Power Factor Correction System Using MATLAB With different Loads

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Abstract — Power factor is an important parameter in electrical power systems as it directly affects system efficiency, voltage regulation, and transmission losses. Industrial and commercial electrical loads are predominantly inductive in nature, resulting in a lagging power factor and increased reactive power consumption. Furthermore, load conditions in practical power systems continuously vary, causing fluctuations in the power factor and making conventional fixed capacitor compensation methods less effective. This work presents the design and simulation of an Automatic Power Factor Correction (APFC) system using MATLAB/Simulink under different load conditions. The proposed system is developed to operate with resistive (R), inductive (L), and combined resistive-inductive (RL) loads that change automatically during the simulation process. A measurement unit continuously monitors voltage, current, active power, reactive power, and power factor of the system. Based on the measured power factor, an automatic capacitor bank switching mechanism is implemented to provide the required reactive power compensation. The proposed APFC system dynamically connects or disconnects capacitor banks according to load variations in order to maintain the power factor close to unity. Simulation results demonstrate that the implementation of capacitor bank compensation significantly improves the power factor, reduces reactive power demand, decreases line current, minimizes transmission losses, and enhances voltage regulation. A comparative analysis between uncompensated and compensated systems is carried out to evaluate the effectiveness of the proposed approach. The results confirm that the MATLAB/Simulink-based Automatic Power Factor Correction system provides an efficient and reliable solution for maintaining power quality and improving overall system performance under varying load conditions.

Keywords: Power Factor Correction, Automatic Capacitor Bank Switching, MATLAB/Simulink, Reactive Power Compensation, Different Loads, APFC System, Power Quality

I. INTRODUCTION

Power factor is an important parameter in electrical power systems that indicates how effectively electrical energy is converted into useful work. It is defined as the ratio of real power (kW) to apparent power (kVA) consumed by a load. A higher power factor signifies efficient utilization of electrical energy, whereas a lower power factor indicates the presence of excessive reactive power in the system. Low power factor conditions increase current demand, resulting in higher power losses, poor voltage regulation, and increased operating costs. Therefore, maintaining a power factor close to unity is essential for improving system efficiency, reducing energy losses, and ensuring economical operation of electrical networks.. [1]

A. Importance of power factor correction in electrical systems.

Power Factor (PF) is defined as the ratio of useful or real power (kW) to the total apparent power (kVA) consumed by an AC electrical system. It represents the efficiency with which electrical energy is converted into useful work. An ideal power factor is unity (1), indicating that all the supplied power is effectively utilized. However, when the power factor is less than unity, additional apparent power is required to deliver the same amount of useful power, leading to increased current flow, higher power losses, and reduced system efficiency. Therefore, maintaining a high-power factor is essential for the economical and efficient operation of electrical installations. [3]

Power factor can also be expressed as the cosine of the phase angle between voltage and current in an AC electrical system.

Power Factor= cosθ

Where:

- θ (theta) is the phase angle between the voltage and current waveforms.
- cos θ represents the power factor of the system.
- When the voltage and current are perfectly in phase (θ=0∘)(\theta = 0^\circ)(θ=0∘), the power factor is unity (PF=1)(PF = 1)(PF=1).
- As the phase angle increases, the power factor decreases, resulting in higher reactive power demand and reduced system efficiency.

