IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 5, Issue 4, December 2025

Impact Factor: 7.67

Power Factor Correction with Synchronous Condenser for Power Quality Improvement in Industrial Load

H M Elia Sundaram[1], Devaraja[2], J Devaraja[3], Akash Annappa Angadi[4],

Assistant Professor, Electrical and Electronics Engineering, India[1]

Student, Electrical and Electronics Engineering, India[2,3]

Rao Bahadur Y. Mahabaleswarappa Engineering College, Ballari, Karnataka, India

Abstract: *Industrial power systems mainly use inductive loads such as motors, pumps, compressors, welding machines, and transformers. These loads require a large amount of reactive power, which causes the power factor to become low. A low power factor increases the current drawn from the supply. This results in higher transmission and distribution losses, large voltage drops, excess heating of electrical equipment, and reduced system efficiency. It also leads to higher electricity bills and possible penalty charges from power utilities. Poor power factor also affects voltage stability and the reliable operation of industrial equipment. Conventional power factor correction methods using fixed or switched capacitor banks are not suitable for loads that change frequently. These methods may cause over-compensation, resonance problems, and reduced system reliability. To overcome these problems, this project proposes the use of a synchronous condenser for power factor correction. A synchronous condenser is a synchronous motor operating without mechanical load. By controlling its excitation current, it can either supply or absorb reactive power. When over-excited, it supplies leading reactive power to compensate for lagging industrial loads. The proposed system provides continuous and dynamic reactive power compensation, better voltage regulation, reduced power losses, and improved system stability. Thus, using a synchronous condenser significantly improves the power factor, efficiency, and power quality of industrial power systems.*

Keywords: *Power Factor Correction – Improving system efficiency, Synchronous Condenser – Controls reactive power., Power Quality – Quality of power supply., Industrial Load – Heavy inductive equipment., Reactive Power Compensation – Balancing reactive power., Voltage Regulation – Keeping voltage constant., Lagging Power Factor – Current lags voltage.*

I. INTRODUCTION

Industrial power systems use many inductive loads like motors, pumps, compressors, welding machines, and furnaces. These loads need reactive power to work. Because of this, the power factor becomes low. Low power factor causes high current, more power losses, voltage drops, and low efficiency. It also increases electricity bills and can lead to penalty charges from power companies. Electrical equipment may also get overheated and damaged. To improve the power factor, industries use power factor correction methods. One effective method is the synchronous condenser. A synchronous condenser is a synchronous motor without mechanical load connected to the power system. By changing its excitation current, the synchronous condenser can supply or absorb reactive power. When it supplies reactive power, it improves the lagging power factor of industrial loads. Unlike capacitor banks, a synchronous condenser gives continuous and automatic control of reactive power. It helps in maintaining voltage, reducing losses, and improving power quality. Therefore, using a synchronous condenser improves power factor, system efficiency, and reliable operation in industrial power systems.

II. PROBLEM STATEMENT

Industries need a good and stable power supply. Many industrial machines like motors, furnaces, and welding machines are inductive. These machines need reactive power to work. Because of this, the power factor becomes low. Low power factor causes high current, more power loss, and voltage drop. It also increases electricity bills and may lead to penalty charges. Machines may not work properly and can get damaged. To improve the power factor, industries use a synchronous condenser. It is a synchronous motor without load. By changing its excitation, it can give or absorb reactive power. The synchronous condenser helps to improve power factor, maintain voltage, and reduce losses. It also improves system stability. Therefore, it is very useful in industrial power systems.

III. LITERATURE REVIEW

Several studies have focused on improving power quality and power factor in industrial systems using synchronous condensers. Researchers found that traditional capacitor banks provide only fixed compensation and are less effective under variable loads. In contrast, synchronous condensers offer dynamic reactive power control, voltage stabilization, and better system reliability. Many works also highlight their role in reducing losses, enhancing efficiency, and supporting modern power networks integrated with renewable energy sources.

Our Contribution**:**

1. System Design: We designed an industrial power factor correction system using a synchronous condenser.
2. Power Factor Measurement: We implemented real-time sensing of voltage and current to calculate power factor.
3. Reactive Power Compensation: We achieved dynamic supply and absorption of reactive power to maintain unity power factor.

