APFC Panel Using PLC

Automatic Power Factor Correction Using Mitsubishi FX5U PLC with Modbus-Based Energy Metering and HMI Monitoring

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***Abstract*—Industrial and commercial electrical systems operating at low power factor draw excessive reactive current, resulting in higher utility bills, increased I²R losses, transformer overloading, and penalty charges enforced by state electricity boards. This paper presents the design, hardware implementation, and laboratory validation of an Automatic Power Factor Correction (APFC) panel built around the Mitsubishi FX5U-32M Programmable Logic Controller (PLC). The system continuously acquires real-time electrical parameters—voltage, current, frequency, active power, reactive power, and power factor—from a Selec EM2M-1P-C-100A-CE multifunction energy meter via RS-485 Modbus RTU communication. Based on the measured power factor, the PLC executes a ladder logic control algorithm that switches a three-step capacitor bank (10 µF, 12.5 µF, and 15 µF; total 37.5 µF / 0.62 kVAr) through Omron relay modules to maintain the power factor above the target setpoint of 0.98. System parameters are displayed and monitored in real time on a Mitsubishi GS2107-WTBD-N 7-inch TFT HMI, which communicates with the PLC over Ethernet. The panel enclosure, designed in AutoCAD with overall dimensions of 500 × 500 × 200 mm, has been fabricated and fully wired. Laboratory tests confirm successful improvement of power factor from as low as 0.50 to 0.98, validating the effectiveness of the proposed PLC-based APFC approach.**

Keywords— APFC, Mitsubishi PLC FX5U-32M, Energy meter, Modbus RTU, RS-485, HMI.

I. INTRODUCTION

Power factor (PF) is defined as the ratio of active power (P, in watts) to apparent power (S, in volt-amperes): PF = P / S = cosφ, where φ is the phase angle between the supply voltage and load current phasors. In purely resistive loads, voltage and current are in phase and PF equals unity. However, inductive loads such as motors, transformers, ballasts, and arc furnaces cause the current to lag the voltage, depressing the power factor well below unity. A low power factor forces the supply network to carry a larger apparent current than the useful load actually demands, increasing conductor I²R losses, causing voltage drops, and reducing the effective capacity of distribution equipment.

From a regulatory standpoint, Indian electricity tariff structures penalise consumers whose power factor falls below a threshold—typically 0.95 lagging—and may offer rebates when it is maintained at or above 0.98. For educational institutions and small industries operating variable inductive loads throughout the day, this creates a compelling case for dynamic, automatic power factor correction rather than fixed capacitor compensation.

Traditional Automatic Power Factor Correction (APFC) relays available commercially are standalone analogue or microprocessor-based units with limited communication capability and no integration with supervisory systems. The present work demonstrates a fully integrated, PLC-based APFC panel in which a Mitsubishi FX5U-32M PLC serves as the central intelligence: it reads all electrical parameters digitally from a Selec EM2M multifunction energy meter over RS-485 Modbus RTU, computes the required capacitor combination, drives relay-switched capacitor banks accordingly, and simultaneously reports the live power factor and all energy parameters to an operator via a Mitsubishi GS2107 touchscreen HMI. This approach offers superior accuracy, programmability, data-logging capability, and scalability compared to conventional analogue APFC methods.

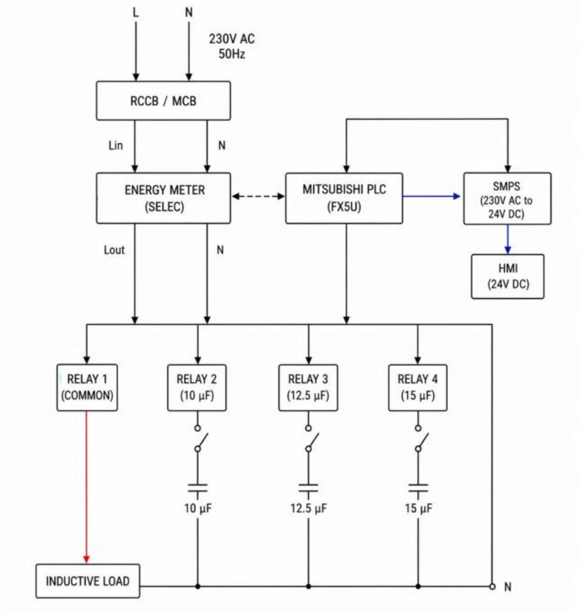


Fig. 1. Block Diagram of APFC Panel Using PLC(single phase)

Figure 1 shows a PLC-based Automatic Power Factor Correction (APFC) system. A 230V AC supply is provided through an MCB to an energy meter, which measures parameters like power factor and sends the data to a Mitsubishi PLC. Based on this input, the PLC controls relays to switch capacitor banks of different ratings connected in parallel with the inductive load. These capacitors compensate reactive power and improve the power factor. An SMPS supplies 24V DC to the PLC and HMI, enabling monitoring and control of the system.

