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Power Factor improvement of Power System by Sliding Control based Static Compensator

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Abstract

This paper presents an essential aspect of enhancing the reliability of power transmission and distribution networks. Power factor, a vital parameter, plays a pivotal role in determining the system's overall performance. The paper explores the utilization of a Static Compensator in conjunction with a hysteresis mode sliding control technique to optimize power factor. The research begins by providing an understanding of power factor and its significance in electrical systems, the consequences of a low power factor on energy efficiency and system stability. Subsequently, discusses the static compensator and sliding control used in power 3 phase 50 Hz power system. Through simulations in MATLAB/Simulink environment, effectiveness of sliding control-based static compensator in dynamically adjusting reactive power to maintain a unity power factor, even in the presence of variable loads, is demonstrated. The proposed solution enhances power quality of system. This research contributes to the development of more robust and adaptive power systems capable of accommodating the demands of modern power system.

Keywords: Power System, Power factor, power quality, hysteresis mode sliding control technique, variable loads.

1. Introduction

In today's rapidly evolving world, the efficient generation, transmission, and utilization of electrical power are pivotal to sustaining modern civilization. The presence of electrical energy in our daily lives, spanning from domestic applications to industrial processes, underscores the significance of a reliable and high-quality power supply [1]. As the demand for electricity continues to surge worldwide, power utilities and industries face a continuous challenge to ensure that power systems operate efficiently, delivering electrical energy with the highest level of reliability and cost-effectiveness. In this context, one of the enduring challenges encountered in power systems is the management of reactive power, a facet of electricity that is often overshadowed by its more conspicuous counterpart, active power. Reactive power, though not directly contributing to the performance of electrical work, plays a pivotal role in maintaining the stability and voltage levels of a power system [2]. An imbalance in reactive power can lead to voltage fluctuations, equipment overheating, and overall system inefficiency. Thus, the management of reactive power becomes essential to ensure the smooth operation of electrical grids and to minimize energy losses.

The concept of power factor improvement and reactive power compensation is central to addressing these challenges in three-phase electrical systems, which serve as the backbone of most industrial and commercial electrical networks. Within this context, static capacitor-based inverters have emerged as a compelling technological solution [3]. These devices possess the unique ability to either generate or absorb reactive power, making them indispensable for enhancing power factor, regulating voltage levels, and improving overall system efficiency in three-phase systems [4].

The primary focus of this paper is to power factor improvement by reactive power compensation in three-phase systems, with specific emphasis on the utilization of static capacitor-based inverters as a transformative tool to address these multifaceted challenges. This comprehensive exploration aims to investigate the theoretical foundations, practical applications, and the latest technological advancements in the field of reactive power compensation, with a particular focus on the role of static capacitor-based inverters as a catalyst for change [5]. This paper will encompass a thorough investigation into control for effective reactive power compensation using static capacitor-based inverters. Through simulations analyses, it will explore the practical implementation of these devices and evaluate their real-world effectiveness in enhancing the power quality and efficiency of electrical networks.

2. Aim of Power Factor Correction

In the modern landscape, power electronic devices have become important, finding applications in various settings, including Uninterruptible Power Supply (UPS) systems for computers and rapidly changing loads [6]. However, their widespread use has had adverse effects on the quality of electrical energy. Often, the introduction of inductive loads can alter the behavior of the electrical network, leading to unfavorable consequences.

To mitigate these issues, a certain amount of reactive power needs to be injected into the mains to ensure proper network operation. Reactive power compensation is primarily driven by economic considerations. Industrial facilities that generate excessive reactive power must find ways to manage it efficiently. When no compensating devices are integrated into the mains, the responsibility for absorbing the surplus reactive power falls upon the energy supplier, resulting in additional charges to the customer [7].