IV. METHODOLOGY

The proposed system is used to improve power factor and power quality in an industrial electrical system using a synchronous condenser. First, a three-phase AC supply (440 V, 50 Hz) is given to the industrial load. The industrial machines are mostly inductive, so when the load changes, the power factor reduces. A power factor sensing circuit continuously measures the voltage and current of the system. Using these values, it finds the power factor. This power factor value is sent to a microcontroller. The microcontroller compares the measured power factor with a reference value (near unity). Based on this comparison, it controls the excitation of the synchronous condenser. If the power factor becomes lagging, the excitation is increased so that the synchronous condenser supplies reactive power. If the power factor becomes leading, the excitation is reduced so that the condenser absorbs reactive power. This automatic control keeps the power factor close to unity even when the load changes. As a result, the power supplied to the load has less losses, stable voltage, and better power quality. Finally, a power quality measurement unit records values like voltage, current, and power factor to confirm the improvement. This method provides a simple, reliable, and energy-efficient solution for industrial power factor correction.

V. WORKING

The proposed system uses a synchronous condenser to improve the power factor and power quality in an industrial electrical system. A three-phase AC supply feeds the industrial load, where the power factor reduces due to inductive equipment. A sensing circuit continuously measures voltage and current to calculate the power factor. This value is compared with a reference using a controller. Based on the result, the excitation of the synchronous condenser is adjusted automatically. This helps in maintaining the power factor close to unity and ensures stable and efficient system operation.

WORKING PRINCIPLE

Step 1: Switch ON the 3-phase main supply.

Step 2: Vary the three phase variac and apply rated voltage in between 380 to 400V.

Step 3: DC Motor starts running with certain speed about 1500RPM.

Step 4: Before the DC excitation the motor acts as an induction motor.

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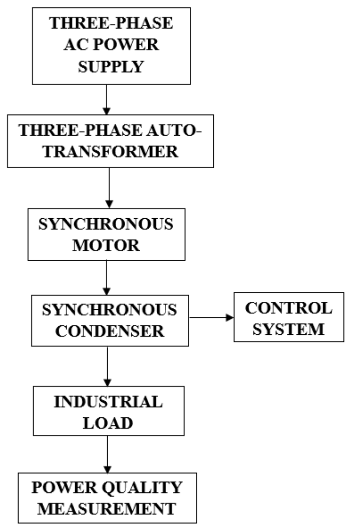
Step 5: Switch on the DC supply, using excitation unit slowly apply the excitation to the DC motor.
Step 6: Soon after getting the excitation, the motor acts as a synchronous motor.
Step 7: Note down the voltage, current and power factor readings under NO LOAD condition, the obtained power factor will be lagging power factor.
Step 8: Gradually apply the Mechanical load on DC Motor in steps and again note down the values of power factor that also lagging.
Step 9: By adding the Capacitive load gradually, note down the values of power factor and observed that, slowly the power factor increases and becomes leading.
Step 10: Hence, power factor is improved from lagging to leading by using capacitive load.

VI. BLOCK DIAGRAM



COMPENTS USED
1. Three-phase AC Power supply
2. Three-phase Auto-Transformer
3. Synchronous Motor
4. Synchronous Condenser
5. Control system
6. Industrial Loads
7. Power Quality Monitoring Unit

VII. COMPONENTS DESCRIPTION

Three-phase AC Power Supply

The power supply provides the main three-phase AC voltage (440 V, 50 Hz) to the entire industrial system. It acts as the primary source of electrical energy that feeds both the industrial load and the synchronous condenser setup. The supply delivers active and reactive power through transmission lines, ensuring continuous operation of all connected equipment. A stable and reliable power supply is essential to maintain proper system performance and efficiency.

Three-phase Auto-transformer

The three-phase auto-transformer is used to regulate and control the voltage levels between the supply and the motor. It can either step up or step down the input voltage as per the system's requirements. This ensures that the synchronous motor receives the correct voltage for smooth starting and efficient operation. The auto-transformer also helps reduce current surges during motor starting, protecting both the supply system and connected equipment. By maintaining a stable voltage, it improves the reliability and performance of the entire power correction setup.

Synchronous Motor

In this system, it serves as the base machine for the synchronous condenser. When the mechanical load is removed and the motor is over-excited, it operates as a condenser, supplying leading reactive power to the system. This ability makes it suitable for maintaining the desired power factor and voltage levels in the network.

