NUML International Journal of Engineering and Computing
Volume: 2 Issue: 1
https://numl.edu.pk/journals/nijec
Print ISSN: 2788-9629
E-ISSN: 2791-3465
DOI: 10.52015/nijec.v2i1.30

Design and Implementation of Switched Capacitor Banks Controlled by a Programmable Logic Controller for Power Factor Improvement of Three-Phase Induction Motors

Amir Hamza[a, *], Muhammad Awais[b], Mohammad Hamza[c], Faiza Ahmad[a], and Zahid ur Rehman[a]

[a] *Department of Electrical & Computer Engineering, COMSATS University Islamabad, Wah Campus, Pakistan (amir.hamza.wec@gmail.com , faiza.ahmad141.fa@gmail.com , Sh362265@gmail.com)*
[b] *Department of Electrical Engineering, University of Wah, Pakistan (m.awais7248@gmail.com)*
[c] *Department of Electrical Engineering, Bahria University, Islamabad Campus, Pakistan (pharain99@gmail.com)*

Submitted	Revised	Published
24-May-2023	23-June-2023	26-July-2023

Abstract

Industries widely use three-phase inductive loads, such as induction motors, due to their cost-effectiveness, low maintenance, reliability, and durability. However, these loads decrease the power factor, which leads to power wastage, higher billing costs, and penalties from electric power supply companies. To address this issue, a system has been developed that employs a programmable logic controller (PLC) to enhance the power factor of three-phase loads, which reduces the plant's operating costs and lessens the demand for electricity supply from the utility side. The system combines hardware and software components. The software includes logic-based PLC programming that controls the sequence of operations step by step, whereas hardware consists of power and control circuits and protective devices. When an inductive load is added to the system, the PLC reads the input signal from the magnetic contactor's contactor coil connected with the motor and sends an output signal to the corresponding contactor coil of the magnetic contactor to switch the appropriate capacitor bank to enhance the power factor. This paper discusses the experimental results for seven cases utilizing different load combinations with and without the developed system. Thus, energy management requires improving the load's power factor, and the PLC is used as a power factor controller (PFC) for many industrial control applications.

Keywords: Induction motor, power factor, programmable logic controller, capacitor bank, protective devices

* Corresponding Author: Amir Hamza (amir.hamza.wec@gmail.com)

1. Introduction

Three-phase Induction Motors are widely used in the applications of industries such as cranes, lathes, elevators, drilling machines, wind tunnels, pumps, fans, conveyors, winders, blowers, etc., because of their reliability, robustness, low cost, and low maintenance. However, Induction Motor takes the reactive power component from the supply to start its operation, i.e., to induce the current in the rotor because the stator field leads the rotor field. Hence, Induction Motors always operate or function at a lagging power factor [1]. Likewise, when we talk about industries, numerous Induction motors transfer reactive power components from the utility side via a network. However, it also results in an increase in network losses in addition to a decrease in output voltages, which ultimately enhances the cost factor and safety problems of motors along with a reduction of reliability. When the power factor is lower, the system will not remain economical. Therefore, from an energy management point of view, improvement of the power factor is significant.

The designed system is based on the power factor improvement of a system by switching the shunt capacitors of the most suited value through the PLC-based algorithm. In many industrial applications, PLC is used as a power factor controller (PFC).

2. Literature Review

In a study [2], the authors proposed a system to improve the power factor of Electrical Generation by a technique called clustering neural networking (CNN). CNN is a pattern recognition technique that compares the power factor when inductive load adds into the system with the reference pattern and value of the power factor. It automatically improves if the power factor (PF) value is less than required. In [3], the authors proposed a system for enhancing the power factor of a three-phase induction motor using plc. A combination of software and hardware implements the system. When the induction motor starts, PF gets reduced, PLC operates according to its programming, and capacitors start switching to compensate for inductive Var. resulting in improving PF. In [4], the authors proposed a system to enhance the induction motor's power factor automatically. They used capacitor banks to improve the power factor, which is connected parallel to the device with low PF. A capacitor having capacitive reactive power opposite to the inductive reactive power cancels its effect, and as a result, the total power factor gets improved.

