Automatic Power Factor Monitoring and Improvement

Ms..Kasturi Tupe[1], Mrs. Ashwini Khade[2]
[1,2]Department of ElectricalEngineering, VES PolytechnicMumbai, India

***Abstract* - This paper presents a comprehensive approach for the automatic monitoring and improvement of power factor in electrical networks. The proposed system integrates real-time monitoring techniques with intelligent control algorithms to continuously assess the power factor status and implement corrective actions as necessary. Initially, the system employs sensors and meters to collect relevant data on voltage, current, and power factor across the network.**

INTRODUCTION

In the current scenario, it has been observed that power is very prized for all and demand of power is always high. The electric power system has grown and complexity with a huge number of interconnections to meet the increase in electric power demand. The use of more inductive load results in a lagging power factor i.e. the system power factor gets poor, due to access of reactive power consumed by inductive load such as induction motors which increases the reactive losses. Also, the reactive power consumption causes the reduction of voltage and power factor in networks. In most power systems, a poor power factor results from the increased usage of inductive loads is often unnoticed. A power factor correction unit would allow the system to restore its power factor close to unity for economical operation. Simple methods include switching in or out banks of capacitors or inductors which act to cancel the inductive or capacitive effects of the load, respectively. The advantages of correcting power factors include reduced power system losses, increased load carrying capabilities, improved voltages etc.

The aim of this project is to build an automatic power factor correction (APFC) unit, which can monitor the energy consumption of a system and automatically improve its power factor. The APFC unit calculates the reactive power consumed by a system's inductive load and compensates the lagging power factor using capacitance from a capacitor bank.

(POWER FACTOR)

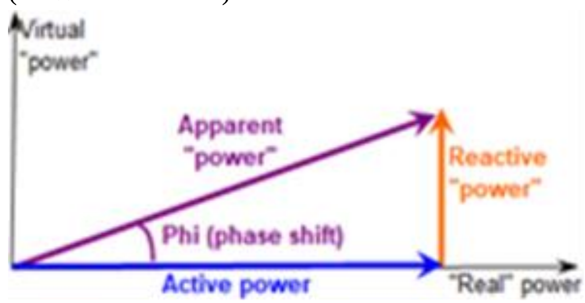

Fig.1 Power Factor Triangle

APFC or Automatic Power Factor Control Panels are are predominantly used for sustainment of Power Factor as per State Electricity Board. Power Factor is defined as ratio of active power to apparent power and it is mainly a key factor in measuring electrical consumption. Therefore it becomes very much important to reduce on electrical consumption for reducing expenditure and economizing the utility expenses by harnessing electrical utility by operation at desired power factor to curtail unwanted electricity penalty rising because of continuous power factor drop. Power factor is the difference between voltage and current sine waves, often expressed as a percentage. The industry standard is for generators to be rated at a 0.8 power factor, meaning it can handle a load of that magnitude. It is found by multiplying (kilovolt Ampere = Volt x Ampere). The result is expressed as kVA units. Power Factor reflects the ratio of true power used in a load circuit to the apparent power delivered to the load circuit. A 96% power factor demonstrates more efficiently than a 75% power factor. If the currents leads the voltage (greater phase angle than voltage) then the power factor is termed leading (capacitive load).

METHODS OF IMPROVING POWER FACTOR

a) Phase advancers
b) Synchronous condenser
c) Static Capacitor bank

a) PHASE ADVANCERS

Phase advancers are devices utilized in induction motors to enhance power factor, which is the ratio of real power (in kW) to apparent power (in kVA). They address the inherent inefficiencies of induction motors, where the power factor tends to be less than unity due to the lagging current drawn by the motor's inductive nature.

1. Phase Advancers Principle: Phase advancers are typically comprised of a capacitor bank connected in series with an auxiliary winding. The capacitor bank introduces a leading current component into the rotor circuit, compensating for the lagging current caused by the motor's inductive reactance.
2. Leading Current Generation: The capacitor bank, when energized, generates a leading voltage across it. This leads to the flow of a leading current in the auxiliary winding.
3. Magnetic Field Interaction: The current flowing through the auxiliary winding produces a magnetic field in the rotor. This magnetic field interacts with the rotating magnetic field from the stator, causing the rotor to advance in phase.
4. Improved Power Factor: By advancing the phase of the rotor current, the overall power factor of the motor is enhanced. The leading current component introduced by the capacitor bank effectively offsets the lagging current in the rotor windings, bringing the power factor closer to unity.
5. Efficiency and Performance: With a higher power factor, the motor operates more efficiently, reducing losses and improving performance. This results in energy savings and may also lead to an increased lifespan of the motor. In essence, phase advancers serve to mitigate the lagging power factor inherent in induction motors by introducing a leading current component into the rotor circuit. This leads to improved efficiency, reduced power consumption, and enhanced performance of the motor.

