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Design of an Automatic Power Factor Correction Panel

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Abstract

A low power factor leads to inefficient energy use, higher utility bills, energy losses, and equipment strain, often resulting in penalties from utility companies. Maintaining a power factor close to unity reduces costs and improves efficiency. APFC panels automate power factor correction by monitoring voltage and current, dynamically switching capacitor banks to compensate for reactive power, eliminating manual errors, and enhancing response time.

Keywords: : Power factor, Capacitor bank, Reactive power compensation, APFC panel, Power quality, Electrical Protection, Control Measurement and Monitoring.

1. Introduction

In today's industrial and commercial scenarios, efficient utilization of electrical power is crucial due to increasing demand and the rising complexity of power systems. Most industrial infrastructures rely on inductive loads, such as transformers and motors, which result in a lagging power factor due to excessive reactive power consumption. A low power factor indicates inefficiency, causing higher energy losses, voltage drops, and additional utility charges. To address these challenges, power factor correction is employed by compensating a lagging current with a leading current using capacitors. Automatic Power Factor Correction (APFC) panels play a vital role in this process by dynamically monitoring and improving the power factor. These systems measure the power factor from line voltage and current, calculate reactive power requirements, and automatically adjust capacitor banks to maintain an optimal power factor, typically close to unity. This reduces reactive power circulation, minimizes transmission losses, enhances system efficiency, and prevents penalties imposed by utility providers. The integration of microcontroller-based embedded technology in APFC systems ensures precise, real-time control, making them an indispensable solution for modern power management. The penalties and losses associated with a low power factor in an electrical system result in increased costs and energy waste. A low power factor indicates inefficient use of electrical power, leading to higher utility bills and greater energy loss as heat in wires and equipment, which in turn causes them to work harder and increases operational costs. An Automatic Power Factor Correction (APFC) panel effectively addresses these issues by optimizing the overall efficiency and stability of the electrical system. By automatically adjusting capacitance to match the load, the APFC panel ensures correct voltage and frequency alignment, minimizing the risk of equipment damage. The panel is designed with precise sizing and capacity, facilitating accurate power factor correction while preventing overloading and promoting energy efficiency. With user-friendly interfaces and simplified operation and maintenance features, the APFC panel also enhances training and operational readiness among personnel, providing a reliable, efficient, and compliant solution for improving power factor and overall electrical system performance.

2. Materials

Current Transformer-A current transformer (CT) is used to measure the current flowing through the inductive load. It works by stepping down the high current from the main power lines to a smaller, more manageable level that can be safely measured by the APFC system. CTs are installed in series with the load. As current flows through the load, it also passes through the primary winding of the CT. This induces a secondary current that is proportional to the primary current.

Ratio- 20/1

Controller- An automatic power factor control relay is a device that regulate the power factor in the electrical system. It used to control the flow of electricity and maintain a good power factor. It monitors the power factor level and regulate the capacitor bank, minimize energy loss and waste and help to maintain a good power factor. First it senses the reactive load then automatically triggered the capacitor bank to maintain the power factor at the desired level.

Rating-

Phase- Single Phase, Model No.- BR-4000 ER, Power Consumption- 200W, Type- Automatic, Steps- 4 Steps

Zero Crossing Detector- the ZCD converts the AC waveform into a digital signal by detecting the moments when the voltage or current waveform crosses the zero reference point. The ZCD outputs a pulse at each zero-crossing point, which is sent to the APFC's microcontroller. The microcontroller uses these pulses to determine the phase difference between the voltage and current, which is crucial for calculating the power factor. By comparing the zero-crossing of voltage and current, the system identifies whether the power factor is leading or lagging and adjusts the capacitor banks accordingly.

Fuse: Fuse is an electrical safety device that operates to provide overcurrent protection of an electrical circuit. Its essential component is a metal wire that melts when too much current flows through it.

Rating-

Current Rating- 6A

Miniature Circuit Breaker-The MCB continuously monitors the current flowing through the APFC system. If the current exceeds a predefined threshold (due to an overload or fault), the MCB automatically trips, disconnecting the circuit to prevent damage to components like the microcontroller, capacitor banks, and transformers. Once the fault is cleared, the MCB can be reset manually to restore normal operation.

Rating-

Current Rating- 16A

Number of Poles- 3

Contactor-The controller sends signals to the contactor, which uses an electromagnetic mechanism to open or close its contacts. When the contactor is energized, it closes the circuit, connecting the capacitor bank to the system. When de-energized, it opens the circuit, disconnecting the capacitor bank. This switching helps adjust the reactive power and improve the power factor.