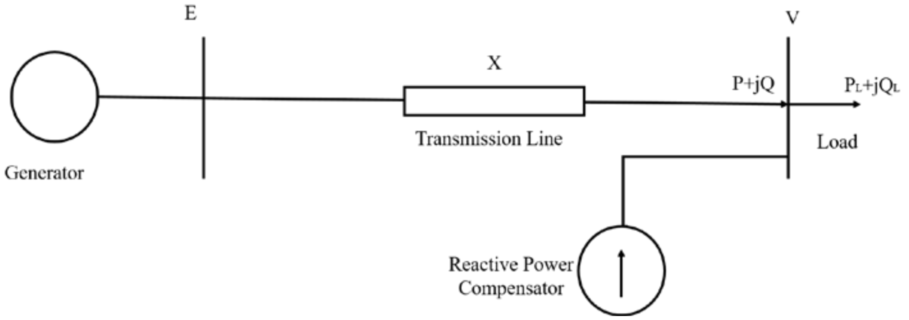

Figure 1: Reactive Power Compensation at the Load Side

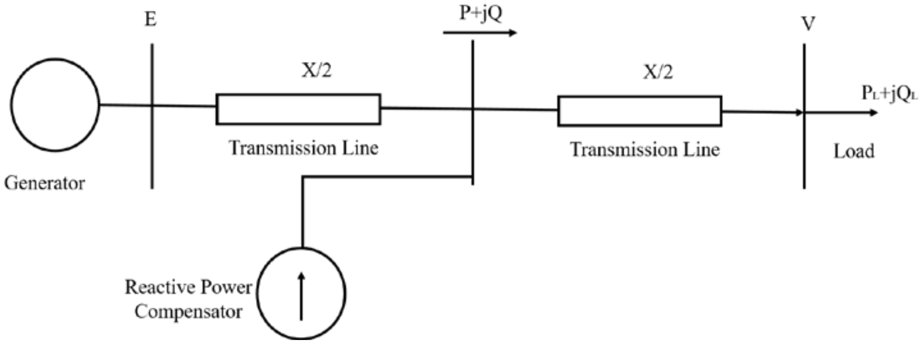

Figure 2: Reactive Power Compensation at the mid-point

3 Power Factor Correction for Fixed Load vs Variable Load

Efficient power utilization is a paramount concern in the realm of electrical engineering, with power factor correction serving as a pivotal strategy to enhance the performance of electrical systems. Power factor correction addresses the apparent power versus real power disparity, aiming to optimize the power factor. However, the approach to power factor correction differs significantly between fixed loads and variable loads due to the distinct nature of these loads. Fixed loads are characterized by their consistent power consumption and power factor under steady-state conditions. Common examples of fixed loads include electric heaters, incandescent lighting, and resistive loads. Power factor correction for fixed loads primarily focuses on maintaining a stable power factor close to unity.

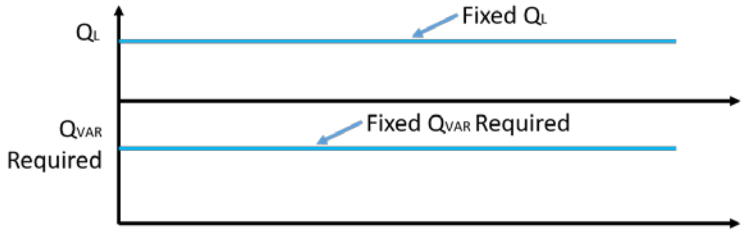

Figure 3: Reactive Power for fixed Q to maintain power factor.

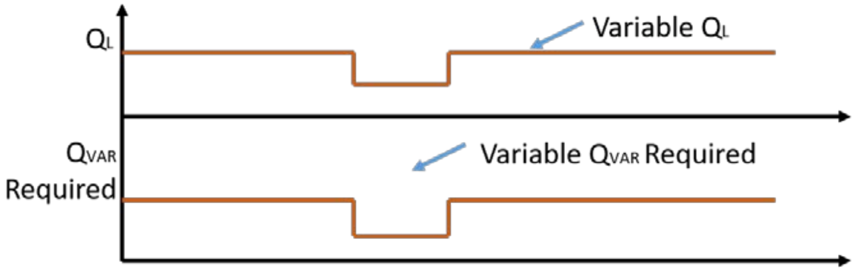

Figure 4: Reactive Power for Variable Q to maintain power factor.

