International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Passive Power Factor Correction Using Capacitor Bank in MATLAB

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ABSTRACT:

Power factor correction (PFC) plays a vital role in enhancing the efficiency of electrical systems by reducing reactive power and minimizing energy losses. This paper presents a MATLAB-based simulation study on passive power factor correction using capacitor banks. The simulation focuses on evaluating the impact of capacitor banks in improving the power factor of an inductive load within an AC circuit.

In this study, the system is modeled using MATLAB's Simulink environment, where the load is represented as a combination of resistive and inductive elements. To compensate for the lagging power factor caused by the inductive load, capacitor banks are introduced. The simulation analyzes key electrical parameters — including power factor, active power, reactive power, and apparent power — both before and after applying the correction.

The results reveal a significant improvement in the power factor, contributing to reduced line losses and enhanced overall system efficiency. This work highlights the effectiveness of passive power factor correction using capacitor banks and offers a practical simulation-based approach for designing and optimizing power factor correction systems for real-world electrical applications.

Keywords: Power Factor, Power Factor Correction (PFC), Capacitor Bank, MATLAB Simulation, Active Power, Reactive Power, Passive Filter

1. Introduction:

An element of energy represents the actual energy perceived by the visible energy load flowing within a region. Essentially, it measures how electrical current is transformed into active, usable energy. The smaller the power factor of a system, the less economically efficient it becomes. A poor power factor results in increased energy losses and higher operational costs. [1]

1.1 Importance of Power Factor Correction in Electrical Systems

Power factor is defined as the ratio of useful (true) power (kW) to total (apparent) power (kVA) consumed by AC electrical equipment or an entire electrical installation. It reflects how efficiently electrical power is converted into productive work output. The ideal power factor is unity (1), indicating that all supplied power is being effectively utilized.

A power factor lower than one signifies that additional reactive power is present, meaning extra energy is required to perform the same amount of work. This inefficiency leads to increased energy losses, higher utility bills, and reduced overall system performance. Therefore, power factor correction (PFC) is crucial for minimizing these losses, improving system efficiency, and ensuring economic operation. [3]

1.2 Overview of passive PFC using capacitor banks.

Passive Power Factor Correction (PFC) using capacitor banks is a widely used method to improve the power factor of electrical systems. It is particularly effective for inductive loads such as motors, transformers, and fluorescent lighting, which introduce a lagging power factor due to the presence of reactive power.

1.2.3 Passive Power Factor Correction

Passive Power Factor Correction (PFC) circuits help improve power factor using a reactor (L) in combination with a voltage doubled rectifier. In this setup, the reactor enhances power factor, while diodes and smoothing capacitors convert AC to DC. Since passive PFC circuits operate at mains frequency (50 or 60 Hz), they require large reactors and capacitors to function effectively. Due to these size requirements, passive PFC is typically used for low-capacity power supplies. Figures 1.2 and 1.3 illustrate an example of a passive PFC circuit and its corresponding input current waveform. [5]

2. Literature Review

2.1 Importance of Power Factor Correction

Power Factor Correction (PFC) is essential in electrical systems for improving operational efficiency, minimizing energy losses, and reducing electricity costs. A low power factor increases the reactive power demand, placing additional strain on power distribution networks and contributing to inefficient energy usage (Smith, 2018).

Various methods are employed for PFC, with passive techniques—such as capacitor banks—being among the most popular due to their simplicity, reliability, and cost-effectiveness.

2.1.1 Passive Power Factor Correction Using Capacitor Banks

Passive PFC involves compensating for the reactive power generated by inductive loads through the use of capacitors. By connecting capacitor banks in parallel with inductive components, leading reactive power is introduced to counteract the lagging reactive power from the load. This process reduces the phase difference between voltage and current, thereby enhancing the overall power factor of the system (Jones et al., 2019).

Limitations:

- Ineffective for dynamic or highly variable loads
- Risk of overcompensation, potentially resulting in a leading power factor
- Limited control over real-time load changes

2.2 MATLAB-Based Simulation of Power Factor Correction

MATLAB and its Simulink environment are widely utilized for the simulation and analysis of electrical systems, including power factor correction strategies. Numerous studies have demonstrated the effectiveness of these tools in modeling, simulating, and optimizing capacitor banks for improving power factor in AC circuits.