In a study [5], the authors proposed a system to improve the power factor of a three-phase inductive load using PLC. When the induction motor starts, the total power factor of the system gets reduced; PLC, which controls digital input and output pins, senses a low power factor, then automatically operates according to the programming done in it, and switching off the capacitor gets starts which compensates inducting reactive power. In a study [6], the authors proposed a system for improving power factor using e Roederstein ESTAmat RPR power factor controller of a three-phase unbalanced inductive load. They used a static capacitor that adds reactive power to the system, compensates inductive reactive power, and improves the power factor. In a study [7], the authors proposed a technique for power factor improvement using boost converters. As there is no neutrality in the 3-wire system, they used the same technique in simple single-phase AC to DC rectifier to improve the input power factor and reduce current harmonics. In a study [8], the authors proposed a technique for improving power factor using SVC thyristors control of inductive loads. SVC was used to maintain output voltage and reactive power in the system. SVC either absorbs or injects reactive power as per requirement.

In a study [9], the authors improved the power factor using capacitors and filters. They used a unit named APFC (Automatic Power Correction) to improve the power factor of linear loads. In [10], the authors proposed a control technique to improve the PF of three-phase Motors. The Blower and pumps were connected to the induction motor for home use. As these motors are continuous-running motors, they also require continuous power to do their operation. In [11], the authors proposed worked on a novel compensation, where the in-phase component and also the quadrature component of current (i.e., input current) is controlled by a vector. The authors implemented the compensator in an electric power system that was already operated with a very low PF, due to which the Total Harmonic Distortion was also very high. After implementing the compensator, the system drew a maximum current. In [12], the authors presented a PMSG-based DG system using STATCOM. The 3-leg voltage-source-converter (VSC) and the capacitors at a DC link are used as STATCOM. Pulse width modulation (PWM) current controller has been used for gating pulses generation of IGBTs. STATCOM controls the voltage, improves power factor, eliminates harmonics, balances load, and compensates.

In a study [13], the authors researched particle swarm optimization (PSO), which is used to improve a system's voltage and power factor. PSO is a non-linear optimization problem. The work is divided into two categories or, say, steps. Firstly, the identification of weaker nodes was made by using the voltage sensitivity factor (VSF) and the combination of 2 sensitivity factors: voltage stability index (VSI) and VSF. Secondly, the capacitors sizing was done through the PSO technique, which calculates the required reactive power compensation. In [14], the authors proposed that the demand for electrical energy is greater due to the large development of industries. Voltage regulation, conductor losses, cost, and ratings of machines are affected by non-linear loads and are also the main reason for poor power factors. In non-linear load, they reduce the harmonics by simulating the boost converter. Table 1 shows that this research has achieved its goal of improving power factor and reducing cost by utilizing the modern module PLC.

Table 1: State-of-the-Art Comparison

Research Paper	Methodology	Remarks
Design and implementation of SC banks controlled by FPGA for power factor correction in induction motors (2016)	FPGA-based Switched Capacitor (SC) banks control	Low THD, high efficiency, easy maintenance
A new intelligent control scheme for switched capacitor banks to improve power factor in three-phase induction motors (2019)	The hybrid intelligent control scheme	High efficiency, reduced THD, low cost
Implementation of a switched capacitor bank controlled by an adaptive fuzzy system for power factor correction in induction motors (2017)	Adaptive fuzzy logic control	High efficiency, low THD, improved power factor

Design and implementation of a switched-capacitor-based reactive power compensator for three-phase induction motors (2020)	SC-based reactive power compensator	High efficiency, fast response, improved power factor
Power factor improvement of induction motor using switched capacitor and microcontroller-based controller (2017)	Microcontroller-based SC control	Low cost, improved power factor, reduced THD
Real-time implementation of a control algorithm for a three-phase induction motor using a switched-capacitor bank (2021)	Real-time SC control	High accuracy, improved power factor, reduced THD
Implementation of an FPGA-Based Controller for a Switched-Capacitor Bank for Power Factor Correction of Induction Motors (2019)	FPGA-based SC control	High accuracy, improved power factor, reduced THD
Design and implementation of a three-phase induction motor controller based on a switched capacitor bank for power factor correction (2018)	SC-based motor control	Improved power factor, reduced THD, low cost
Proposed work	PLC-based PF improvement using SC banks	Improved PF, low cost, ease of implementation

3. Proposed System

Depending upon the inductive load, incorporating capacitors in or out of the system by a switching algorithm is developed with the help of GX Works 2 software.

PLC is central to this power factor improvement (PFI) system. Moreover, the block diagram of the designed system is shown in Figure 1. It shows that under normal conditions, when the switching signals are absent, Capacitor banks remain disconnected. The multifunction meter (MFM) reads the power factor of the three-phase load. According to the switching logic, PLC generates the DC output that further excites the contact coil of the solid-state relay and, thus, capacitors connected across the input terminals of the three-phase load.