II. LITERATURE REVIEW

Traditional power factor correction methods, such as the relay-based APFC panel implemented by Sehwag et al. [6], provide basic reactive power compensation but lack programmable logic, digital communication, and data logging capabilities. To address these limitations, microcontroller-based approaches were introduced, such as the system proposed by Deepak et al. [8], which utilized an Arduino platform for real-time power factor measurement and switching. While effective for laboratory-scale testing, these microcontrollers lack industrial-grade electromagnetic compatibility (EMC) and scalability for complex multi-stage correction. Further industrial advancements were demonstrated by Gawande et al. [7], who utilized a PLC (Delta DVP12SA2T) with Modbus communication to achieve more deterministic control. However, this system remained constrained by the absence of an integrated HMI and advanced control algorithms, such as HOLD dead-bands, to prevent relay hunting.

In parallel with control hardware development, researchers have explored IoT-based integration to address remote monitoring needs. Kamal et al. [4] and Sandra et al. [5] implemented APFC systems utilizing Raspberry Pi and ESP32 platforms, respectively, which provided real-time cloud-based visualization of electrical parameters. Although these systems facilitate remote oversight, they rely on consumer-grade hardware susceptible to network latency and lack the robust local control interfaces required in factory settings. Furthermore, as emphasized by Pandya et al. [3], the economic drive for such systems is substantial; avoiding utility penalties requires maintaining a power factor above 0.96.

Despite these advancements, existing literature reveals a gap in combining industrial-grade reliability with user-centric functionality. No prior work integrates a Mitsubishi FX5U-32M PLC with native Ethernet/RS-485 communication, a dedicated HMI for real-time trend visualization, a seven-stage switching algorithm with anti-hunting protection, and a dual-mode (Simulation/Actual) operating environment. The present work addresses these limitations by developing a comprehensive, industrial-rated APFC system specifically optimized for single-phase inductive loads.

A. Proposed System

The conventional method for power factor correction involves fixed capacitor banks switched by analogue power factor relays. While effective for static loads, this approach fails when load varies dynamically throughout the day, as it cannot adapt the compensation level in real time without human intervention [6]. To overcome these limitations, the proposed system employs a Mitsubishi FX5U-32M PLC as the central intelligence, which continuously reads all electrical parameters from a Selec EM2M-1P-C-100A-CE multifunction energy meter via RS-485 Modbus RTU, executes a seven-state switching algorithm, and drives a three-step relay-switched capacitor bank automatically.

The proposed APFC panel is organized into five functional layers:

(1) Power and Protection Layer: 230 V AC, 50 Hz single-phase supply is fed through a double-pole MCB (6 A) providing main isolation and short-circuit protection for all downstream equipment.