In contrast to fixed loads, variable loads exhibit a dynamic nature, leading to fluctuating power factors as they operate. These loads are prevalent in various industrial and commercial applications and include motors, variable speed drives, and electronic equipment. Power factor correction for variable loads requires a more adaptive and dynamic approach. Adaptive compensation techniques are essential when dealing with variable loads. Power factor correction equipment for variable loads needs to adjust its compensation in real-time to account for changing load conditions. This often involves employing advanced technologies like automatic capacitor banks or static compensators equipped with intelligent controllers [8].

4 Issue with Capacitor bank for Reactive Power Compensation for Variable Load

The control functions of a microgrid can be divided into four main categories: Grid topology Unit, Protection Coordination Unit, Relay Information Unit, and Fault current calculation Unit [9]. Its Functions are listed in Table-1. The operation can be carried out in either a centralized control mode or a decentralized control mode. Safety is a crucial aspect of microgrid protection. Capacitor banks are widely used for reactive power compensation in electrical systems, primarily to improve power factor and reduce energy losses. While they are effective for fixed loads, they can encounter issues when applied to variable loads, such as those found in industrial settings.

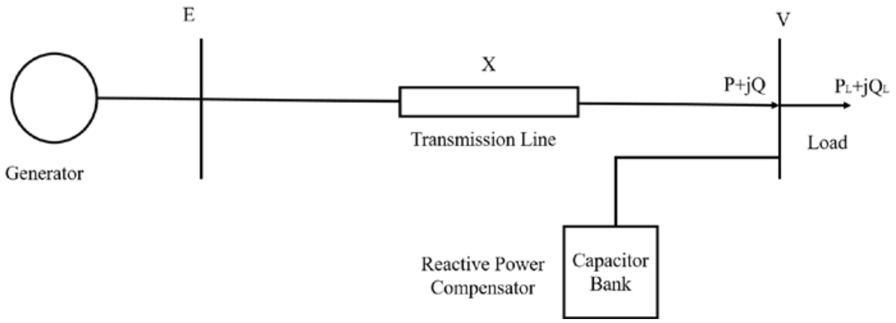

Figure 5: Reactive Power Compensation and power factor improvement by capacitor bank at the Load Side

For the Fixed capacitor required to maintained fixed power factor can be calculated by following equation:

$$Q_{VAR} = P\ \tan\left[\angle\ Power\ Factor_{actual} - \angle\ Power\ Factor_{required}\right] \quad (1)$$

With above formula if the required power factor is 0.95 for the active load of 10 kWand actual power factor of the load is 0.8944. Then the Qvar required can be calculated to 10*tan [cos (0.8944) – cos (0.95)] = 1.472 kVAR.

The above calculation is made to have for static kVAR. So, for dynamic load various capacitor banks have to be configured which is practically not possible. One major issue with capacitor banks in variable load scenarios is the difficulty in maintaining the optimal power factor across a wide range of load conditions. Variable loads, such as motors with varying loads or variable frequency drives, cause fluctuations in the reactive power requirements. Capacitor banks, once installed with fixed ratings, may not be dynamically adjustable to address these changes. As a result, they can either overcompensate or undercompensate, leading to undesirable power factor values.

Another challenge is the potential resonance between the capacitor bank and the inductance inherent in many variable loads. This resonance can create voltage and current distortions, causing harmonic issues in the electrical system. These harmonics can lead to increased losses, reduced equipment lifespan, and diminished power quality, negating the benefits of power factor correction.

Furthermore, safety concerns arise when dealing with capacitor banks for variable loads. Rapid switching of capacitors can lead to voltage transients and inrush currents, posing risks to sensitive electronic equipment and impacting the stability of the power system. To address these issues, modern power factor correction systems for variable loads often employ advanced controllers, such as automatic capacitor banks or static VAR compensators (SVCs). These controllers provide dynamic and real-time adjustment of reactive power compensation, ensuring optimal power factor across varying load conditions while minimizing harmonic distortions and safety risks.