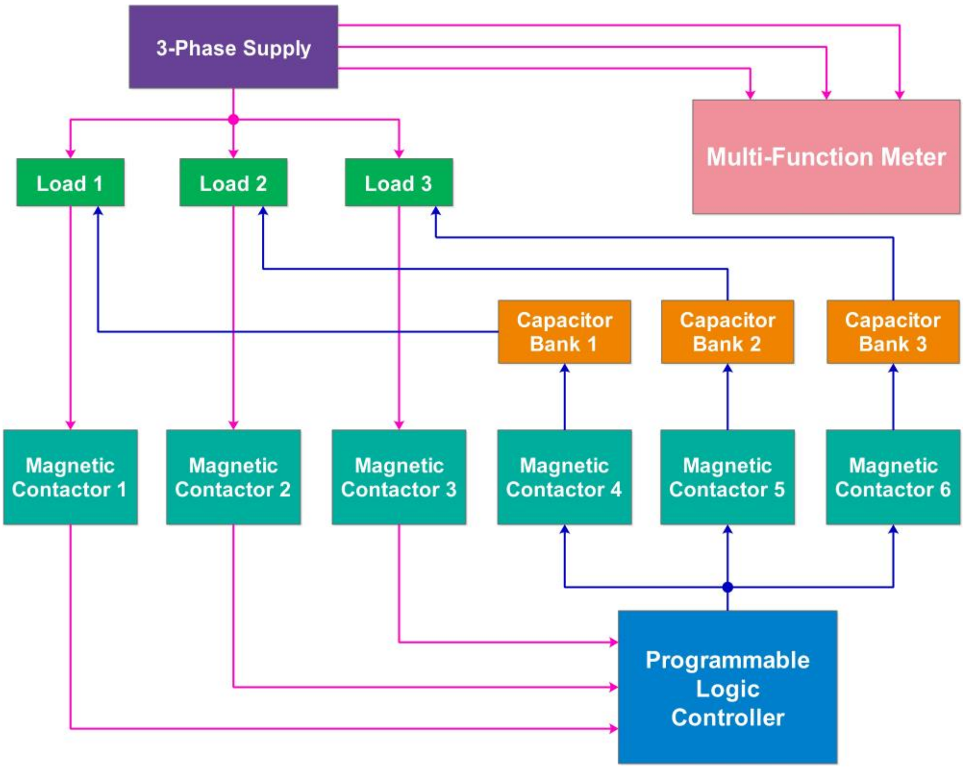

Figure 1: Block Diagram of the Designed System

3.1 Power Factor Improvement (PFI)

In the designed scheme of power factor improvement, when the start button of any of the three motors is pressed, PLC will read the signal as an input from the contactor coil of the magnetic contactor connected with the motor and will send a signal as an output to corresponding contactor coil of the magnetic contactor to connect the capacitor bank to improve PF. In case the stop button of the motor is pressed, PLC will again read the signal as an input and disconnect the capacitor bank. As for safety precautions, a miniature circuit breaker (MCB) is used to protect the hardware, and for the motor's safety, overload relays are used, which will protect the motor in case of overload conditions. It will also protect the motor by sensing the current going toward the motor. PLC will read input signals from MCB, 3 OFF push buttons, 3 ON buttons, three overload relays, and three contactors attached with motors and will give three output signals to contractors attached to capacitor banks.

3.2 Switching Algorithm

A switching algorithm has been developed with the help of GX Works 2 software, through which capacitors will be incorporated into or out of the system depending upon the inductive load. For practical implementation, this algorithm was burnt to the PLC by using a ladder diagram.

3.3 Capacitor Banks Calculation

As we are improving the power factor by using capacitor banks, it is essential to calculate the correct value of capacitor banks. The formula used to calculate the value of capacitor banks for induction motors is given below.

$$Q = kVAR = P\,(\tan\theta 1 - \tan\theta 2) \tag{1}$$

Where,

P is the rated power of three phase induction motor.

θ_1 is the inverse cosine of power factor at no load, i.e.

$$\theta_1 = \cos^{-1}(\text{PF at no load}) \tag{2}$$

θ_2 is the inverse cosine of the target power factor, i.e.

$$\theta_2 = \cos^{-1}(\text{Target PF}) \tag{3}$$

3.4 Flowchart of the Designed System

The switching algorithm has been developed in GX Works 2 software, so the flowchart of the designed system is all about its Ladder Diagram. When either of the three start push buttons of the motors is pressed, the motors will start running. If the motor doesn't start due to some fault and the motor check is not cleared. As a result, the timer will not start. When the motor starts, and the check is cleared, the timer will start, and the capacitor bank of the respective motor is connected, as shown in Figure 2.