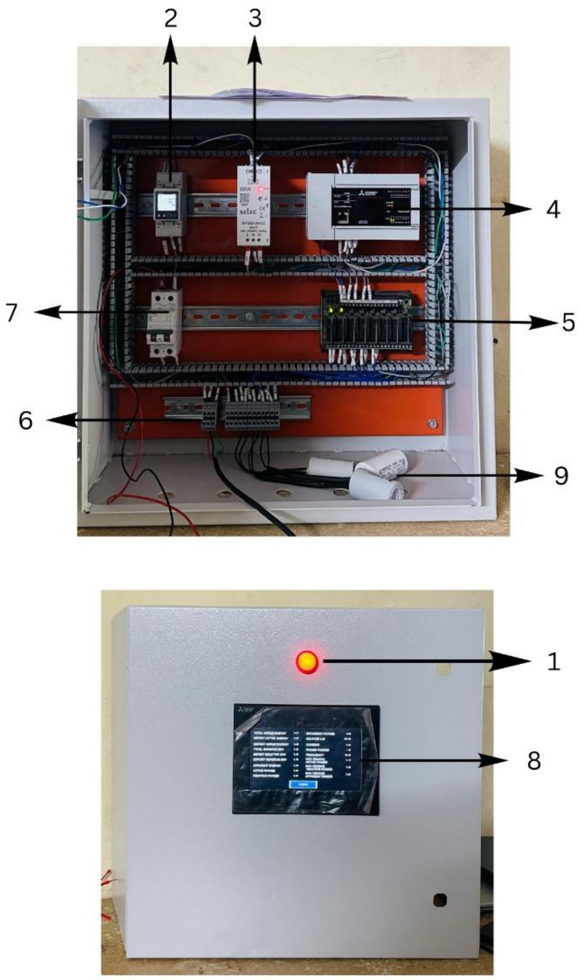
(2) Measurement Layer: The Selec EM2M-1P-C-100A-CE multifunction energy meter is connected in-line with the supply. It continuously measures eighteen electrical parameters with Class 1 accuracy and transmits all parameters to the PLC digitally via RS-485 Modbus RTU, eliminating the need for any analogue voltage or current sensor circuits.

(3) Control Layer: The Mitsubishi FX5U-32M PLC reads energy meter registers every one second, executes the seven-state power factor switching algorithm in ladder logic developed in Melsoft GX Works3, and generates digital output signals to the relay module.

(4) Actuation Layer: An Omron 8-channel relay module switches three AC capacitors — C1 (10 µF), C2 (12.5 µF), and C3 (15 µF) — via PLC outputs Y0, Y1, and Y2 respectively.

(5) Supervision Layer: A Mitsubishi GS2107-WTBD-N 7-inch TFT touchscreen HMI communicates with the PLC over Ethernet, displaying all 18 energy parameters, a live power factor trend graph, and providing dual Simulation/Actual operating modes.

Fig. 2. Hardware Implementation for APFC Using PLC



Compared to the analogue relay-based APFC panel of Sehwag et al. [6] and the Delta PLC system of Gawande et al. [7], the proposed Mitsubishi FX5U-32M based system provides:

- Native Ethernet communication for direct HMI integration
- Modbus RTU energy metering for digital parameter acquisition
- Seven-state switching algorithm with HOLD dead-band (0.95–0.98)
- Dedicated 7-inch HMI with real-time PF monitoring and trend display
- Simulation Mode for safe testing and commissioning
- 5-second anti-hunting timer to reduce unnecessary relay switching

Table No. 1. List of Components Used in Hardware

Component No.	Component Name
1	Indication Lamp
2	Energy Meter (Selec EM2M)
3	SMPS (Selec RPS60-24-CE)
4	PLC (Mitsubishi FX5U-32M)
5	Relay Card (Omron 8-channel)
6	Terminal Blocks
7	MCB (DP MCB 6 A)
8	HMI (Mitsubishi GS2107)
9	Capacitors

III. THEORETICAL BACKGROUND

B. *Power Triangle and Reactive Power*

In an AC circuit supplying an inductive load, the current I lags the voltage V by angle φ. The three power quantities form a right-angled power triangle:

- Active power: $P = V I \cos\varphi$ (watts) — performs useful work
- Reactive power: $Q = V I \sin\varphi$ (VAr) — sustains the magnetic field of inductive devices
- Apparent power: $S = V I$ (VA) — total power drawn from the supply, $S^2 = P^2 + Q^2$

The power factor $PF = \cos\varphi = P / S$. Improving power factor means reducing Q, which reduces S and hence the current drawn from the supply for the same useful work P.

C. *Capacitor Compensation*

A shunt capacitor C connected in parallel with the load generates leading reactive power:

$$Q_C = V^2 \times 2\pi f \times C \times 10^{-6} \ (kVAr)$$

This leading reactive power directly offsets the lagging reactive power drawn by the inductive load. The net reactive power becomes $Q_{net} = Q_l - Q_C$, reducing φ and increasing PF. If $Q_C = Q_l$, the power factor is corrected to unity. Over-compensation ($Q_C > Q_l$) leads to a leading PF, which is undesirable as it can cause voltage rise. The APFC system therefore uses a closed-loop approach: measure PF, compute Qc required, switch the closest available capacitor combination.