Synchronous Condenser (Capacitive Load)

A capacitive load is an electrical load in which the current leads the voltage by 90 degrees. It stores energy in the form of an electric field between capacitor plates and releases it back to the circuit when required. Such loads supply reactive power to the system, helping improve the power factor and regulate voltage. Examples include capacitor banks and over-excited synchronous condensers. In power systems, capacitive loads are mainly used for power factor correction and voltage stabilization, ensuring efficient and reliable operation of electrical networks.

Control System

The control system monitors the power factor, voltage, and current of the supply using sensors. It compares the measured power factor with a reference value and adjusts the excitation of the synchronous condenser accordingly. When the system power factor falls below the desired value, the control unit increases the excitation to supply more reactive power. This automatic control ensures consistent power factor correction without manual intervention, making the operation more efficient and stable.

Industrial Load

The industrial load consists of various machines such as induction motors, transformers, welding units, and compressors, which draw inductive current from the supply. This inductive nature causes the current to lag behind the voltage, leading to a poor power factor. Such loads demand more reactive power and can affect voltage regulation. By using a synchronous condenser, these negative effects are minimized, and the load operates more efficiently with improved voltage stability.

Power Quality Measurement

The power quality measurement unit continuously records important electrical parameters such as voltage, current, power factor, and harmonics. It helps in analysing the performance of the power factor correction system and ensures that the desired power quality is maintained. This unit also verifies the effectiveness of the synchronous condenser in providing dynamic compensation, reducing line losses, and improving overall system efficiency.

VIII. ADVANTAGES

1. **Improved Power Factor:** Maintains power factor close to unity by controlling reactive power.
2. **Better Voltage Regulation:** Maintains stable voltage during load variations.
3. **Reduced Transmission Losses:** Reduces current flow and minimizes I^2R losses.
4. **Low Maintenance:** Requires minimal maintenance due to robust design.
5. **Extended Equipment Life:** Protects equipment from voltage fluctuations and overheating.

IX. LIMITATIONS

1. **High Initial Cost:** Installation cost is higher compared to capacitor banks.
2. **Large Size:** Requires more space due to its rotating machine structure.
3. **Skilled Operation Needed:** Needs trained personnel for operation and control.
4. **Mechanical Losses:** Has losses due to friction and windage in rotating parts.
5. **Slower Than Static Devices:** Response is slower compared to electronic VAR compensators.

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X. CONCLUSION

This project demonstrates that the use of a synchronous condenser is an effective solution for improving power factor and power quality in industrial power systems. By supplying or absorbing reactive power according to load requirements, it maintains the power factor close to unity and ensures stable voltage conditions. This results in reduced power losses, improved system efficiency, and reliable operation of industrial equipment. Compared to conventional capacitor banks, the synchronous condenser provides smooth and dynamic compensation under varying load conditions. Therefore, the proposed system offers a reliable, efficient, and practical approach for achieving better energy utilization and enhanced power system performance in modern industries.

XI. FUTURE SCOPE

In the future, synchronous condensers are expected to play a bigger role in improving power factor and voltage stability in modern industrial power systems. With the growth of smart grids, they can be integrated with advanced digital controllers for automatic and accurate reactive power control. The use of IoT and SCADA systems will allow remote monitoring and real-time performance analysis. Synchronous condensers can also be combined with capacitor banks, STATCOMs, or energy storage systems to provide faster and more efficient compensation. Additionally, their importance will increase in supporting renewable energy systems such as solar and wind power. Overall, future developments will focus on improving efficiency, reducing size, enhancing dynamic response, and ensuring better grid stability and power quality.

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ABOUT AUTHOR

	Name – Mr H M Elia Sundaram Designation-Assistant professor M.Tech (Electrical Power systems) Rao Bahadur Y Mahabaleswarappa Engineering college Email ID- eliasundaram@gmail.com
	Name – Devaraja Designation- Student USN – 3VC22EE017 Phone Number –7019311673 E-mail id – devaraja.eee.rymec@gmail.com
	Name- J Devaraja Designation-Student USN –3VC22EE028 Phone Number –8310277331 E-mail id – jdevaraja.eee.rymec@gmail.com
	Name- Akash Annappa Angadi Designation- Student USN- 3VC22EE002 Phone Number-6363327667 E-mail id – akashannappaangadi@gmail.com