2.2.1 Simulation of Passive PFC Using Capacitor Banks

Principle:
In this method, capacitor banks are connected in parallel with inductive loads to supply leading reactive power. This reduces the reactive component of the load current, decreases the phase angle between voltage and current, and improves the overall system power factor.

Advantages:

- Effective for steady-state, predictable loads
- Straightforward to simulate and implement

Limitations:

- Limited responsiveness to fluctuating or dynamic load conditions
- Potential risk of overcompensation leading to a leading power factor
- Not well-suited for systems with frequently changing load profiles

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Literature Review Table.

s.no	Title	Candidate details	Drawback/ soltuion
1	Power factor correction system using MATLAB with different loads.	Dr. B Anil Kumar1 , J.Hima Bindu2 , B.Shruthi3 , Sai Sruthika4 1Assistant Professor, Dept. of EEE, Malla Reddy Engineering College for Women, Hyderabad, 2 3 4Research Student, Dept. of EEE, Malla Reddy Engineering College for Women, Hyderabad [9]	Not suitable for highly variable loads.

2	MATLAB Simulation of Passive Power Factor Correction Using Capacitor Banks MATLAB	Anjali Yadav RSR RCET bhilai . Guide Dr.S.P Makhija Associate professor	**Reactive Power Controllers**: Use reactive power controllers that measure the reactive power demand and switch capacitors accordingly to avoid overcompensation.

3. Methodology:

3.1 Solution.

Automatic Power Factor Correction (APFC) Panels:

- Install APFC panels that continuously monitor the power factor and adjust the capacitor banks to maintain a near-unity power factor.
- These panels prevent overcompensation by switching capacitors in small steps.

3.2 Power factor correction methodology

The entire system consists of five interconnected modules that work together to identify capacitance and rectify the power factor. These modules are as follows:[6]

- Power Input
- Voltage Sensor Circuit
- Current Sensor Circuit
- System Loading
- Capacitor Bank

3.3 Capacitor bank

A **capacitor bank** is an essential component in electrical systems, primarily used for **power factor correction** and **voltage stabilization**. It consists of multiple capacitors connected in either series, parallel, or a combination of both, depending on the system's design requirements. These capacitors store surplus electrical energy when power generation exceeds demand and release it when necessary, promoting a more balanced and stable distribution of power across the network.

By supplying leading reactive power, capacitor banks significantly reduce the total reactive power in a system, thereby **minimizing energy losses**, lowering electricity costs, and improving overall system efficiency. They are widely employed in **industrial facilities**, **commercial buildings**, **renewable energy installations** (such as solar and wind farms), and **high-demand residential areas**.

In large-scale electrical networks, capacitor banks also play a crucial role in **regulating voltage fluctuations**, enhancing **load stability**, and relieving **stress on transformers and transmission lines**. Their contribution is vital for maintaining power quality and operational reliability in modern power distribution systems. [8]