D. *Required Compensation — Design Formula*

To improve power factor from an initial value PF_1 to a desired target PF_2 for a load of active power P (kW), the required reactive power compensation is:

$$Q_C = P \times (\tan\varphi_1 - \tan\varphi_2) \ (kVAr)$$

For the present system, the worst-case load is approximately 0.355 kW at $PF_1 = 0.50$, and the target is $PF_2 = 0.98$. Substituting: $Qc = 0.355 \times (\tan(60°) - \tan(11.5°)) \approx 0.355 \times (1.732 - 0.203) \approx 0.543$ kVAr, which rounds up to the selected bank total of 0.62 kVAr.

IV. SYSTEM HARDWARE & SOFTWARE DESIGN

A. *Mitsubishi FX5U-32M PLC*

The Mitsubishi FX5U-32M is the heart of the control system. It provides 16 digital inputs (including 2 high-speed analogue inputs), 16 transistor outputs (including 1 analogue output), and a 24 V DC operating supply. Its built-in RS-485 port is configured at 9600 baud, 8 data bits, even parity, 1 stop bit to communicate with the Selec EM2M via Modbus RTU. The Ethernet port (100BASE-TX) connects to the GS2107 HMI and the monitoring laptop through a standard Ethernet hub. The PLC runs the APFC ladder logic program developed in Melsoft GX Works3, with a typical scan cycle of 0.98 ms for the 600-step program, ensuring fast response to load changes.

The discrete I/O assignment is: Input X0 is the Start switch (NO contact), X1 is the Emergency Stop (NC contact), and X2 is reserved for future expansion. Output Y0 drives Relay R1 to switch capacitor stage C1 (10 µF), Y1 drives Relay R2 for C2 (12.5 µF), and Y2 drives Relay R3 for C3 (15 µF). The relay coils are powered by the 24 V DC bus.

B. *Selec EM2M Energy Meter*

The Selec EM2M-1P-C-100A-CE is a DIN-rail mounted single-phase multifunction energy meter rated for 176–276 V AC at up to 100 A direct connection, operating across 45–65 Hz. It measures and stores all parameters needed for APFC: voltage (V), current (A), frequency (Hz), power factor (PF), active power (kW), reactive power (kVAr), apparent power (kVA), and total energy (kWh). Communication is via RS-485 with Modbus RTU protocol at user-configurable baud rates and a fixed Modbus register map. The meter was observed displaying PF = 0.794 under the initial inductive test load before any capacitor compensation was applied, validating its measurement accuracy against a reference instrument.

C. *Mitsubishi GS2107 HMI*

The Mitsubishi GS2107-WTBD-N is a 7-inch TFT colour touchscreen HMI with 800 × 480 pixel resolution, powered by 24 V DC. The HMI screen design was created in GT Designer3 (GT Works3 software suite) and includes a main parameter display screen showing all eighteen electrical parameters. A dedicated control screen provides Auto/Manual mode toggle buttons, individual capacitor step indicators, and alarm annunciations. The HMI communicates with the PLC through Mitsubishi's MELSEC iQ-F Ethernet protocol, with the PLC IP address configured as 192.168.3.250.

D. *Omron 8-Channel Relay Card*

The Omron 8-channel relay module provides electrical isolation between the Mitsubishi FX5U PLC outputs and the external load circuits. It features eight independent relay channels with 24 V DC coil operation, rated at 10 A, 250 V AC per channel. In the proposed system, only three channels are used for switching capacitor/control stages, while the rest are kept spare. Individual LED indicators assist in monitoring relay status during operation and troubleshooting.

E. *PLC Ladder Logic — GX Works3*

The APFC control logic is implemented as a structured ladder logic program in Melsoft GX Works3. The Modbus RTU communication block, executed on a 1-second clock pulse (using the ADPRW instruction), reads 26 floating-point registers from the Selec EM2M meter covering all electrical parameters. Each 32-bit float occupies two consecutive Modbus registers and is transferred into PLC data registers D50–D82. The power factor register (D74) is the primary input to the control algorithm.

The control decision block compares the current PF reading against two thresholds: the lower setpoint $PF_{lo}c = 0.95$ and the upper setpoint $PF^{hIgh} = 0.98$. If $PF < 0.95$, the logic increments the active capacitor combination upward (adding the next smallest step not yet connected). If $PF > 0.98$, it decrements the combination (disconnecting the smallest active step). Switching is gated by an inter-step timer (T0, 5-second delay) to prevent rapid relay cycling and contact wear—a standard anti-hunting mechanism. Interlocks prevent simultaneous energisation of incompatible combinations and ensure safe de-energisation on Emergency Stop activation.

