PLC Based Power Factor Improvement of Three-Phase Loads

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ABSTRACT

This paper presents a novel technique of Power Factor Improvement (PFI) for end users of electricity. The technique incorporates all the important aspects of a cost effective Power Factor Improvement System and gives a complete PLC based low cost solution. In industries, three-phase inductive loads such as induction motors are widely used due to their low cost, easy maintenance, reliability and robustness. Due to inductive loads, power factor is reduced which results in the wastage of power, high billing cost and penalty from electric power supply companies. In order to resolve this issue, we designed a system for improvement of power factor of three phase loads using PLC. The system is implemented by the combination of Hardware and software. The software consist of PLC programming whereas hardware consist of power and control circuit along with the protective devices. The programing of PLC is logic based which control step by step sequence of operations. In this project we observed that how PLC can improve power factor by switching of different capacitors in prescribed form and how inductive VAR get improved by capacitive VAR of capacitor bank in the system.

Keywords: Cost effective, power factor improvement, programmable logic controller, induction motor, protective devices.

1. INTRODUCTION:

Three phase Induction Motors are widely used in the applications of industries such as elevators, refrigerators, lathes, cranes, washing machines, fans, conveyors, drilling machine, winders, blower, wind tunnels, pumps, etc. because they are reliable, robust, having low cost, and maintenance is easy [1]. But Induction Motor takes the reactive component of power from supply to start its operation i.e. to induce the current in rotor because the stator field leads the rotor field in due to which the Induction Motors always operate or function at lagging power factor [1]. Similarly, industries have a huge number of Induction Motors which causes large transferring of reactive component of power from the utility side through network. It increases the losses of network and reduces output voltages which make a motor less reliable, costly and the safety problems also get increased. Lower the Power Factor of the system, less the economically will be system operate. So from the perspective of energy management we have always a need to improve the power factor of the Load.

The designed system deals with the power factor improvement of a system by switching the shunt capacitors of most suited value through the PLC (Programmable Logic Controller) based algorithm. Due to many controls industrial applications the PLC is used as a Power Factor Controller.

2. LITERATURE REVIEW

Afaaf Ahmad Abeid proposed a system to improve power factor of Electrical Generation by a technique called clustering neural networking. CNN is basically a pattern recognition technique that compare power factor when inductive load add in to the system, with the reference pattern and value of power factor. If the value of PF is less than the required one then it automatically improve it [2].

Vikesh Rajek and Dr. VS Kaale proposed a system for improvement of power factor of a 3 phase induction motor using plc. The system is implemented by the combination of software and hardware. When induction motor start, PF get reduced, PLC then perform operation according to the programing done in it and capacitors start switching for compensating inductive Var. As a result PF get improved [3].

Mr Nikil P Jamaalpur, et al. proposed a system to automatically improve the power factor of induction motor. They used capacitor banks for improving power factor which is connected parallel to the device having low PF. Capacitor having capacitive reactive power which is opposite to the inductive reactive power, both cancel their effect and as a result the total power factor get improved [4].

Gauraav S Chengaale, et al. proposed a system to improve power factor of 3-phase inductive load using PLC. when induction motor starts the total power factor of the system get reduced , PLC which basically control digital input and output pins sense low power factor then it automatically perform operation according to the programing done in it and switching of capacitor get starts which compensating inducting reactive power [5].

C.M Denis, et al. proposed a system for improvement of power factor using e Roederstein ESTAmat RPR power factor controller of a 3 phase unbalanced inductive load. They used static capacitor which adds reactive power in system and compensating inductive reactive power and improving power factor [6].

3. DESIGNED SCHEME

A switching algorithm is developed with the help of GX Works 2 software through which capacitors will be incorporated to the system or out from the system depending upon the inductive load.

A block diagram of Power Factor Improvement System (PFI) is presented in Figure 1. PLC is the central part of this Power Factor Improvement System.