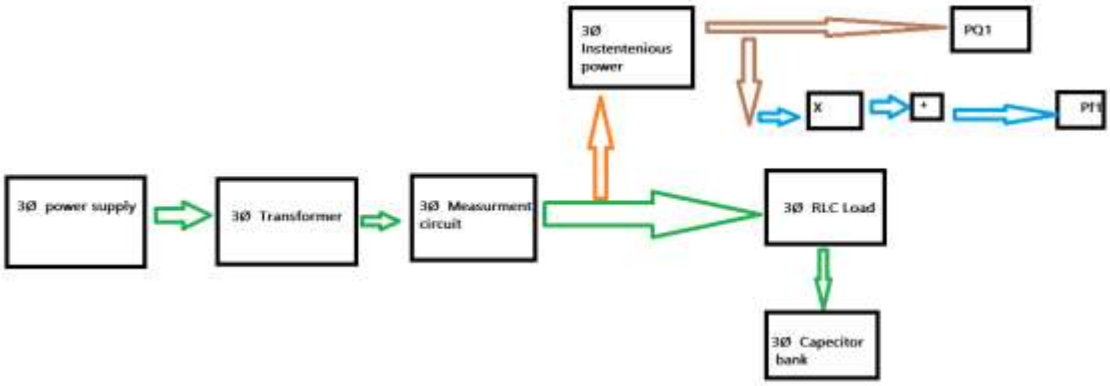

Figure:3.1 Blocked diagram of Power Factor Correction (APFC) Panels

3.4 Calculation of Reactive Power

In this section, the **reactive power (Q)** is calculated to determine the amount of compensation required to improve the power factor to the target value of **Cos φ = 0.98**. The calculation involves both the **initial reactive power (Q_1)** and the **target reactive power (Q_2)** for **Transformer 1** and **Transformer 3** at **PT. Sunrise Steel**.

The reactive power is determined using the following formula:

$$Q = S \times \sin\phi$$

Where:

- **Q** = Reactive Power (in VAR)
- **S** = Apparent Power (in VA)
- **φ** = Phase angle corresponding to the power factor

By applying this formula to the previously obtained apparent power values, the initial reactive power for each transformer is computed. These values serve as a basis for calculating the required compensation, defined as the difference between the initial and target reactive power. This difference ultimately determines the necessary **capacitor bank size** for effective installation. [20]

After performing these calculations, a significant reduction in reactive power was observed for both transformers upon improving the power factor to **Cos φ = 0.98**.

- For **Transformer 1**, the reactive power decreased from **1,199.98 kVAR** (at an initial power factor of 0.67) to **219.94 kVAR** after correction.
- Similarly, for **Transformer 3**, it dropped from **179.60 kVAR** to **32.04 kVAR** after implementing the power factor improvement.

This reduction represents the **amount of reactive power compensation needed**, which directly influences the size and configuration of the capacitor bank required to optimize system performance.

The required compensation, or **Qc**, is calculated using the formula:

$$Qc = Q_1 - Q_2$$

Where:

- **Q_1** = Reactive power before power factor correction (in VAR)
- **Q_2** = Reactive power after correction (in VAR)
- **Qc** = Required reactive power compensation (in VAR)

Following the determination of **Qc**, the next step involves calculating the **capacitive reactance (Xc)** based on the system's operating conditions at **Cos φ = 0.98**. This value guides the final configuration of the capacitor bank.

The formula for capacitive reactance is:

Xc=12πfCXc = \frac{1}{2\pi f C}Xc=2πfC1

Where:

- **Xc** = Capacitive Reactance (in Ohms)
- **f** = Frequency (in Hertz)
- **C** = Capacitance (in Farads)

To meet the target power factor, it was determined that **20 additional 50 kVAR capacitors** were required. These capacitors were installed in parallel increments, increasing the system's overall reactive power compensation capacity and enhancing power factor performance.

3.4.1 Implementation of Capacitor Banks

The design of a capacitor bank requires careful consideration of several factors, particularly when aiming to improve power factor and enhance voltage stability in a power system.

In this study, the global compensation method was applied on the main LVMDP of Transformer 1. Initially, a capacitor bank with a total capacity of 1200 kVAR was installed, consisting of 12 steps, with each step using 50 kVAR capacitors.

4. Simulation and Analysis

In MATLAB, power factor correction (PFC) circuits can be designed in two configurations. The first configuration, similar to the "Before PFC" section in Fig. 4(a), operates without a capacitor bank, while the second configuration, resembling the "After PFC" concept in Fig. 4(b), includes a capacitor bank. The MATLAB simulation model comprises both a block diagram and circuit implementation, allowing for a comparative analysis of these two setups. This comparison highlights the impact of capacitor banks on power factor improvement and reactive power reduction.[10]

Here we used extra methodology in Metlab for calculating power factor .