With three binary relay outputs, eight distinct switching states (000 to 111) are possible, corresponding to capacitance values ranging from 0 to 37.5 µF and reactive power injection from 0 to 0.62 kVAr. The program occupies approximately 600 steps out of the FX5U-32M's 64,000-step program memory.

F. *HMI Design — GT Designer3*

The operator interface was designed in GT Designer3 and downloaded to the GS2107 panel over Ethernet. The main home screen (B-0:HOME) displays all eighteen electrical parameters in a grid layout using numeric display objects linked directly to PLC data registers D50–D82. Lamps linked to Y0, Y1, and Y2 indicate the switching state of each capacitor stage. A MENU button navigates to sub-screens for trend views, alarm history, and manual override controls. Data logging and real-time trend views are configured in GT Designer3 for commissioning and testing.

G. *Communication Architecture*

The full device communication chain is: 230 V AC supply → MCB → (a) load branch and (b) SMPS → 24 V DC bus → PLC + HMI. The PLC RS-485 port connects to the Selec EM2M energy meter via a twisted-pair RS-485 cable using Modbus RTU protocol. The PLC Ethernet port and the HMI Ethernet port connect to an Ethernet hub. A monitoring laptop also connects to the hub for real-time GX Works3 online monitoring. Initial hardware testing was performed with the energy meter connected directly to a laptop via an RS-485 to RS-232 converter, allowing independent verification of the Modbus register map and data accuracy.

H. Algorithm Used

The power factor correction algorithm is implemented as a structured ladder logic program in Melsoft GX Works3. The program executes the following five steps continuously:

Step 1: Read power factor value from the Selec EM2M energy meter via RS-485 Modbus RTU using the ADPRW instruction, triggered by a 1-second clock pulse (M8013). The power factor register value is stored in PLC data register D74.
Step 2: Compare the measured PF (D74) against the seven threshold bands defined in the ladder logic using comparison instructions.
Step 3: Determine the required capacitor combination based on the PF band in which the measured value falls, as per the decision logic described below.
Step 4: Energise or de-energise relay output coils Y1 (C1), Y2 (C2), Y3 (C3) to switch the corresponding capacitor stages in or out of circuit. A five-second inter-step timer must expire before any switching action is executed, providing anti-hunting protection and extending relay contact life.
Step 5: Return to Step 1 and repeat continuously.

The seven-state decision logic applied in Step 3 is as follows:

- PF < 0.65 → Turn ON all capacitors: C1 + C2 + C3 (37.5 µF total)
- 0.65 ≤ PF < 0.75 → Turn ON C1 + C3 (25 µF), turn OFF C2
- 0.75 ≤ PF < 0.87 → Turn ON C1 only (10 µF), turn OFF C2 and C3
- 0.87 ≤ PF < 0.94 → Turn ON C1 + C2 (22.5 µF), turn OFF C3
- 0.94 ≤ PF < 0.95 → Turn ON C1 + C2 (22.5 µF)
- 0.95 ≤ PF ≤ 0.98 → HOLD — no change (target operating band)
- PF > 0.98 → Turn OFF capacitors one by one: C3 → C2 → C1 (prevent over-compensation)