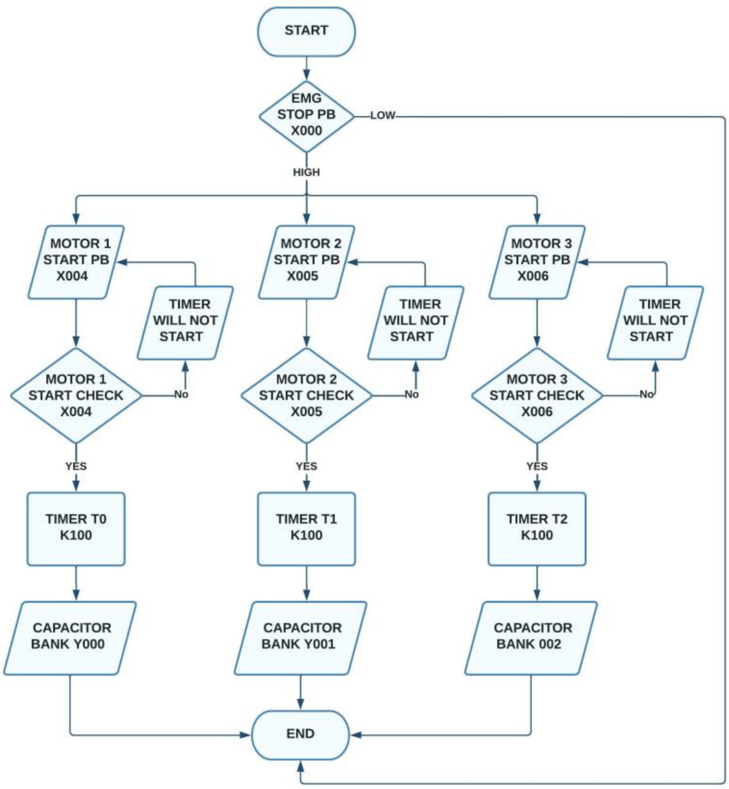

Figure 2: Flowchart of the Designed System

4. Discussion on Simulation Results

The Power Factor Improvement System (PFI) is simulated using GX Works 2 software. Programming languages, including sequential function charts (SFC), structured text (ST), and ladders, are the languages for programming in GX Works 2. In addition, several languages, including SFC, ST, and ladders, can also be used. This project uses Ladder logic PLC programming to incorporate capacitor banks with the respective motor. The simulation results of the designed PFI and their descriptions follow.

4.1 Capacitor Bank-1 Logic

When the timer is finished, PLC will generate an output at the Y000 terminal to which the capacitor bank is connected. If the motor-1 stop button is pressed, the capacitor bank will be disconnected as M1 memory will become low. As a result, M2 memory will also become low to disconnect the capacitor bank, as shown in Figure 3.

Figure 3: Capacitor Bank-1 Output Logic

4.2 Motor-1 Output Logic

When motor-1 starts, X004 receives a high signal, and M0 memory will become high. When M0 becomes high, PLC will generate an output at the Y003 terminal to start motor-1, as shown in Figure 4.

Figure 4: Motor-1 Output Logic

4.3 Capacitor Bank-2 Logic

When the timer is finished, PLC will generate an output at the Y001 terminal to which the capacitor bank is connected. If the stop motor-2 button is pressed, the capacitor bank will be disconnected as M3 memory will become low. As a result, M4 memory will also become low to disconnect the capacitor bank, as shown in Figure 5.

Figure 5: Capacitor Bank-2 Output Logic

4.4 Motor-2 Output Logic

When motor-2 starts, X005 receives a high signal, and M3 memory will become high. When M3 becomes high, PLC will generate an output at the Y004 terminal to start motor-2, as shown in Fig. 6.