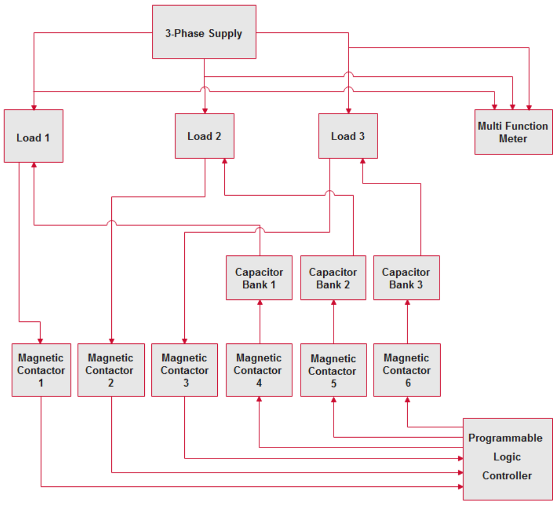

Figure 1: Block Diagram of PFI

From Figure 1, it is clear that under normal condition when the switching signals are absent; Capacitor banks remain disconnected. The MFM (Multifunction Meter) read the Power Factor of Three-Phase Load. According to the switching logic, PLC is generating the DC output which further excites the contact's coil of the solid state relay and thus capacitors connected across the input terminals of the Three-Phase Load.

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 signal as an input from contactor coil of magnetic contactor connected with motor and will send signal as an output to corresponding contactor coil of magnetic contactor to connect the capacitor bank in order to improve PF. In case stop button of motor is pressed PLC will again read signal as an input and will disconnect the capacitor bank. As for safety precautions a MCB is used in order to protect the hardware and for motor's safety overload relays are used which will protect motor in case of overload condition. It will also protect the motor by sensing current going towards motor. PLC will read input signals from MCB, 3 OFF push buttons, 3 ON buttons, 3 overload relays and 3 contactors attached with motors and will give 3 output signals to contactors attached with capacitor banks.

3.2. Switching Algorithm

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

3.3. Capacitor Banks Calculation

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

$Q = kVAR = P (\tan \theta_1 - \tan \theta_2)$

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. $\theta_1 = \cos^{-1}(PF\, at\, no\, load)$

θ_2 is the inverse cosine of target power factor, i.e. $\theta_2 = \cos^{-1}(Target\, PF)$

3.4 Flowchart of PFI

As we developed our switching algorithm in GX Works 2 software, so the flowchart of our project is all about its Ladder Diagram. When either of the 3 start push buttons of motors is pressed, motors will start running. In case motor doesn't start due to some fault and motor check is not cleared then as a result timer will not start. When motor starts and check is cleared then timer will start and after the timer is finished capacitor bank of the respective motor is connected as shown in Figure 2.

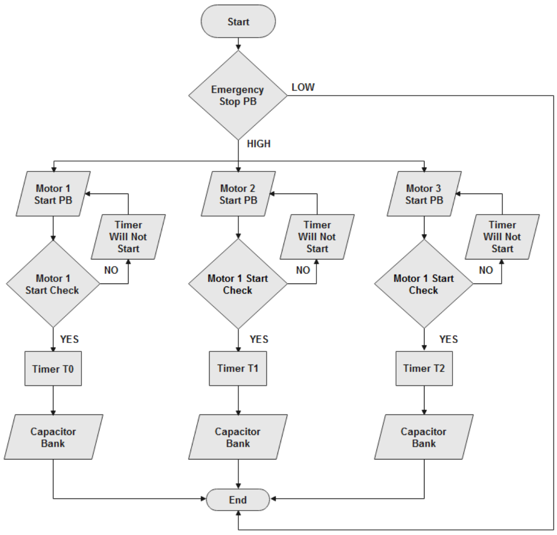

Figure 2: Flowchart of PFI

4. SIMULATION RESULTS

The Power Factor Improvement System (PFI) is simulated using GX Works 2 software. Programming languages including SFC, 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. In our project we used Ladder logic PLC programing for the incorporation of capacitors with respective motor.

Following are the simulation results of designed PFI along with their descriptions.

4.1. Capacitor Bank 1 Output Logic

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

Figure 3: Capacitor Bank 1 Output Logic

4.2. Motor 1 Output Logic

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

Figure 4: Motor 1 Output Logic

4.3. Capacitor Bank 2 Output Logic

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

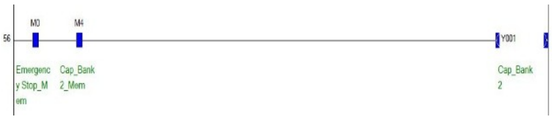

Figure 5: Capacitor Bank 2 Output Logic

4.4. Motor 2 Output Logic

When motor 2 start X005 receives a high signal M3 memory will become high. When M3 will become high PLC will generate an output at Y004 terminal to start motor 2 as shown in Figure 6.