5. Hysteresis based Sliding Mode Control

The hysteresis based sliding mode control (SMC) implementation diagrams is shown in Figure 6. The control system will have blocks as shown and feeds the signal to the plant (the converter circuit as in Figure 7). The input signal r is subtracted with the output y generating the error signal e this is further processes with the discrete function which is function of sample time Ts. which further processed with hysteresis non-linear control stages generating the signal u witch fed to the plan t. since the plant is three phase inverter (as in Fig. 7), the signal u is processed to fed to the SVPWM to generate the switching pulses to the switched present on three arms of the bridge inverter.

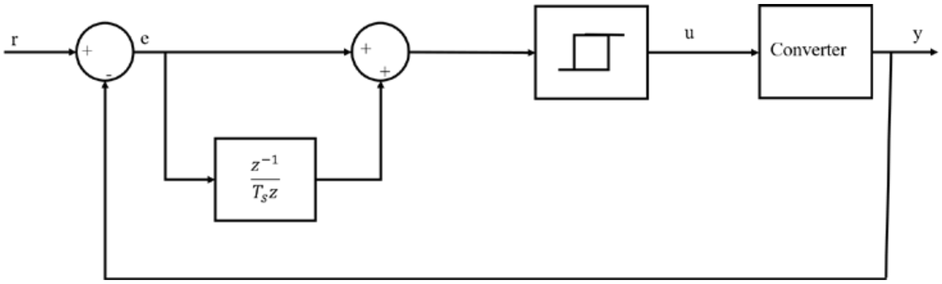

Figure 6: Block diagram of hysteresis based SMC

5. Simulation Model

Simulink diagram in MATLAB of Power system is shown in Figure 7, consisting of source, transmission line of reactance R+jX, Transformer, Load and Static Reactive Power Compensator. The parameter selected is shown in Table I.