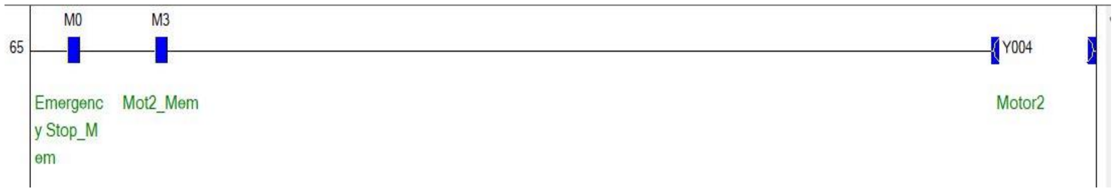

Figure 6: Motor-2 Output Logic

4.5 Capacitor Bank-3 Logic

When the timer is finished, PLC will generate an output at the Y002 terminal to which the capacitor bank is connected. If the motor-3 stop button is pressed, the capacitor bank will be disconnected as M05 memory will become low. As a result, M6 memory will also become low to disconnect the capacitor bank, as shown in Figure 7.

Figure 7: Capacitor Bank-3 Output Logic

4.6 Motor 3 Output Logic

When motor-3 starts, X006 receives a high signal, and M5 memory will become high. When M5 becomes high, PLC will generate an output at the Y004 terminal to start motor-3, as shown in Figure 8.

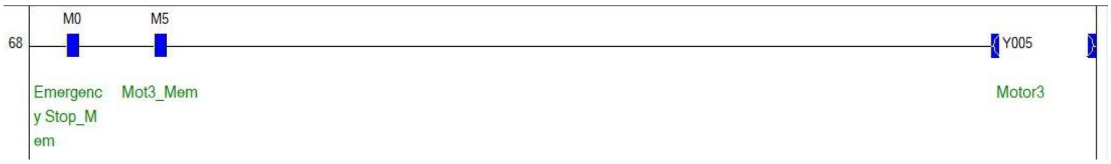

Figure 8: Motor-3 Output Logic

5. Complete Hardware

All components for the PFI system have been integrated into a panel box. In addition, this panel box consists of PLC, overload relays, magnetic contactors, capacitor banks, digital multifunction meters, and induction motors, as shown in Figure 9.

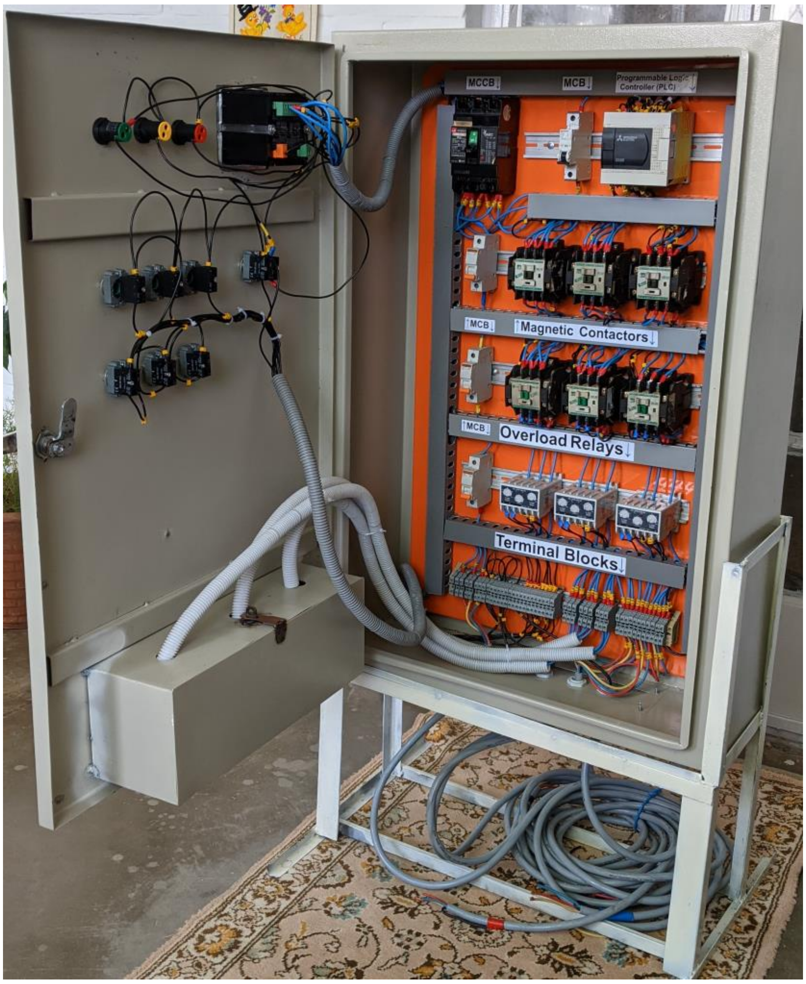

Figure 9: Complete Hardware of PFI

The main goal of the designed system is to improve the power factor. Every industry aims to improve power factors to make their system economical. The lagging power factor is due to the use of inductive load at the consumer end, so capacitor banks are used to correct the power factor. It minimizes electricity use and charges at the user end. In addition, this system can be used for shipboards, information centers, flying machines, and other electronic loads bigger than 1,000 watts.