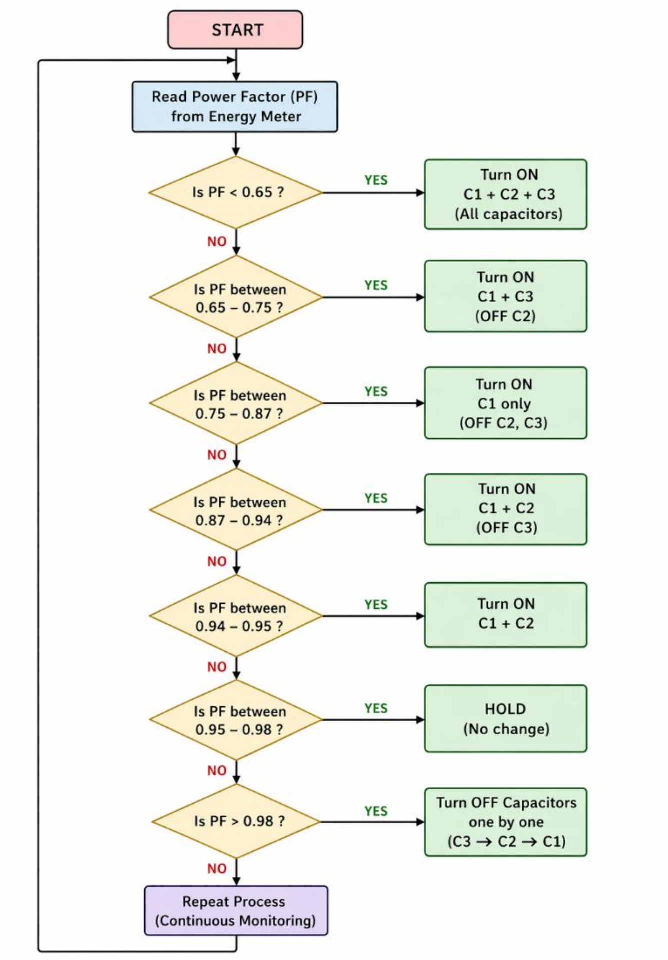


Fig. 3. Flowchart of PLC-Based Power Factor Control Algorithm

I. Calculations

The power factor as measured by the Selec EM2M energy meter is computed according to the MERC tariff formula [7]:

$$PF = \frac{KWH}{\sqrt{[(KWH^2) + (RKVAh\ lag)^2]}} \dots (1)$$

When both leading and lagging reactive components are present:

$$PF = \frac{KWH}{\sqrt{[(KWH^2) + (RKVAh\ lag + RKVAh\ lead)^2]}} \dots (2)$$

Step 1: Calculation of Reactive Power of Each Capacitor Stage

Using the standard formula for reactive power generated by a shunt capacitor at 240 V, 50 Hz:

$$Q\ (kVAr) = \frac{V^2 \times 2\pi f \times C \times 10^{-6}}{1000} \dots (3)$$

$I\ (A) = V \times 2\pi f \times C \times 10^{-6} \dots (4)$

For $C_1 = 10\ \mu F$:

$Q_1 = \frac{240^2 \times 2\pi \times 50 \times 10 \times 10^{-6}}{1000} = 0.181$ kVAr,

$I_1 = 0.754$ A

For $C_2 = 12.5\ \mu F$:

$Q_2 = \frac{240^2 \times 2\pi \times 50 \times 12.5 \times 10^{-6}}{1000} = 0.226$ kVAr,

$I_2 = 0.942$ A

For $C_3 = 15\ \mu F$:

$Q_3 = \frac{240^2 \times 2\pi \times 50 \times 15 \times 10^{-6}}{1000} = 0.452$ kVAr,
$I_3 = 1.131$ A

Step 2: Calculation of Required Compensation

Using the standard reactive power compensation formula [4]:

$$Qc = P \times (\tan \varphi_1 - \tan \varphi_2) \quad \ldots (5)$$

For worst-case test load P = 355 W = 0.355 kW at initial $PF_1 = 0.50$, target $PF_2 = 0.98$:
$\varphi_1 = \cos^{-1}(0.50) = 60°$, $\tan \varphi_1 = 1.732$
$\varphi_2 = \cos^{-1}(0.98) = 11.48°$, $\tan \varphi_2 = 0.203$

$$Qc = 0.355 \times (1.732 - 0.203) = 0.543\ kVAr$$

From the table, Q load at 355 W, PF = 0.50 is 615 VAr = 0.615 kVAr, and Q required = 543 VAr = 0.543 kVAr, which matches the formula result exactly, validating the calculation.
The total bank capacity of 0.679 kVAr (37.5 µF) exceeds this requirement, confirming the bank is adequately sized for full correction at worst-case load.

Step 3: Capacitor Value Verification

$$C = \frac{Qc}{2\pi f \times V^2 \times 10^6} \quad \ldots (6)$$

$$C = \frac{543}{2\pi \times 50 \times 240^2 \times 10^6} = 30.1\mu F$$

The selected bank total of 37.5 µF provides 24.6% headroom above this minimum, ensuring reliable correction at all tested load conditions.