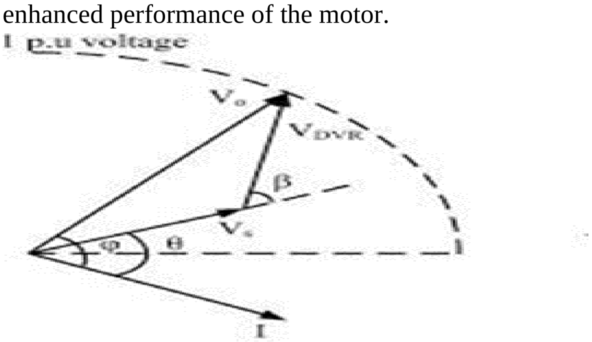

Fig.2. Phasor Diagram of Phase Advancers

b) SYNCHRONOUS CONDENSER

Synchronous condensers are integral components in electrical systems aimed at enhancing power factor, operating on the principle of synchronous motors but devoid of mechanical loads. Their role lies in injecting or absorbing reactive power to adjust the system's power factor to desired levels.

These machines are characterized by their ability to dynamically respond to changes in system conditions, making them effective for real-time power factor correction. By regulating field excitation, synchronous condensers can precisely control the amount of reactive power injected into the system, thereby compensating for the reactive power drawn by inductive loads. Moreover, synchronous condensers offer a cost- effective solution for power factor correction, especially when compared to static compensation devices like capacitors. Their seamless integration into existing power systems and capability to synchronize with the grid make them an attractive choice for utilities and industrial applications alike.

In industrial settings with substantial inductive loads, such as steel mills or mining operations, synchronous condensers play a crucial role in optimizing power factor and minimizing losses.

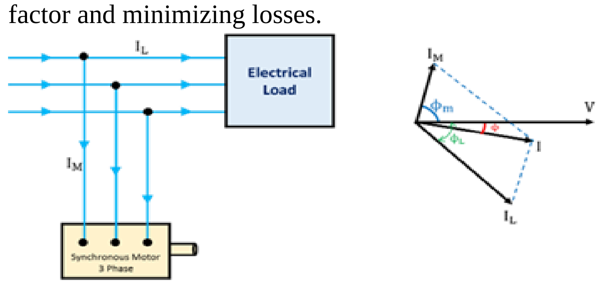

Fig.3 Basics of Synchronous Condensers

c) STATIC CAPACITORS

The capacitors are connected in parallel with the equipment to improve the power factor of the system operating at a lagging power factor. The capacitors draw the leading current and partly or completely neutralizes the lagging reactive component of current.

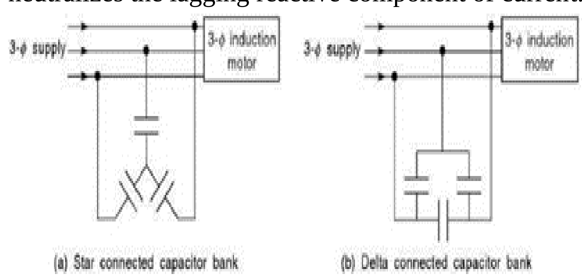

Fig.4. Static Capacitors

Need of APFC Unit

APFC panels are preferred over static capacitors, synchronous condensers, and phase advancers due to their dynamic response capabilities, efficiency, and space-saving design. Unlike static capacitors, APFC panels can adjust power factor in real-time, ensuring optimal correction under fluctuating loads. They are also more cost- effective in terms of initial investment and maintenance compared to synchronous condensers or phase advancers. Furthermore, it offer automation features for remote monitoring and control, enhancing operational convenience. Their flexibility allows for easy integration into existing power distribution systems and scalability as per changing requirements. With robust reliability and safety features, APFC panels provide a secure operating environment while ensuring compliance with regulatory standards and utility requirements related to power factor correction. Overall, APFC panels offer a comprehensive solution for efficient power factor correction in industrial and commercial applications.