5.1 Power Circuit

Every phase of the three-phase supply in the power circuit has been connected with molded case circuit breaker (MCCB). Each phase is connected with a circuit breaker of rating 4A because it will damage the power analyzer if it exceeds the limit. For this reason, the circuit breaker has been connected with each phase, and three phases are connected with all of the six contractors. The first three contactors are connected with the three-phase induction motors, so overload relays are used to protect motor winding. The next three contactors are connected with the three circuit breakers, which also connect the three phases to protect the power analyzer.

5.2 Control Circuit of PLC Inputs

In the control circuit diagram, 24V has been given for operating PLC using sink-to-source communication. Sink-to-source communication is the internal circuit of PLC, which has been used in the designed scheme. Different PLCs have different input and output pins operated on different communication circuits. After that, in the control circuit, there are seven switches; switch S1 is the emergency stop push button, which will be operated in case of emergency, and switch S2, S3, and S4 are the OFF button which will be used for OFF purpose, the switch S5, S6, S7 are the ON button which will be used for the starting of motors. Next, three overload relays are connected with three contactors (C1, C2, C3) to protect the motors. Because sometimes the motor current exceeds the limits, the overload relay will become ON for protection and overheating.

5.3 Control Circuit of PLC Outputs

In the control circuit of PLC outputs, MCB has been connected with an emergency stop push button, and PLC is connected to neutral. The output pins of PLC with names COM0, COM1, COM2, and COM3 have been connected at one end of the emergency stop push button, which protects in case of emergency. At the output pin, all the contractors have been connected, which is also neutral to the PLC and shows the behavior and readings of the designed project working on the power analyzer.

6. Discussion on Hardware Results

Some experiments with different loads were performed to test the designed system. The test results for seven different scenarios for different load combinations are shown below. In addition, the digital multifunction meter is used to check the system parameters.

6.1 Case 1: Motor-1 (P=1 hp)

When an inductive load, 'Motor-1' of 1hp or 746 watts, is switched ON, the power factor drops to 0.20. Now PLC, as per requirement, injected reactive power from the capacitor bank to improve the power factor. Experimental results of both cases, i.e., with and without the proposed system, are shown below in Table 2. It is observed that with the proposed system power factor is improved from 0.20 to 0.99. In addition, the current and reactive power drawn by the load is also reduced, which means that the proposed system saved energy up to a significant amount.

Table 2: Case-1 Experimental Results

Loads	Parameters	Before Adding Capacitor Banks	After Adding Capacitor Banks
1-hp Motor	Current	1.137 A	0.29 A
	Voltage	408.5 V	408.5 V
	Active Power	0.158 kW	0.158 kW
	Reactive Power	0.784 kVAR	0.019 kVAR
	Apparent Power	0.793 kVA	0.158 kVA
	Power Factor	0.20	0.99

6.2 Case 2: Motor-2 (P=0.5 hp)

When an inductive load, 'Motor-2' of 0.5hp or 373 watts, is switched ON, the power factor drops to 0.27. Now PLC, as per requirement, injected reactive power from the capacitor bank to improve the power factor. Experimental results of both cases, i.e., with and without the proposed system, are shown in Table 3. It is observed that with the proposed system power factor is improved from 0.27 to 0.95. In addition, the current and reactive power drawn by the load is also reduced, which means that the proposed system saved energy up to a significant amount.

Table 3: Case-2 Experimental Results

Loads	Parameters	Before Adding Capacitor Banks	After Adding Capacitor Banks
0.5-hp Motor	Current	1.025 A	0.29 A
	Voltage	408.5 V	408.5 V
	Active Power	0.201 kW	0.201 kW
	Reactive Power	0.710 kVAR	0.070 kVAR
	Apparent Power	0.731 kVA	0.217 kVA
	Power Factor	0.27	0.95

6.3 Case 3: Motor-3 (P=0.25 hp)

When an inductive load, 'Motor-3' of 1hp or 186.5 watts, is switched ON, the power factor drops to 0.29. Now PLC, as per requirement, injected reactive power from the capacitor bank to improve the power factor. Experimental results of both cases, i.e., with and without the proposed system, are shown in Table 4. The proposed system power factor is observed to be improved from 0.29 to 0.99. In addition, the current and reactive power drawn by the load is also reduced, which means that the proposed system saved energy up to a significant amount.