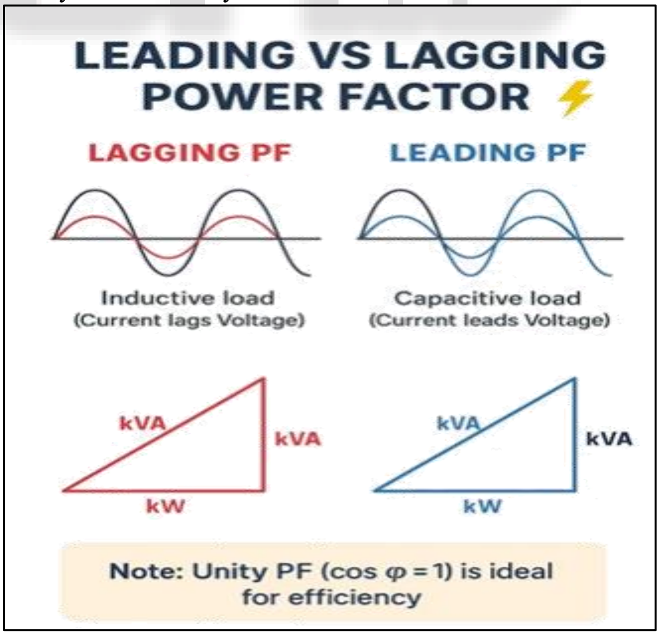

Fig. 1.1: Power factors leading & lagging

B. A Power System

A power system is an interconnected network responsible for the generation, transmission, distribution, and utilization of electrical energy. It serves as the backbone of modern society by delivering electrical power from generating stations to end users in a reliable and efficient manner. The primary function of a power system is to convert various forms of energy, such as thermal, hydro, solar, wind, or nuclear energy, into electrical energy and transmit it to consumers through a coordinated network of equipment and infrastructure.

A typical power system consists of several essential components, including power generating stations, transformers, transmission lines, substations, distribution networks, and consumer loads. Various electrical devices such as synchronous generators, motors, transformers, circuit breakers, protective relays, and conductors work together to ensure the continuous supply of electrical power. Each component performs a specific function that contributes to the overall operation and stability of the system.[11]

C. The power triangle

The power triangle is a graphical representation of the relationship between real power, reactive power, and apparent power in an AC electrical system. It provides a clear understanding of power flow and is widely used in the analysis of power factor and power quality. The power triangle forms the foundation for evaluating the efficiency of electrical energy utilization and determining the reactive power compensation requirements of a system.[12]

D. Combined RL Load (Resistive-Inductive Load)

A Combined RL Load consists of both resistive (R) and inductive (L) components connected within the same electrical circuit. This type of load is one of the most commonly encountered load configurations in modern electrical power systems, particularly in industrial and commercial applications. Equipment such as induction motors, transformers, welding machines, air conditioning systems, pumps, and industrial drives exhibit combined resistive and inductive characteristics during normal operation.

In MATLAB/Simulink-based power factor correction studies, RL loads are frequently used to evaluate the effectiveness of compensation techniques because they closely represent practical industrial loading conditions. By varying the resistance and inductance values, different loading scenarios can be simulated to analyze power factor behavior and the performance of automatic capacitor switching systems.[23]

RL Load Impedance:

Z=R+Jxl   Inductive Reactance:

XL=2πfL_

Power Factor: PF=cos θ

Apparent Power:

$$S = \sqrt{P^2 + Q^2}$$

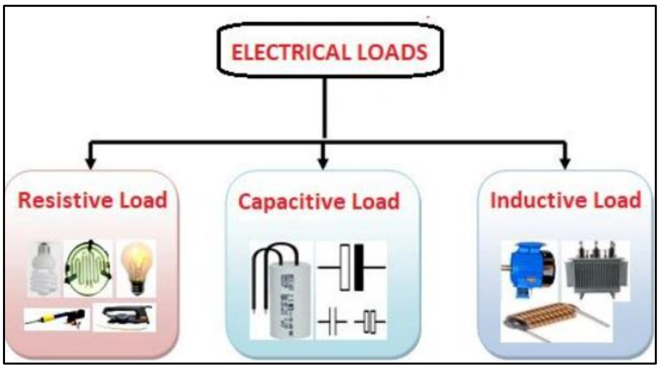

Fig. 1.2: electrical load

II. Literature Review

A. Power Factor Correction System Using MATLAB with Different Loads

Dr. B. Anil Kumar, J. Hima Bindu, B. Shruthi, and Sai Sruthika (2018) proposed a MATLAB/Simulink-based power factor correction system for different electrical loads. The study analyzed the impact of various load conditions on power factor and demonstrated the effectiveness of capacitor bank compensation in improving system performance. The simulation results showed significant improvement in power factor and reduction in reactive power demand. However, the proposed system primarily focused on static load conditions and did not provide an adaptive compensation mechanism for continuously varying loads.[24]