Table No. 2. Capacitor Bank Switching States

Step	Cap (µF)	kVAr	I (A)	PF at 0.2 kW	PF at 0.355 kW
C1	10	0.166	0.723	0.894	0.620
C2	12.5	0.208	0.903	0.959	0.657
C3	15	0.249	1.084	0.996	0.697
C1+C2	22.5	0.374	1.626	1.000	0.827
C1+C3	25.0	0.415	1.807	1.000	0.872
C2+C3	27.5	0.457	1.987	1.000	0.914
C1+C2+C3	37.5	0.623	2.710	1.000	1.000

V. RESULTS

The fabricated APFC panel was tested in the electrical machines laboratory using a variable autotransformer (dimmerstat) as the inductive load connected to a 240 V AC / 50 Hz single-phase supply. Tests were conducted across four load levels — 100 W, 200 W, 285 W, and 355 W — at initial power factor values ranging from 0.50 to 0.80 lagging, covering all seven switching states.

A. HMI PF Control Panel — Simulation Mode

Fig. 4 shows the HMI screen during Simulation Mode testing with setpoint 0.65. All CONNECT/DISCONNECT buttons and relay status indicators responded correctly, confirming HMI–PLC communication was functional. The Simulation Mode verified the complete switching algorithm without a physical load — a novel feature absent in all reviewed prior works [6][7][8][4][5].

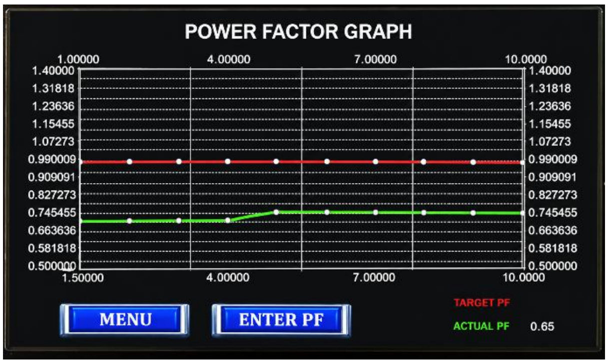
ACTUAL PF :- 1.00
TARGET PF :- 0.95
CURRENT PF :- 0.00
FINAL PF :- 0.65
STAGE 1 :- 0.60
STAGE 2 :- 0.40
STAGE 3 :- 0.20
SIMULATION PF SETPOINT:- 0.65

Fig. 4. HMI PF Control Panel — Simulation Mode

B. Real-Time Power Factor Graph

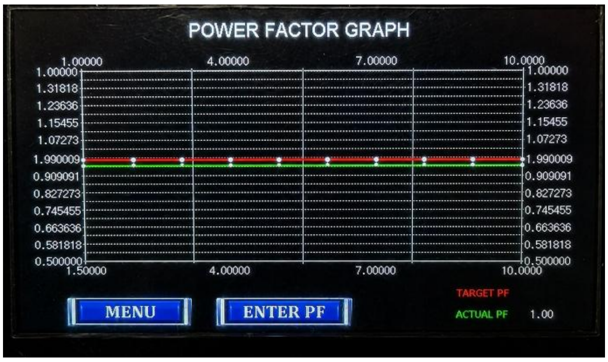
Fig. 5 shows the HMI Power Factor Graph with the red line as Target PF and green line as Actual PF. As capacitor stages switched in sequence, the Actual PF rose toward the target band, confirming correct algorithm execution. This graphical trending capability is unavailable in any referenced prior system.

BEFORE SWITCHING CAPACITORS



ACTUAL PF 0.65

AFTER SWITCHING CAPACITORS

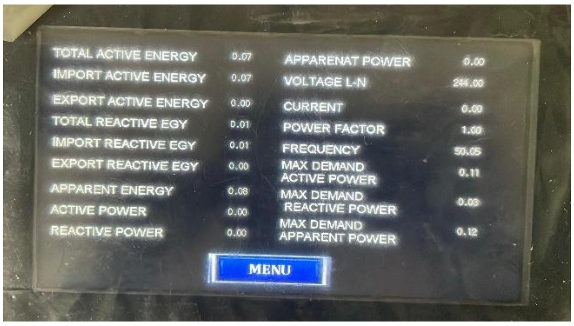


ACTUAL PF 1.00

Fig. 5. HMI Power Factor Graph

C. Energy Parameters Screen

Fig. 6 shows all 18 electrical parameters acquired from the Selec EM2M meter via Modbus RTU. Key readings: Voltage = 243.00 V, Frequency = 50.05 Hz, PF = 1.00 under corrected no-load condition. No communication faults were observed throughout testing.