Table 4: Case-3 Experimental Results

Loads	Parameters	Before Adding Capacitor Banks	After Adding Capacitor Banks
0.25-hp Motor	Current	0.189 A	0.10 A
	Voltage	408.5 V	408.5 V
	Active Power	0.048 kW	0.048 kW
	Reactive Power	0.142 kVAR	0.009 kVAR
	Apparent Power	0.147 kVA	0.048 kVA
	Power Factor	0.29	0.99

6.4 Motor-1 in Parallel with Motor-2

When inductive loads, 'Motor-1' in parallel with 'Motor-2', are switched ON, the power factor drops to 0.23. Now PLC, as per requirement, injected reactive power from the capacitor bank to improve the power factor. Experimental results of both cases, i.e., with and without the proposed system, are shown in Table 5. It is observed that with the proposed system power factor is improved from 0.23 to 0.97. In addition, the current and reactive power drawn by the load is also reduced, which means that the proposed system saved energy up to a significant amount.

Table 5: Case-4 Experimental Results

Loads	Parameters	Before Adding Capacitor Banks	After Adding Capacitor Banks
1-hp Motor + 0.5-hp Motor	Current	2.13 A	0.583 A
	Voltage	408.5 V	408.5 V
	Active Power	0.352 kW	0.352 kW
	Reactive Power	1.483 kVAR	0.081 kVAR
	Apparent Power	1.511 kVA	0.363 kVA
	Power Factor	0.23	0.97

6.5 Case 5: Motor-2 in Parallel with Motor-3

When inductive loads, 'Motor-2' in parallel with 'Motor-3', are switched ON, the power factor drops to 0.27. Now PLC, as per requirement, injected reactive power from the capacitor bank to improve the power factor. Experimental results of both cases, i.e., with and without the proposed system, are shown in Table 6. It is observed that with the proposed system power factor is improved from 0.27 to 0.96. In addition, the current and reactive power drawn by the load is also reduced, which means that the proposed system saved energy up to a significant amount.

Table 6: Case-5 Experimental Results

Loads	Parameters	Before Adding Capacitor Banks	After Adding Capacitor Banks
0.5-hp Motor + 0.25-hp Motor	Current	1.215 A	0.358 A
	Voltage	408.5 V	408.5 V
	Active Power	0.240 kW	0.240 kW
	Reactive Power	0.847 kVAR	0.077 kVAR
	Apparent Power	0.874 kVA	0.259 kVA
	Power Factor	0.27	0.96

6.6 Case 6: Motor-1 in Parallel with Motor-3

When inductive loads, 'Motor-1' in parallel with 'Motor-3', are switched ON, the power factor drops to 0.20. Now PLC, as per requirement, injected reactive power from the capacitor bank to improve the power factor. Experimental results of both cases, i.e., with and without the proposed system, are shown in Table 7. It is observed that with the proposed system power factor is improved from 0.20 to 0.99. In addition, the current and reactive power drawn by the load is also reduced, which means that the proposed system saved energy up to a significant amount.

Table 7: Case-6 Experimental Results

Loads	Parameters	Before Adding Capacitor Banks	After Adding Capacitor Banks
1-hp Motor + 0.25-hp Motor	Current	1.308 A	0.344 A
	Voltage	408.5 V	408.5 V
	Active Power	0.191 kW	0.191 kW
	Reactive Power	0.928 kVAR	0.025 kVAR
	Apparent Power	0.940 kVA	0.190 kVA
	Power Factor	0.20	0.99

6.7 Case 7: Motor-1 in Parallel with Motor-2 and Motor-3

When inductive loads, 'Motor-1' in parallel with 'Motor-2' and 'Motor-3' are switched ON, the power factor drops to 0.23. Now PLC, as per requirement, injected reactive power from the capacitor bank to improve the power factor. Experimental results of both cases, i.e., with and without the proposed system, are shown in Table 8. It is observed that the proposed system's power factor is improved from 0.23 to 0.97. In addition, the current and reactive power drawn by the load is also reduced, which means that the proposed system saved energy up to a significant amount.