PROPOSED METHODOLOGY

Firstly, a thorough analysis of the electrical system is conducted to assess the existing power factor, load characteristics, and energy consumption patterns. This analysis helps determine the required capacity and configuration of the APFC panel system. Next, the design phase involve selecting appropriate components such as capacitors, reactors, control devices, and monitoring equipment based on the analysis results. Factors such as system voltage levels, harmonic mitigation strategies, safety standards compliance, and integration with existing infrastructure are carefully considered during this phase. Once the design is finalized, the implementation phase begins with the installation of the APFC panel system. This involves physical mounting of components, wiring connections, and integration with the existing electrical distribution network. Commissioning and testing procedures are then carried out to ensure proper functionality and performance. Following installation, the management phase involves ongoing monitoring and maintenance of the APFC panel system. This includes regular inspections, tuning of capacitor banks, monitoring of power factor and other performance parameters, and addressing any issues or anomalies that may arise during operation. Additionally, training and capacity building for operators and maintenance personnel are essential to ensuring effective management of the system.

Throughout the methodology, adherence to relevant standards and regulations, as well as coordination with stakeholders such as electrical contractors, equipment suppliers, and utility providers, is crucial to the success of the APFC panel implementation. By following this systematic methodology, organizations can optimize power quality, enhance energy efficiency, and ensure there reliable operation of their electrical systems with APFC technology.

CIRCUIT DIAGRAM

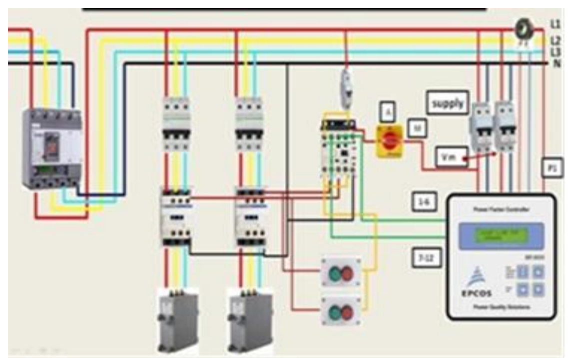

Fig 5. Circuit diagram of APFC Unit

WORKING MAIN COMPONENTS REQUIRED

Sr.No.	Component	Specification	Quantity
1.	Capacitor	2 kVAR & 3 kVAR	2
2.	Contractor switch	4 kVAR	1
3.	APFC Relay	Digital Voltmeter Digital AmmeterPower factor meter Relay	1
4.	3 Digital True RMS Dual AC Meter	Voltmeter: 0-500 V Ammeter: 0-20 Amp	1
5.	MCBs	4 pole MCB 32 Amp 3 pole MCB 32 Amp	1 2
6.	CDC Display	7.5 kVAR	1
7.	Selecting switches		2
8.	Indicators		3
9.	Indicators		3

The Circuit diagram of the project is shown in the figure. Starting with capacitor bank, the capacitor bank, rated at 3 kVAR & 2 kVAR, is connected in parallel with the motor load. The control circuitry includes a contractor switch and APFC relay for controlling the connection of the capacitor bank based on the power factor requirements.

Initially, when the motor is started, the power factor may be lagging due to the inductive nature of the motor load. The capacitor senses this lagging power factor through the contractor switch. The relay continuously monitors the current and voltage waveform phase difference, indicating the power factor. When the power factor drops below a certain threshold (usually set to improve efficiency, e.g., 0.95), the relay switch triggers the control circuitry. The control circuitry energizes the contactor, connecting the capacitor bank in parallel with the motor load. By connecting the capacitor bank, the reactive power drawn by the motor is compensated, thereby improving the power factor towards unity. If the motor load changes or other factors affect the power factor, it dynamically responds by adjusting the capacitor bank to maintain the desired power factor level. When the motor is stopped or the load changes significantly, and the power factor rises above the threshold, the control circuitry de- energizes the contactor, disconnecting the capacitor bank.

