The insertion of the capacitor bank can improve the power factor based on the requirement. **Table 2** tabulates the acquired results based on the power factor correction experimentation.

In addition to the capacitor bank, compensate for the lagging current, and the power factor reaches close to unity. The current becomes the leading improved power factor based on the capacitor addition method.

To measure the energy consumed, it is necessary to maintain the load for a specific period. The Raspberry Pi can be used to monitor the time as well as to measure the energy consumption for each type of load. Continuously connect the loads for a definite time and perform continuous monitoring with extreme care.

In this paper, the inductance causes a lag with a power factor of 0.7. Using the proposed model, the capacitor banks are connected based on the inductive load and achieve a power factor of 0.99. It almost gives the unity power factor. Therefore, the imposing of penalties were reduced, and power efficiency and quality improved.

6. Conclusions

The electricity board is imposing the penalty on the consumer because of the lower or poor power factor. The significant parameter highly influencing power quality is the power factor. The power quality is enhanced by means of power factor improvement of the implemented proposed system and continuously monitoring of the energy using Raspberry Pi. This paper performed the modeling of an IoT-associated hardware prototype model for energy monitoring and automatic power factor correction by appropriate switching of the capacitor bank with respect to the measured load power factor. The calculation of capacitor value was carried out to correct the power factor computed by Raspberry Pi regarding the program. The IoT technology continuously monitors the energy and power factor. It enhances the power system's security and control. The proposed system is simple, easy to implement, and suitable for real-time and industrial applications to overcome the power factor's stress and burden.

Conflict of interest

The author declares that there is no conflict of interest.

References

1. Biswas RS, Mal S. Automatic PF improvement using microcontroller. In: International Conference and Workshop on Computing and Communication (IEMCON); 2015 Oct 15–17; Vancouver, BC, Canada. New York: IEEE; 2015. p. 1–6.
2. Kabir Y, Mohsin YM, Khan MM. Automated power factor correction and energy monitoring system. In: 2017 Second International Conference on Electrical, Computer and Communication Technologies (ICECCT); 2017 Feb 22–24; Coimbatore, India. New York: IEEE; 2017. p. 1–5.
3. Chooruang K, Meekul K. Design of an IoT energy monitoring system. In: 2018 16th International Conference on ICT and Knowledge Engineering (ICT&KE); 2018 Nov 21–23; Bangkok, Thailand.

New York: IEEE; 2018. p. 1–4. doi: 10.1109/ICTKE.2018.8612412.

4. Luqman AN, Lestari NS, Setiawan I. Simplified automatic VAR/Power factor compensator using fuzzy logic based on internet of things. Journal of Physics: Conference Series 2019; 1195(1): 012016. doi: 10.1088/1742-6596/1195/1/012016.
5. Bhagavathy P, Latha R, Thamizhmaran E. Development of IoT enabled smart APFC panel for industrial loads. In: 2019 10th International Conference on Computing, Communication and Networking Technologies (ICCCNT); 2019 Jul 6–8; Kanpur, India. New York: IEEE; 2019. p. 1–5. doi: 10.1109/ICCCNT45670.2019.8944899.
6. Jawaduddin A, Airij AG, Poopalan P. Automatic energy monitoring system. AIP Conference Proceedings 2020; 2203(1): 020001. doi: 10.1063/1.5142093.
7. Mane S, Sapat R, Kor P, *et al*. Microcontroller based Automatic Power Factor Correction system for power quality improvement. In: 2020 International Conference for Emerging Technology (INCET); 2020 Jun 5–7; Belgaum, India. New York: IEEE; 2020. p. 1–6. doi: 10.1109/INCET49848.2020.9154008.
8. Praveen AAA, Kumaran MM, Ali AN, Premkumar K. Minimization of power factor penalty charges for non-linear domestic loads with IoT technology. IOP Conference Series: Materials Science and Engineering 2020; 937(1): 012011. doi: 10.1088/1757-899X/937/1/012011.
9. Madhiarasan M, Keerthana T, Shakeel M, *et al*. Modeling and implementation IoT based transmission line monitoring, protection and control. Water and Energy International Journal 2019; 62(5): 35–39.
10. Madhiarasan M. Design and development of IoT based solar powered versatile moving robot for military application. International Journal of System Assurance Engineering and Management 2021; 12(3): 437–450. doi: 10.1007/s13198-021-01089-9.