Drawback: The system is not suitable for highly dynamic load variations.

s.no	Title	Candidate details	Drawback/ soltuion
1	Inductive Load power factor Correction using Capacitor Bank	M. Shanmugapriya[1], Aarim C. Sijini[1], Srinivas V. T[2], Karthick M[2], Pavan S[2]. [1]Assistant Professor, Dept. of EEE, Vel Tech High Tech Dr. Rangarajan Dr. Sakunthala Engineering College, Chennai. Publication Year: 2021 [6]	A fixed capacitor cannot accurately track these changes, reducing the efficiency of power factor correction.
2	Power factor correction using capacitors & filters	Karthik Subramanian[1]*, Shantam Tandon[1]. [1]Department of ECE, SRM Institute of Science and Technology, Chennai, India. *Corresponding author E-mail: karthiksubramanian1997@gmail.com. Vol. 7, Issue 2.12, Publication Year: 2018 [2]	Risk of overcompensation leading to leading power factor.
3	Power factor correction system using MATLAB with different loads.	Dr. B. Anil Kumar[1], J. Hima Bindu[2], B. Shruthi[3], Sai Sruthika[4]. [1]Assistant Professor, Dept. of EEE, Malla Reddy Engineering College for Women, Hyderabad. [234]Research Students, Dept. of EEE, Malla Reddy Engineering College for Women, Hyderabad. Vol. 14, Issue 11, Publication Year: 2018 [10]	Not suitable for highly variable loads.

Table 2.1: Literature Review

III. METHODOLOGY

A. *Solution.*

1) *Proposed Methodology*

Problem Identified from Literature

A comprehensive review of the literature reveals that most existing Power Factor Correction (PFC) systems are developed for fixed or constant load conditions. However, in practical power systems, load characteristics are not constant and continuously vary depending on operating requirements. Different types of loads such as resistive (R), inductive (L), and combined resistive-inductive (RL) loads create varying reactive power demands. These load variations lead to continuous changes in the power factor and adversely affect the overall performance of the electrical system. Conventional capacitor compensation techniques are generally designed for static operating conditions and are unable to provide effective reactive power compensation during dynamic load changes. As a result, under-compensation or over-compensation occurs, leading to poor voltage regulation, increased transmission losses, and reduced system efficiency.

2) *Research Gap*

The majority of MATLAB/Simulink-based studies available in the literature focus on power factor correction under fixed load conditions using static capacitor compensation methods. Only limited work has been reported on automatic capacitor bank switching for systems operating under continuously varying load conditions. Furthermore, existing approaches do not adequately address the dynamic reactive power requirements associated with different load types. Therefore, there exists a significant need for an adaptive and automatic power factor correction system capable of responding to load variations and providing appropriate reactive power compensation in real time.

3) *Proposed Solution*

To address the limitations identified in previous studies, a MATLAB/Simulink-based Automatic Power Factor Correction (APFC) system is proposed. The proposed model is designed to operate under different load conditions, including resistive, inductive, and combined RL loads. An automatic capacitor bank switching mechanism is incorporated to continuously monitor the system power factor and provide the required reactive power compensation according to the load demand. The controller dynamically connects or disconnects capacitor banks to maintain the power factor near unity. By implementing this approach, the proposed system minimizes reactive power consumption, reduces transmission losses, improves voltage regulation, and enhances the overall efficiency and reliability of the power system under varying load conditions.