- CONTRACTOR:

The control circuitry continuously monitors the power factor of the electrical system. This monitoring can be done using sensors such as current transformers (CTs) and voltage transformers (VTs). Based on the power factor readings, the control circuitry determines whether the capacitor bank needs to be connected or disconnected to correct the power factor. When the control circuitry detects a lagging power factor (indicating the need for capacitive reactive power to improve the power factor), it sends a signal to activate the single-phase contractor. The activation signal energizes the electromagnetic coil within the single-phase contractor. Energizing the coil creates a magnetic field, which pulls the movable contacts of the contractor towards the stationary contacts. As a result, the contacts of the single-phase contractor close, allowing the capacitor bank to be connected in parallel with the electrical load. When the control circuitry detects that the power factor has been sufficiently corrected, or if the load conditions change, it sends a signal to deactivate the single- phase contractor. Deactivation of the contractor causes the contacts to open, disconnecting the capacitor bank from the electrical system

The APFCR (Automatic Power Factor Correction Relay) is an essential component in an Automatic Power Factor Correction (APFC) system. It is responsible for monitoring the power factor of an electrical system and controlling the connection of capacitors to correct the power factor as needed. Here's a breakdown of the components typically found in an APFCR:

- Power Factor Meter: This component measures the power factor of the electrical system. The power factor indicates how effectively electrical power is being utilized. A lower power factor indicates inefficient use of power, often due to inductive loads such as motors or transformers.
- Ammeter: An ammeter measures the current flowing through the electrical system. It helps to assess the load on the system and determine whether reactive power compensation is necessary.
- Voltmeter: A voltmeter measures the voltage across the electrical system. Voltage fluctuations can affect the power factor, so monitoring voltage helps ensure accurate power factor correction.

- Relay: The relay in the APFCR is responsible for controlling the connection of capacitors to the electrical system based on the measurements from the power factor meter, ammeter, and voltmeter. When the power factor falls below a predetermined threshold, indicating a lagging power factor, the relay triggers the connection of capacitors to compensate for the reactive power and improve the power factor.

- Digital TRUE RMS DUAL AC METER

The dual AC meter configuration allows simultaneous monitoring of two separate electrical parameters, such as voltage, current, or power, across all three phases. This capability is particularly beneficial in APFC panels where monitoring both active power and reactive power is necessary for effective power factor correction. By continuously monitoring these parameters, the APFC system can dynamically adjust capacitor banks to compensate for reactive power, thus improving the power factor and maximizing the efficiency of the electrical system.

- MCBs

MCB, or Miniature Circuit Breaker, is a fundamental component in electrical systems providing essential protection against overloads and short circuits.

MCBs are compact devices designed to fit into distribution boards, consumer units, or electrical panels. They serve as automatic switches that interrupt the flow of electricity when abnormal conditions occur in a circuit. The primary function of an MCB is to protect electrical circuits from two common faults. The MCB protects the electrical circuit from excessive currents that could potentially damage the wiring, components, or the single-phase motor itself.

If the current flowing through the circuit exceeds the rated capacity of the MCB, it trips and interrupts the flow of electricity, thereby preventing overheating and potential fire hazard

In the event of a short circuit, where a sudden and significant increase in current occurs due to a fault in the circuit, the MCB quickly detects the abnormal current flow and trips to disconnect the circuit. This rapid interruption of current flow helps to prevent damage to the electrical equipment and reduces the risk of electrical fires. By incorporating a single-phase MCB in the APFC panel, the overall safety and reliability of the electrical system are enhanced.

The MCB provides a convenient and effective means of protecting the circuit against faults, ensuring the smooth and uninterrupted operation of the single-phase motor and associated equipment.

• CDC (CAPACITOR DUTY CONTRACTOR)

The contractor duty capacitor rated at 7.5 kVAR in the APFC panel for a three-phase motor is to provide robust and reliable reactive power compensation, optimize system efficiency, The contactor duty capacitors are specifically designed to handle the switching transients and inrush currents associated with capacitor switching applications. Upon receiving the signal from the APFC relay, the respective contactor duty capacitor contactors close their contacts, connecting the selected capacitors to the electrical system in parallel with the motor load. The higher rating of the contractor duty capacitor (7.5 kVAR) means fewer capacitors need to be switched in parallel to achieve the desired reactive power compensation. This reduces the frequency of switching operations on the contactors, minimizing wear and tear on the contactor components and prolonging their lifespan.