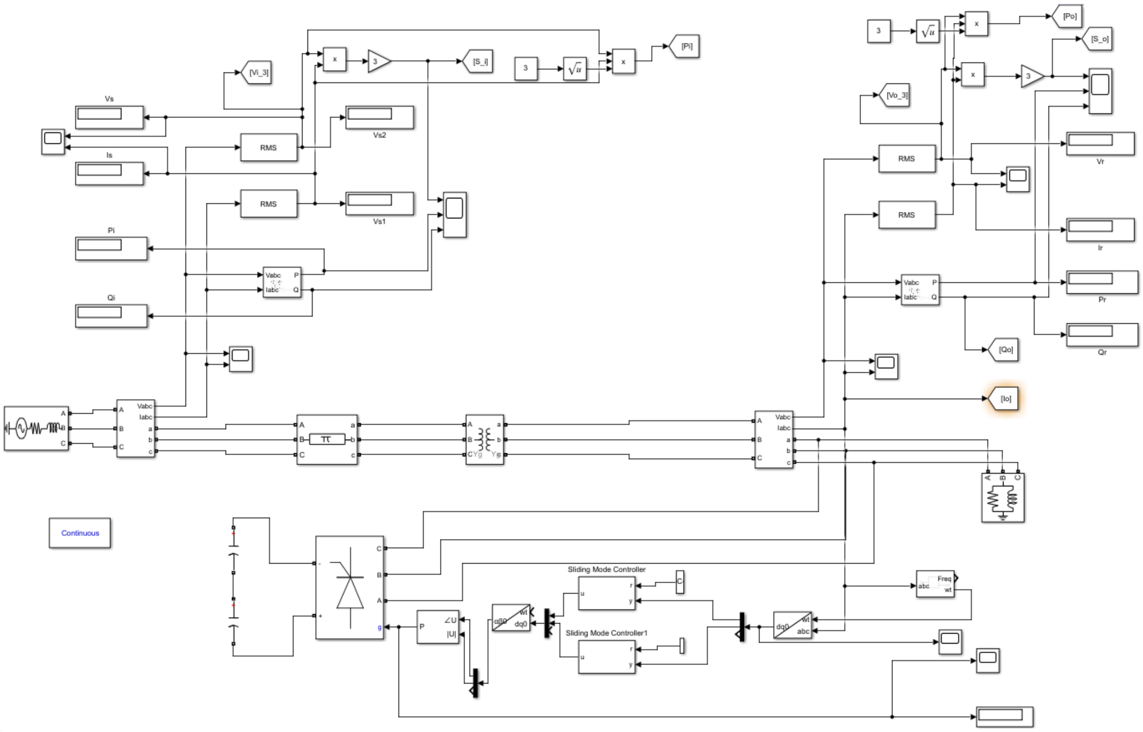

Fig 7 Simulation diagram of three phase system with static compensator

Table I Power System Parameter

Parameters	Value

Source Voltage	11 kV
Frequency	50 Hz
Transmission Line Length	50 Km
Transformer Parameter	25 MVA, 11 kV/415 kV, 50 Hz Primary winding – R1 = 0.002 pu, X1 = 0.08 pu Secondary winding – R2= 0.002 pu, X2= 0.08pu

6. Result

The waveform plots in Figures 8-Figure 11 demonstrate the Power System Active, Reactive, Apparent Power and Power factor waveform under various scenarios. The Simulation is carried out in MATLAB/SIMULINK environment. Figures 7 depict the waveform of the power system when the load in inductive in nature. Due to which the load consumes the reactive power. The power factor (i.e. P.F= R/Z) reduced. This leads power quality issue in the system. More inductive load will reduces the more power factor. For the inductive load which consumes the active power (P) of 10kW and reactive Power (Q) of 7 kVAR have power factor around 0.7139.

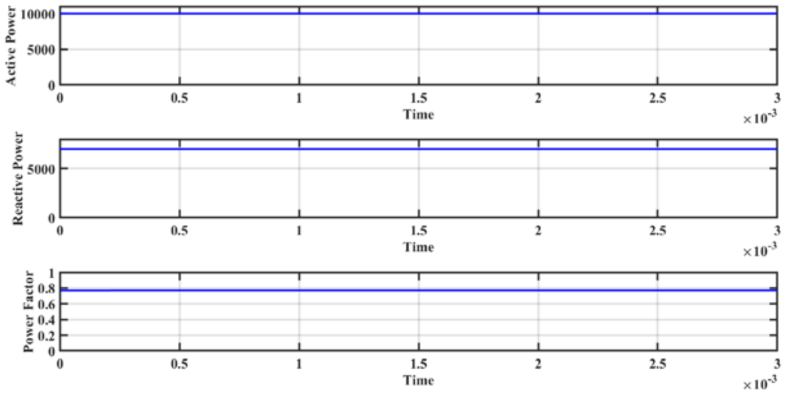

Figure 8 Active Power P, Reactive Power Q and Power Factor without compensation for the load value P= 10 kW, Q= 7 kW. The corresponding power factor is approximately 0.7139.

Figure 9 depict the waveform of the power system when the load is varying at 1 ms and then 2 ms time instant. Since, load is inductive in nature the power factor drops as more reactive power consumed by load and no reactive power compensation provided in the system. Till 1 ms the load is selected that consumes active power of 10 kW and reactive power of 5 kVAR, after 1 ms it changes to 10 kW to 5kW with the reactive power of 8 kVAR to 6 kVAR. The simulation is performed based on these values and power factor is simulated and calculated based on the parameters.

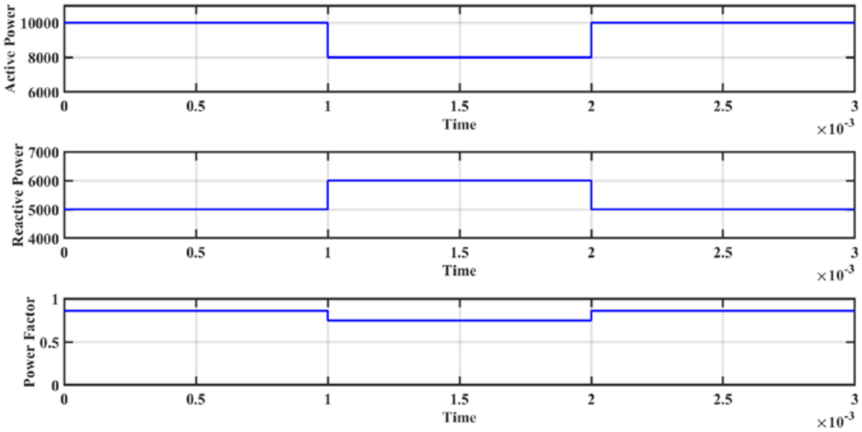

Figure 9 Active Power P, Reactive Power Q and Power Factor without compensation for the variable load value and the corresponding power factor.