Figure 6: Motor 2 Output Logic

4.5. Capacitor Bank 3 Output Logic

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

Figure 7: Capacitor Bank 3 Output Logic

4.6. Motor 3 Output Logic

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

Figure 8: Motor 3 Output Logic

5. COMPLETE HARDWARE

The Power Factor Improvement System (PFI) has been integrated into a panel box mainly consisting of PLC, Magnetic Contactors, Overload Relays, Digital Multifunction Meter, Capacitor Banks and Induction Motors as shown in Figure 9.

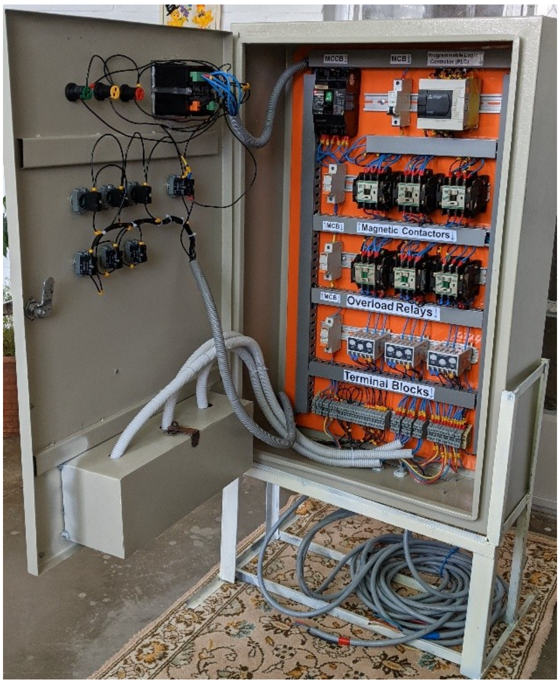

Figure 9: Complete Hardware of PFI

The main purpose of our project is the control of power factor because it is the goal of every industry to maintain its Power Factor one or unity. The lagging power factor is due to having a lot of induction motors. So we use capacitor in our project for the purpose of correcting the power factor for the saving of electricity and industry charges. And we apply this method of power factor improvement of three-phase supply control frameworks, information centers, flying machine, shipboard, and other electronic loads bigger than 1,000 watts.

5.1. Power Circuit

In power circuit, first we connect every phase of three phase supply with MCCB and each phase connect with circuit breaker of rating 4A because if current exceed the limit then it will destroy the power analyzer. For this reason, we circuit breaker connect with each phase. And we connect each of three phases with all six contactors but the first three contactor connect with three phase induction motors so we use overload relay for the protection of motor winding. And the next three contactors connect with three circuit breakers which also connect the three phases for the protection of power analyzer as shown in Figure 10.

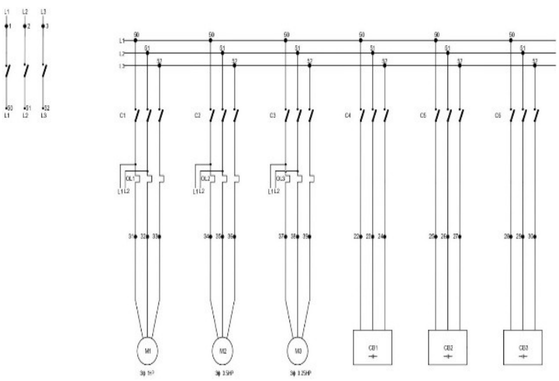

Figure 10: Power Circuit

6. HARDWARE RESULTS

A number of tests have been carried out with different loads to test the circuit design of proposed system. The experimental results for seven different cases utilized by different combinations of loads, without and with the used of developed system discussed below. The Digital Multifunction Meter is also used to verify the results of proposed system.

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

When an inductive load, 'Motor-1' of 1hp or 746 Watt is connected to the hardware, the system's voltage and current is out of phase, means that there was phase shift. PLC is calculating the PF and according to PF requirement, PLC incorporates the required capacitor bank for improving the system PF. Experimental results of both cases i.e. with and without proposed system are shown below in Table 1. Result shows that with the proposed system PF has been improved from 0.20 to 0.99. Also it has been observed that current and reactive power drawn by load is reduced with proposed system, which means that energy is saving up to significant amount.