B. *Working*

Three-Phase Source
↓
Different Loads (R, L, RL)
↓
Automatic Load Change
↓
Voltage & Current Measurement
↓
Power Factor Calculation
↓
PF < Reference Value?
↓
Automatic Capacitor Bank Switching
↓
Reactive Power Compensation
↓
Power Factor Improvement
↓
Performance Evaluation

IV. SIMULATION AND ANALYSIS

A. *MATLAB/Simulink Model for Power Factor Correction*

In the present work, two different Power Factor Correction (PFC) configurations are developed and simulated using the MATLAB/Simulink environment to evaluate the effect of capacitor bank compensation under different load conditions.

The first configuration represents the electrical system without capacitor bank compensation, corresponding to the "Before PFC" condition, as illustrated in Fig. 4(a). Under this operating condition, the inductive load draws a considerable amount of reactive power from the source, resulting in a low power factor, higher source current, increased transmission losses, and reduced overall system efficiency.

The second configuration represents the system with capacitor bank compensation, corresponding to the "After PFC" condition shown in Fig. 4(b). In this configuration, a capacitor bank is connected in parallel with the load to provide the required reactive power locally. As a result, the reactive power demand from the supply is significantly reduced, leading to an improved power factor, lower line current, reduced power losses, and enhanced voltage regulation.

The complete MATLAB/Simulink model includes both block diagram and circuit-level implementations, enabling a detailed comparison between the uncompensated and compensated systems. Simulation results are analyzed by comparing important electrical parameters such as power factor, source current, reactive power, active power, apparent power, and system efficiency. The obtained results demonstrate that capacitor bank compensation effectively improves the power factor, minimizes reactive power consumption, reduces line current, and enhances the overall performance of the electrical power system.[10]

Here we used extra methodology in MATLAB 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