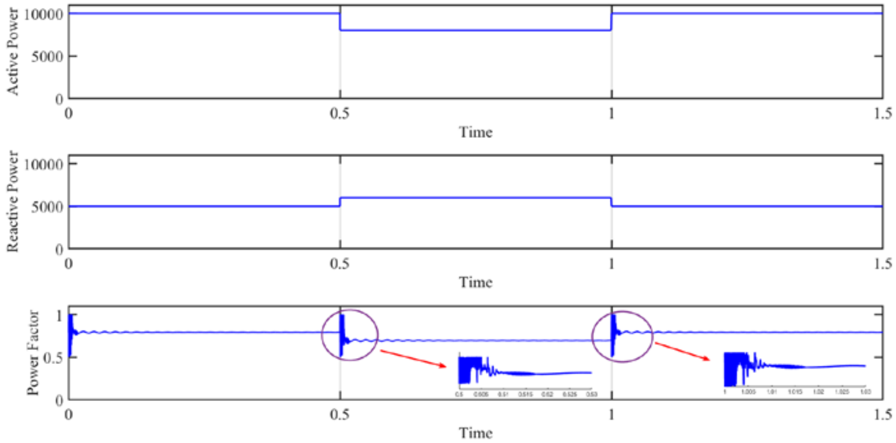

Figure 10 Active Power P, Reactive Power Q and Power Factor with compensator reactive power compensation for the load and the corresponding power factor making operation and attaining stability at finite time.

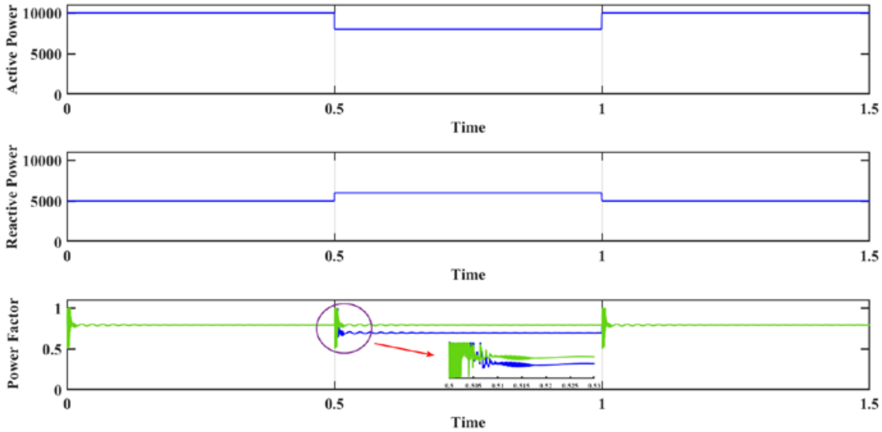

Figure 11 Active Power P, Reactive Power Q and Power Factor with Static Compensator with sliding control reactive power compensation for the load and the corresponding power factor making operation and attaining stability at finite time and uniform power factor.

Figure 10 shows the compensator reactive power compensation for the load and the corresponding power factor making operation and attaining stability at finite time. Figure 11 shows graph with Static Compensator with sliding control reactive power compensation for the load and the corresponding power factor making operation and attaining stability at finite time and uniform power factor.

5. Conclusions

In summary, a simulation to assess the impact of Reactive Power compensation on improving the power factor under varying load conditions was carried out. This simulation offered valuable insights into the system's performance and behavior. The results demonstrate its ability to maintain a stable power factor as the varying load within the power system. Additionally, the simulation emphasized the effectiveness of employing hysteresis based sliding control based static compensator for enhanced stability during transient events. Utilizing MATLAB/Simulink as a simulation platform allowed to model a three-phase AC power system, which included components such as transformers and transmission lines, with the latter represented as a Pi-section for simulation purposes. The inclusion of static capacitors with converters played a crucial role in the operation, contributing significantly to maintaining the desired power quality standards.

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