Assembly of Panel:

- The main incoming power supply lines are connected to the four-pole MCB (Miniature Circuit Breaker) for overall protection against overcurrent and short circuit
- The capacitor bank comprises capacitors rated at 3 kVAR and 5 kVAR, along with a contractor duty capacitor rated at 7.5 kVAR.
- These capacitors are connected in parallel to provide reactive power compensation and improve the power factor of the electrical system.
- A double-pole MCB is installed to provide protection for the capacitor circuits, ensuring their safety during operation.
- The control circuitry includes an APFC relay, which monitors the power factor of the three- phase electrical system.
- Three-phase contractor duty contactors are employed to switch the capacitor bank in and out of the circuit as directed by the APFC relay
- Current transformers (CTs) and voltage transformers (VTs) are used to provide input signals to the APFC relay, allowing it to monitor the current and voltage levels of the electrical system.
- These monitoring devices enable the APFC relay to determine the power factor and activate the appropriate capacitors for reactive power compensation.
- The components are interconnected using appropriate wiring and connections, ensuring proper electrical continuity and integrity.
- Terminal blocks are used for easy and organized termination of cables.
- All components, wiring, and connections are properly.

CAUSES OF LOW POWER FACTOR

1. Inductive Loads: Certain electrical devices, like motors and transformers, cause delays between voltage and current due to their magnetic properties. This delay results in a low power factor.
2. Imbalanced Electricity Usage: When electrical loads aren't spread evenly across different phases, it creates an imbalance that reduces the overall efficiency of power usage, leading to a low power

factor. Faulty Equipment: Malfunctioning devices like motors or transformers can draw more power than necessary, disrupting the balance between voltage and current and leading to a low power factor.

3. Harmonics from Electronic Devices: Devices like computers or electronic equipment can introduce "extra noise" into the electrical system, disrupting the smooth flow of power and lowering the power factor.

4. Failure of Power Factor Correction Equipment: Sometimes, the equipment meant to correct the power factor, like capacitors or relays, might not work as expected, which can result in a low power factor.

5. Spikes in Power Demand: Certain equipment that demands a lot of power quickly can cause sudden fluctuations in the power supply, impacting the power factor negatively.

ADVANTAGES OF HIGH POWER FACTOR

1. Efficient Use of Electrical Power: High power factor indicates that electrical power is being used efficiently without wasting energy.
2. Reduced Energy Costs: Improved power factor results in reduced energy losses, leading to lower electricity bills for consumers.
3. Increased System Capacity: Higher power factor allows electrical systems to handle more loads without overloading, maximizing system capacity.
4. Improved Voltage Stability: A high power factor helps maintain stable voltage levels, preventing voltage fluctuations that can affect sensitive equipment.
5. Reduced Line Losses: High power factor reduces losses in transmission and distribution lines, improving overall system efficiency.
6. Optimized Equipment Performance: Electrical devices operate more efficiently and last longer when operated at a high power factor, reducing maintenance costs.

FUTURE SCOPE

Automatic Power Factor Correction (APFC) panels is promising, marked by advancements in technology and a growing focus on energy efficiency. These panels are poised to undergo significant development and expansion across various fronts. One prominent direction is the integration of APFC panels with smart grid systems, enabling real-time monitoring and control of power factor correction. This integration promises more dynamic and efficient management of electrical power across the grid. These advancements could enable remote monitoring, predictive maintenance, and optimization algorithms based on real-time data analysis, thereby enhancing their functionality. The scope of a project focused on Automatic Power Factor Correction (APFC) panels. It encompasses a wide range of objectives and activities aimed at optimizing power quality and energy efficiency industrial and commercial electrical systems. Implementation of the APFC panel involves installation, commissioning, and testing procedures to ensure proper functionality and performance.

The scope of a project focused on APFC panel is multifaceted, encompassing analysis, design, implementation, and management activities aimed at optimizing power quality, enhancing energy efficiency, and ensuring the reliable operation of industrial and commercial electrical systems.

CONCLUSION

Automatic power factor correction techniques can be applied in industries, commercial lines and power distribution system to increase stability and efficiency of the system. Care should be taken so that the capacitors are not subject to rapid on off-on conditions as well as overcorrection otherwise the lifespan of capacitor bank decreases significantly. The APFC device helps to pull in high current drawn from the system and reduce charges on utility bills. A reduced power consumption results in lower greenhouse gas emissions and fossil fuel depletion by power stations and would benefit the environment. The implementation of an APFC panel has demonstrated its significant impact on improving power factor efficiency within the electrical system. By dynamically adjusting and controlling reactive power, the panel effectively minimizes wastage and enhances overall system performance. This not only results in reduced electricity consumption but also contributes to cost savings and environmental sustainability. Furthermore, the APFC panel offers a reliable solution for maintaining power quality, ensuring smooth operation of electrical equipment, and mitigating penalties associated with poor power factor. As such, its integration stands as a prudent investment for industries and facilities seeking to optimize their energy utilization and reduce operational expenses.

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