This factor used in Matlab in box form

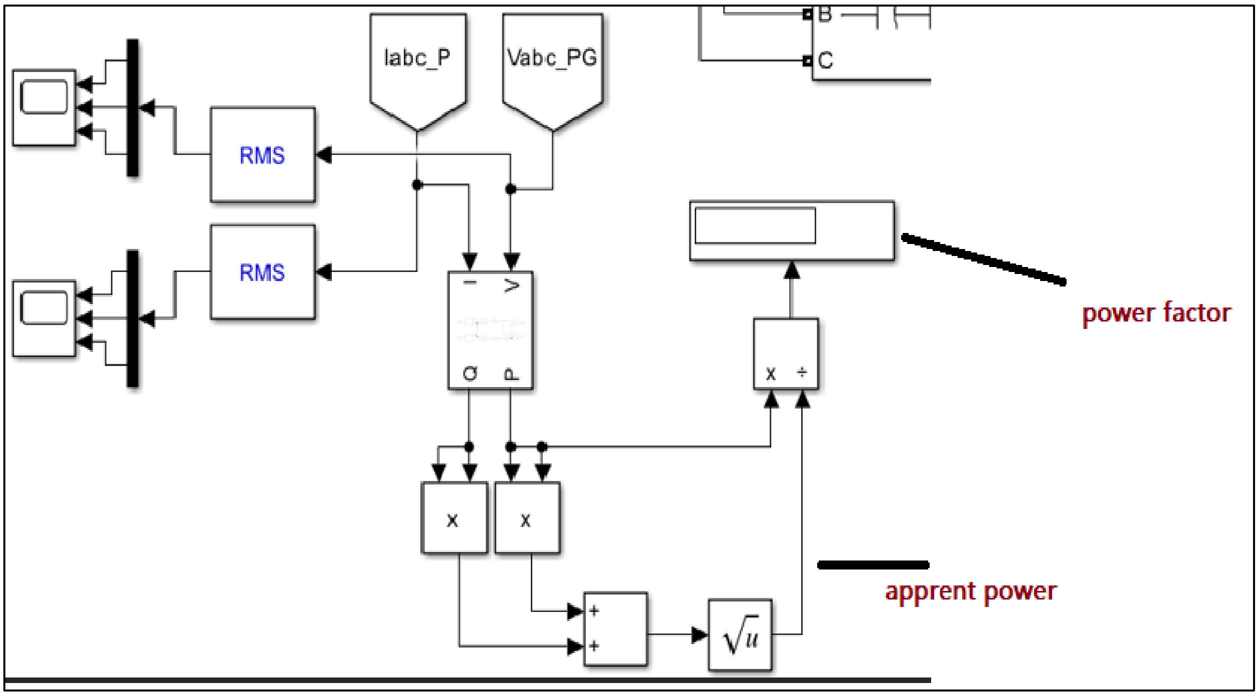

Fig. 4.1: simulation diagram of power factor correction

B. Practical Case Analysis

In simulation described in Chapter 4, the frequency f is fixed at 50 Hz. The capacitor value was adjusted based on changes in reactive power Qc demonstrating the direct proportionality between Qc and capacitance CC.