Table 8: Case-7 Experimental Results

Loads	Parameters	Before Adding Capacitor Banks	After Adding Capacitor Banks
1-hp Motor + 0.5-hp Motor + 0.25-hp Motor	Current	2.320 A	0.629 A
	Voltage	408.5 V	408.5 V
	Active Power	0.385 kW	0.385 kW
	Reactive Power	1.628 kVAR	0.092 kVAR
	Apparent Power	1.658 kVA	0.403 kVA
	Power Factor	0.23	0.97

7. Conclusion

The proposed technique is for a system with three-phase inductive loads for which the power factor is efficiently improved by using PLC. The Purpose of PLC in this system is to read the input signals from motors and produce an output signal to connect capacitor banks. Previously many methods were used for power factor correction, but capacitor banks are used here as they are easy to operate, install, and have better efficiency. According to the proposed control scheme, to obtain a pre-specified value of power factor, a set of capacitor banks were switched ON or OFF by PLC. The control strategy for PLC relies on input parameters like current and power factor. Using these parameters, the system's reactive power was calculated by PLC, and to compensate for reactive power, capacitor banks were switched ON, and hence power factor was improved from 0.24 to 0.97 (it is an average value of different experimental cases we tested at the no-load condition).

Acknowledgments

The authors wish to acknowledge the support provided for this research by the Electrical Engineering Department, Wah Engineering College, and the University of Wah faculty.

References

[1] Y. Prasetyo, N. Hidayatullah, B. Artono et al., "Power factor correction using programmable logic control based rotary method," in Journal of Physics: Conference Series, vol. 1845, no. 1. IOP Publishing, 2021, p. 012045.

[2] M. Kumar, P. Mukherjee, K. Verma, S. Verma, and D. B. Rawat, "Improved deep convolutional neural network based malicious node detection and energy-efficient data transmission in wireless sensor networks," IEEE Transactions on Network Science and Engineering, vol. 9, no. 5, pp. 3272–3281, 2021.

[3] S. Mhetraskar, S. A. Namekar, R. M. Holmukhe, and S. M. Tamke, "Industrial automation using plc, hmi and its protocols based on real-time data for analysis," Int. J. Adv. Res. Eng. Technol. (IJARET), vol. 11, no. 10, 2020.

[4] M. Prasad, P. K. Khan, R. Kumar, K. Pandarinadh, and G. Srinivas, "Automated power factor correction and monitoring system," vol. 8, no. 1, pp. 70–74, 2020.

[5] W. M. O. Narvios and Y. Nguyen, "Automatic power factor correction for three-phase induction motors with embedded iot-based monitoring system," in AIP Conference Proceedings, vol. 2406, no. 1. AIP Publishing LLC, 2021, p. 060002.

[6] C. Li, Z. Xia, F. Li, X. Chen, H. Li, Z. Liu, and G. Wang, "Unbalanced current analysis of three-phase ac–dc converter with power factor correction function based on the integrated transformer," IET Power Electronics, vol. 13, no. 12, pp. 2461–2468, 2020.

[7] M. A. SENOL, "Fuzzy logic based power factor correction in single phase ac-dc system," Bitlis Eren Universitesi Fen Bilimleri Dergisi, vol. 10, no. 2, pp. 602–612, 2021.

[8] B. Bimali, S. Uprety, and R. P. Pandey, "Var compensation on load side using thyristor switched capacitor and thyristor controlled reactor," Journal of the Institute of Engineering, vol. 16, no. 1, pp. 111–119, 2021.

[9] H. C¸Alik, G. Yalc, and E. S Ehirl, "Power factor correction in induction heating system using pfc boost converter," European Journal of Technique (EJT), vol. 10, no. 2, pp. 464–475, 2020.

[10] Y. P. Dhakate and S. A. Ingewar, "Improvement of power factor and efficiency of three phase induction motor by extinction angle control," 2020.

[11] G. Zhu and D. Gao, "Design of a variable-frequency inductive charger for low-power electronic device applications," 2021.

[12] L. Xiong, P. Li, M. Ma, Z. Wang, and J. Wang, "Output power quality enhancement of pmsg with fractional order sliding mode control," International Journal of Electrical Power & Energy Systems, vol. 115, p. 105402, 2020.

[13] R. Li, P. Wong, K. Wang, B. Li, and F. Yuan, "Power quality enhancement and engineering application with high permeability distributed photovoltaic access to low-voltage distribution networks in Australia," Protection and Control of Modern Power Systems, vol. 5, no. 1, pp. 1–7, 2020.

[14] G. P. Prajapati, A. G. Thosar, and A. Kumar, "Unity power factor control using interleaved boost converter for induction motor drive," in IECON 2021–47th Annual Conference of the IEEE Industrial Electronics Society. IEEE, 2021, pp. 1–6.