We know $P = VI \cos \phi$

$P = S \cos \phi$

$\cos \phi = P/S$

- Q = Reactive Power (in VAR)
- S = Apparent Power (in VA)
- φ = The angle corresponding to the power factor

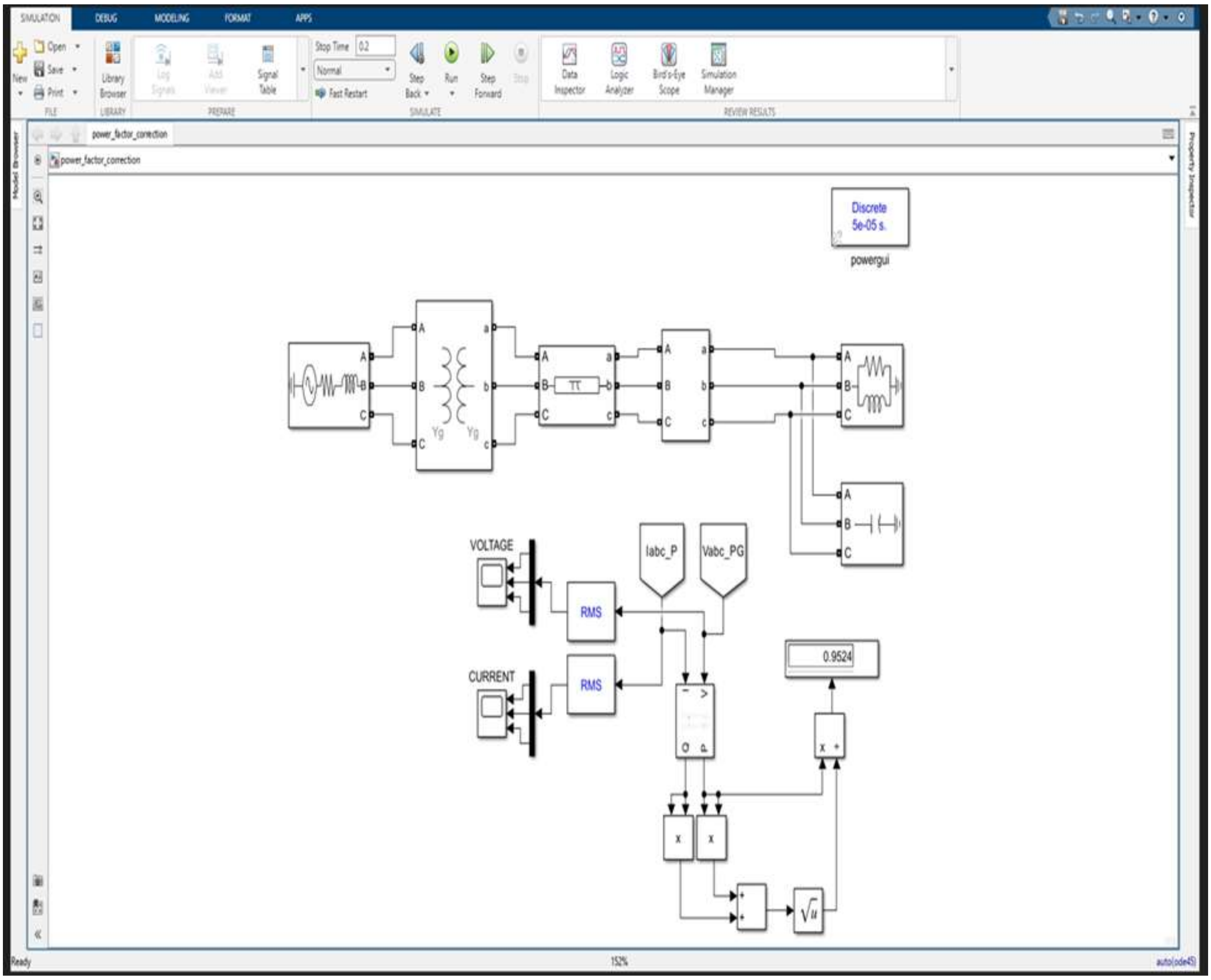

Figure 4.1 : simulation diagram with capacitor bank

4.1 Calculation of Capacitor Value Based on Reactive Power

To calculate the required capacitor value in an AC system, the following relationship is used:

$$Q_c = \frac{V^2}{\omega_c} \qquad C = \frac{Q_c \times 10^3}{V^2 \cdot 2\pi f}$$

Where

Qc is the reactive power in kVAr, Wc (or wc) is the angular frequency in **radians per second**. V is voltage in volt.

The angular frequency ωc\omega_ ωc is given by the formula:

ωc=2πfc where fc_is the frequency in **hertz (Hz)**, π≈3.1416.