TOTAL ACTIVE ENERGY 0.07
IMPORT ACTIVE ENERGY 0.07
EXPORT ACTIVE ENERGY 0.00
TOTAL REACTIVE EGY 0.01
IMPORT REACTIVE EGY 0.01
EXPORT REACTIVE EGY 0.00
APPARENT ENERGY 0.08
ACTIVE POWER 0.00
REACTIVE POWER 0.00
APPARENAT POWER 0.00
VOLTAGE L-N 244.00
CURRENT 0.00
POWER FACTOR 1.00
FREQUENCY 50.05
MAX DEMAND ACTIVE POWER 0.11
MAX DEMAND REACTIVE POWER 0.03
MAX DEMAND APPARENT POWER 0.12

Fig. 6. HMI Energy Meter Parameters

D. Laboratory Test Setup

Figs. 7 and 8 show the complete laboratory test arrangement. Fig. 7 shows the open APFC panel alongside the autotransformer (dimmerstat) and DC Series Motor trainer board used as the inductive load. Fig. 8 shows a close-up of the dimmerstat (rated 0–270 V, 50 Hz), which was used to vary the load impedance and simulate different power factor conditions from approximately PF = 0.50 to near unity. The relay switching was observed on the HMI relay status lamps, and each capacitor stage activated correctly in sequence as the PF crossed the respective threshold bands

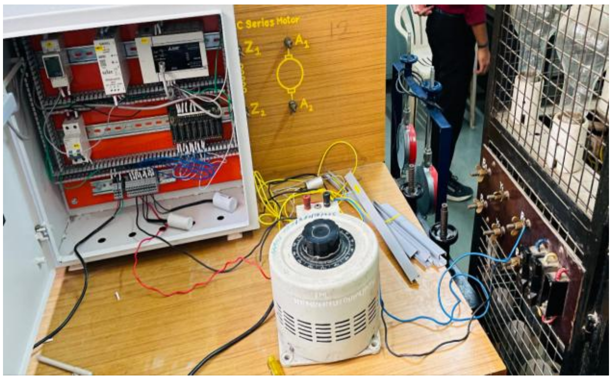


Fig. 7. Lab Setup

The physical enclosure of the APFC panel was designed using AutoCAD by VMS Controls, Pune (Drawing No. 2025–2026/071). The panel is a front-access, free-standing floor-mounted sheet metal enclosure fabricated from 16-gauge CRCA (Cold Rolled Close Annealed) steel, with overall external dimensions of 500 mm (W) × 500 mm (H) × 200 mm (D). The internal mounting plate is powder-coated Siemens Gray (RAL 7035).

The front panel door incorporates a 192 × 184 mm cutout to accommodate the 7-inch Mitsubishi GS2107 HMI touchscreen. The bottom view shows the cable entry gland plate with five 75 mm-spaced cable entry positions for power and communication cables. All internal components—PLC, SMPS, energy meter, relay module, MCB, and terminal blocks—are DIN-rail mounted on the internal steel mounting plate. Cable management is achieved using standard PVC cable ducts routed horizontally and vertically.

VI. CONCLUSION

This paper presented the design and validation of an APFC panel using a Mitsubishi FX5U-32M PLC and a Selec EM2M energy meter. The system utilizes a seven-state switching algorithm with a HOLD dead-band (0.95–0.98) and a five-second anti-hunting timer to control a 37.5 µF capacitor bank. Laboratory testing across loads from 100 W to 355 W and initial power factors from 0.50 to 0.80 lagging confirmed stable Modbus RTU communication and real-time HMI trending. In all test cases, the system successfully improved the power factor to ≥ 0.95, meeting MERC incentive standards. A novel dual Simulation/Actual operating mode was implemented, enabling safe algorithm verification without physical loads.

Future work will focus on extending the system to three-phase loads, implementing IoT-based remote monitoring via the MQTT protocol, and incorporating harmonic spectrum analysis using the PLC's built-in FFT function blocks.

ACKNOWLEDGEMENT

We sincerely thank VMS Controls for sponsoring our project and providing essential resources and support. We are grateful to its Founder, Mr. Milind Pudalik, for his guidance, encouragement, and valuable insights.

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