Table 1: Case 1 Experimental Results

Loads	Parameters	Before Adding Capacitors	After Adding Capacitors
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 inductive load, 'Motor-2' of 0.5hp or 373 Watt is connected to the hardware, the system's voltage and current is out of phase, means that there was phase shift. PLC is calculating the PF and according to PF requirement, PLC incorporates the required capacitor bank for improving the system PF. Experimental results of both cases i.e. with and without proposed system are shown below in Table 2. Result shows that with the proposed system PF has been improved from 0.27 to 0.95. Also it has been observed that current and reactive power drawn by load is reduced with proposed system, which means that energy is saving up to significant amount.

Table 2: Case 2 Experimental Results

Loads	Parameters	Before Adding Capacitors	After Adding Capacitors
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 inductive load, 'Motor-3' of 0.25hp or 186.5 Watt is connected to the hardware, the system's voltage and current is out of phase, means that there was phase shift. PLC is calculating the PF and according to PF requirement, PLC incorporates the required capacitor bank for improving the system PF. Experimental results of both cases i.e. with and without proposed system are shown below in Table 3. Result shows that with the proposed system PF has been improved from 0.29 to 0.99. Also it has been observed that current and reactive power drawn by load is reduced with proposed system, which means that energy is saving up to significant amount.

Table 3: Case 3 Experimental Results

Loads	Parameters	Before Adding Capacitors	After Adding Capacitors
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. Case 4: Motor-1 in Parallel with Motor-2

When inductive loads, 'Motor-1' in parallel with 'Motor-2' are connected to the hardware, the system's voltage and current is out of phase, means that there was phase shift. PLC is calculating the PF and according to PF requirement, PLC incorporates the required capacitor bank for improving the system PF. Experimental results of both cases i.e. with and without proposed system are shown below in Table 4. Result shows that with the proposed system PF has been improved from 0.23 to 0.97. Also it has been observed that current and reactive power drawn by load is reduced with proposed system, which means that energy is saving up to significant amount.

Table 4: Case 4 Experimental Results

Loads	Parameters	Before Adding Capacitors	After Adding Capacitors
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 connected to the hardware, the system's voltage and current is out of phase, means that there was phase shift. PLC is calculating the PF and according to PF requirement, PLC incorporates the required capacitor bank for improving the system PF. Experimental results of both cases i.e. with and without proposed system are shown below in Table 5. Result shows that with the proposed system PF has been improved from 0.27 to 0.96. Also it has been observed that current and reactive power drawn by load is reduced with proposed system, which means that energy is saving up to significant amount.

Table 5: Case 5 Experimental Results

Loads	Parameters	Before Adding Capacitors	After Adding Capacitors
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 connected to the hardware, the system's voltage and current is out of phase, means that there was phase shift. PLC is calculating the PF and according to PF requirement, PLC incorporates the required capacitor bank for improving the system PF. Experimental results of both cases i.e. with and without proposed system are shown below in Table 6. Result shows that with the proposed system PF has been improved from 0.20 to 0.99. Also it has been observed that current and reactive power drawn by load is reduced with proposed system, which means that energy is saving up to significant amount.

Table 6: Case 6 Experimental Results

Loads	Parameters	Before Adding Capacitors	After Adding Capacitors
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 connected to the hardware, the system's voltage and current is out of phase, means that there was phase shift. PLC is calculating the PF and according to PF requirement, PLC incorporates the required capacitor bank for improving the system PF. Experimental results of both cases i.e. with and without proposed system are shown below in Table 7. Result shows that with the proposed system PF has been improved from 0.23 to 0.97. Also it has been observed that current and reactive power drawn by load is reduced with proposed system, which means that energy is saving up to significant amount.

Table 7: Case 7 Experimental Results

Loads	Parameters	Before Adding Capacitors	After Adding Capacitors
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

This hardware implementation of a three phase Inductive load system focuses on the automatic correction of power factor using PLC. With the help of PLC, different performance parameters such as current, real power and inductive power are measured and logged in the PLC. Among various methods being used for improving power factor, capacitor bank method is used as it is easy to install and have more efficiency. According to control strategy to obtain a pre specified power factor, a set of capacitor banks have switched ON or OFF with the help of PLC. This PLC control strategy relies on a lookup table which is based on input parameters -

peak current and power factor at constant voltage. From these parameters, PLC calculated reactive power of the system, the right sequence of the capacitors is switched ON in order to compensate reactive power. And hence power factor is improved.

8. REFERENCES

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