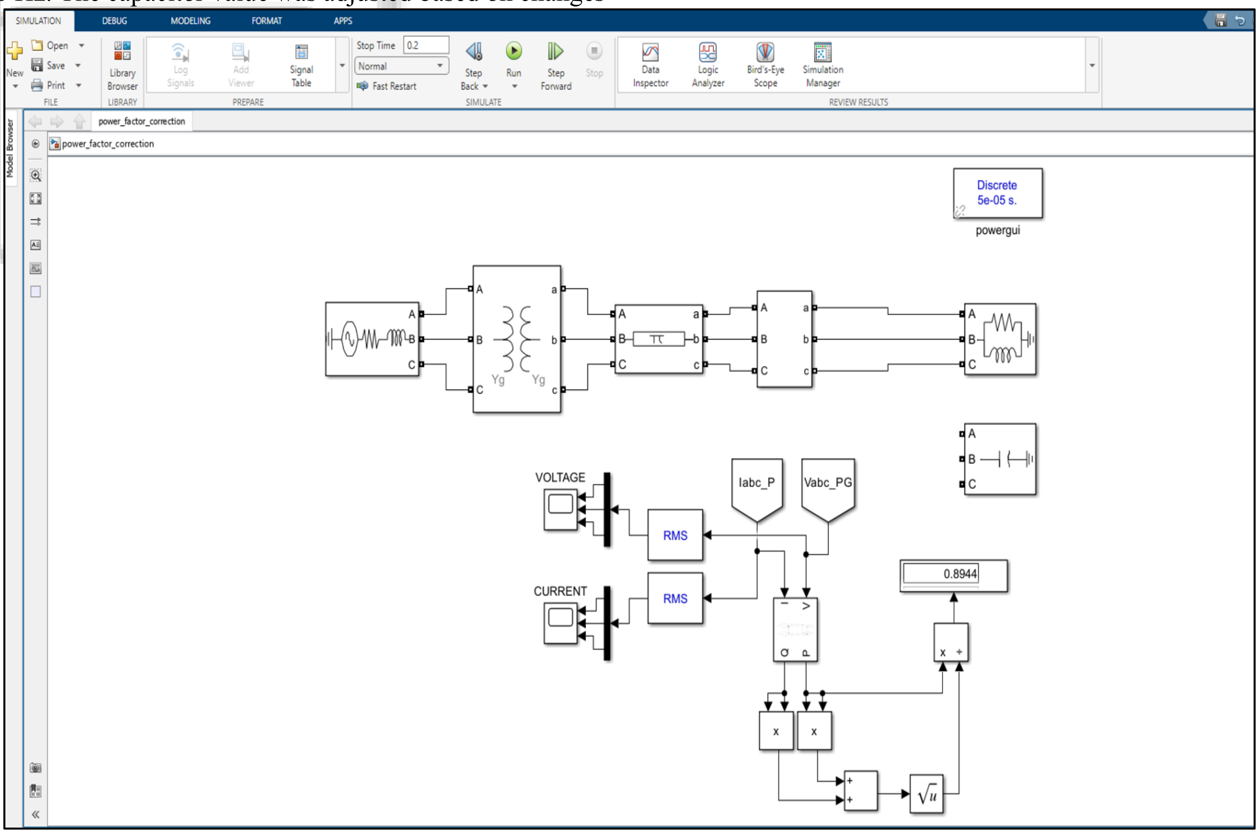

Fig. 4.2: simulation diagram of power factor correction with all

V. Results and Discussion

A. Reactive Power Comparison Before and After Power Factor Correction

Figure 4.1. illustrates the comparison of reactive power before and after the implementation of capacitor bank compensation in the proposed Power Factor Correction (PFC) system. Before compensation, the reactive power requirement is approximately 1.8 kVAR, indicating that the inductive load draws a significant amount of reactive power from the source. This results in a lower power factor, higher line current, increased transmission losses, and reduced overall system efficiency.

After connecting the capacitor bank, the reactive power decreases significantly to approximately 0.4 kVAR. The capacitor bank supplies a major portion of the reactive power locally, thereby reducing the reactive power demand from the supply. As a result, the source current decreases, the power factor improves, and the overall efficiency of the electrical system is enhanced.

The simulation results clearly demonstrate that capacitor bank compensation is an effective technique for minimizing reactive power and improving the performance of the power system under different load conditions.

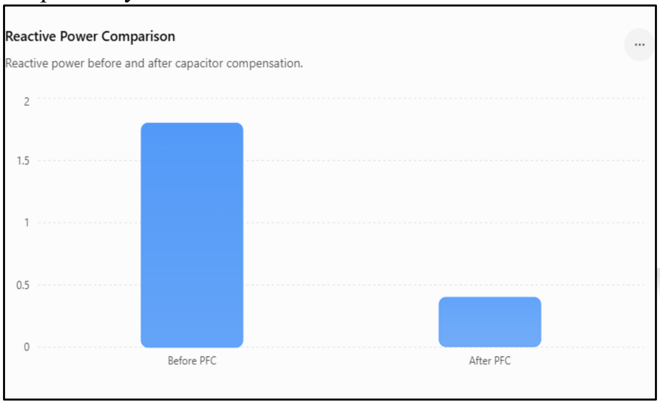

Fig. 5.1: output accepted graph

Load	Power Factor
Resistive	1.00
Inductive	0.82
RL Load	0.88
RL + Capacitor	0.99

Table 5.1: Different Load Conditions

VI. Conclusions and Future Scope

The present work successfully developed and simulated an Automatic Power Factor Correction (APFC) system using MATLAB/Simulink under different load conditions. The proposed system was tested with resistive, inductive, and combined RL loads to evaluate its performance under varying operating conditions. Simulation results demonstrated that load variations significantly affect the power factor and reactive power demand of the system.

An automatic capacitor bank switching mechanism was implemented to compensate for the reactive power requirement according to the load condition. The controller continuously monitored the power factor and connected the required capacitor banks whenever the power factor dropped below the specified limit. As a result, the system maintained the power factor close to unity and reduced reactive power consumption.

The simulation results indicated a considerable improvement in power factor, reduction in line current, minimization of transmission losses, and enhancement of voltage regulation after compensation. Therefore, the proposed APFC system provides an effective solution for maintaining a high power factor under continuously changing load conditions and improving the overall efficiency of electrical power systems.

A. Future Scope

The proposed MATLAB/Simulink-based Automatic Power Factor Correction system can be further enhanced in several ways. In future work, intelligent control techniques such as Fuzzy Logic Controller (FLC), Artificial Neural Network (ANN), and Machine Learning algorithms can be incorporated to achieve faster and more accurate capacitor bank switching. The system can also be extended to three-phase industrial power systems with multiple capacitor bank stages for large-scale reactive power compensation.

Additionally, real-time implementation using microcontrollers, PLCs, or IoT-based monitoring platforms can be developed for practical industrial applications. Renewable energy sources such as solar photovoltaic systems may also be integrated with the APFC system to improve power quality and energy efficiency in smart grid environments. These improvements can further increase system reliability, reduce operational costs, and enhance overall power system performance.

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