Alternatively, the capacitance can be calculated using:

Note: The factor of 10310^3103 is used to convert kVAr to VAr when calculating capacitance in farads (F).

5. Results

5.1 Results and Observations table

S.no	Case	Power factor	Line current	Line losses	Efficiency
1	Without capacitor	0.84	high	High	lower
2	With 1.4 kVAr Cap	0.94	reduce	low	improved
3	With 1.8 kVAr Cap	0.95	low	minimum	high

5.2 Final value change for achieving good power factor PF= 0.952

In MATLAB, to change the value of the capacitor, I modified the parameter settings as shown in Chapter 4 of the simulation. After three iterations, I obtained the final results for the last three cases. The output power factor (PF) achieved was 0.952.

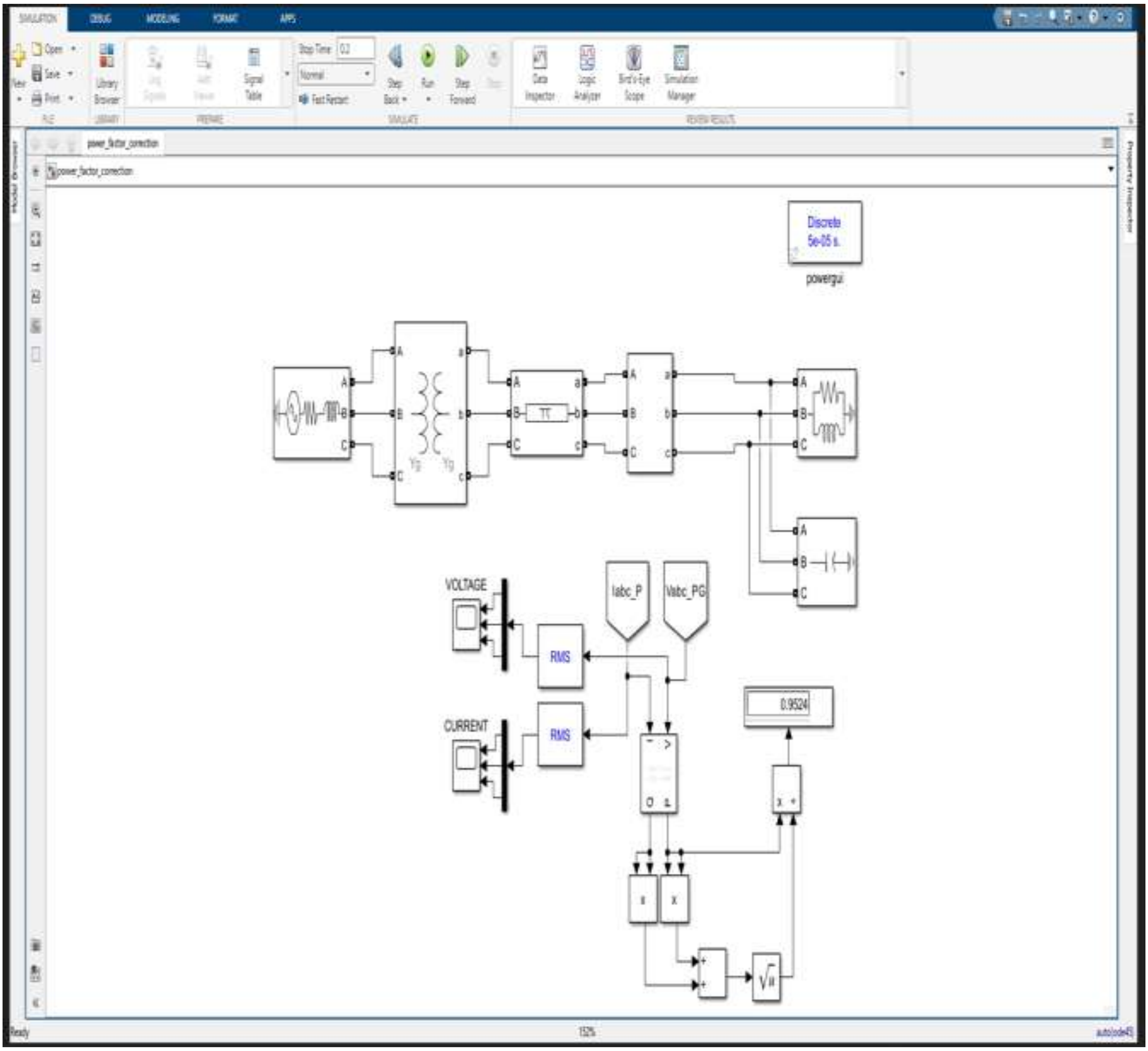

Figure5.1: output power factor (PF) achieved was 0.952.with capecitor

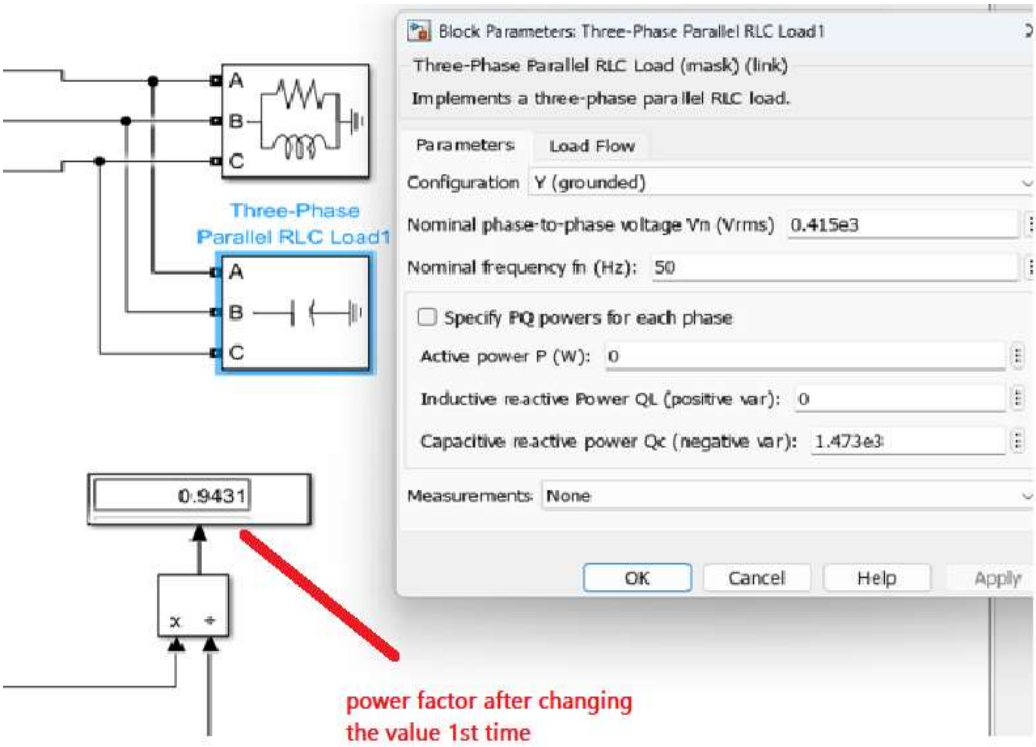

Figure: 5.2 Simulation diagram with capacitor bank capacitor value change

Conclusion

The **MATLAB simulation of passive power factor correction (PFC)** using capacitor banks effectively demonstrated its capability to enhance power factor in electrical systems. The simulation results revealed a notable reduction in the **phase angle between voltage and current waveforms** when appropriately sized capacitor banks were applied. As a result, the system's power factor improved significantly—from initial low values typically between **0.6 and 0.8 lagging** to values approaching unity, achieving between **0.95 and 0.99**.

In addition to the improvement in power factor, the simulation confirmed a **decrease in reactive power (kVAR)** and **apparent power (kVA)** while maintaining the same level of **active power (kW)** demand. This outcome highlights the efficiency of passive PFC in reducing energy losses and enhancing system performance.

Moreover, **harmonic analysis** conducted within the simulation validated that passive power factor correction using capacitors is highly effective for **linear loads**. However, the results also indicated limitations when applied to **nonlinear loads**, where harmonic distortion can reduce the effectiveness of simple capacitor-based correction methods.

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