Rating-

Voltage Rating- 415V

Current Rating- 9A

Capacitors -Inductive loads (like motors) cause the current to lag behind the voltage, resulting in a poor power factor. Capacitors generate reactive power in the opposite direction, causing the current to lead, which offsets the lag caused by the inductive load. When switched into the circuit by the APFC system, capacitors reduce the phase difference between voltage and current, improving the power factor closer to unity.

Rating-

Phase- 3phase

kVAR- 1kVAR & 2kVAR

Current Rating- 2.4A to 4.8A

3. Simulation

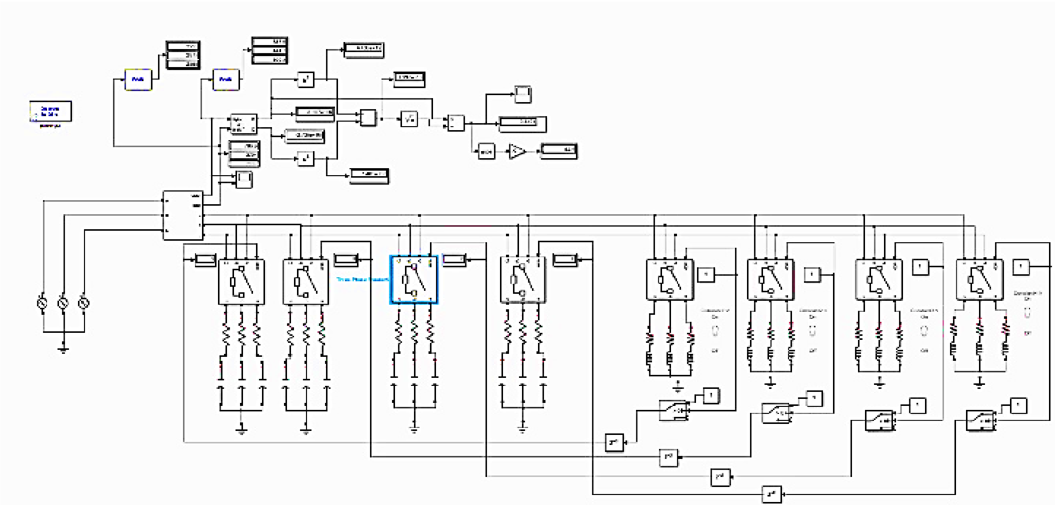

Figure.1. Before turning on the capacitor bank our power factor is lagging

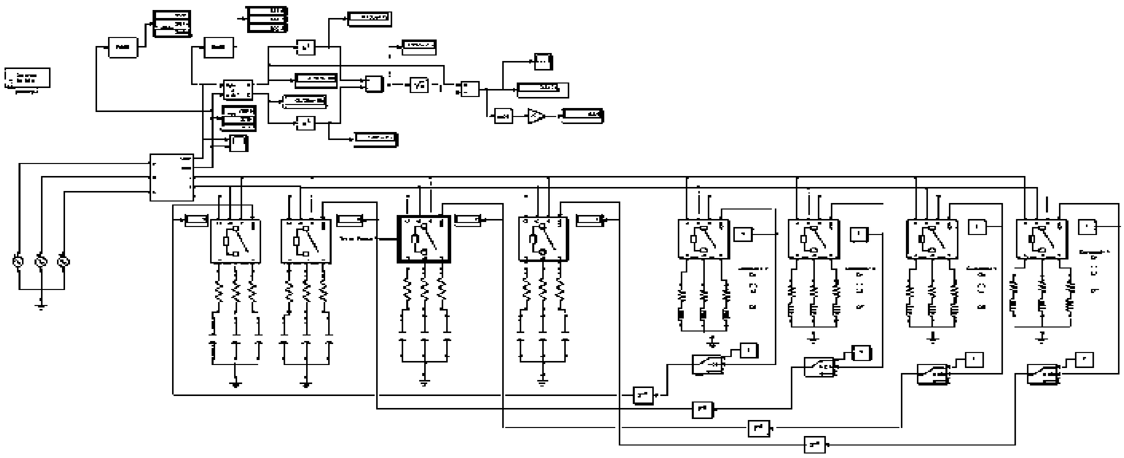

Figure.2. Before turning on the capacitor bank our power factor is near to unity

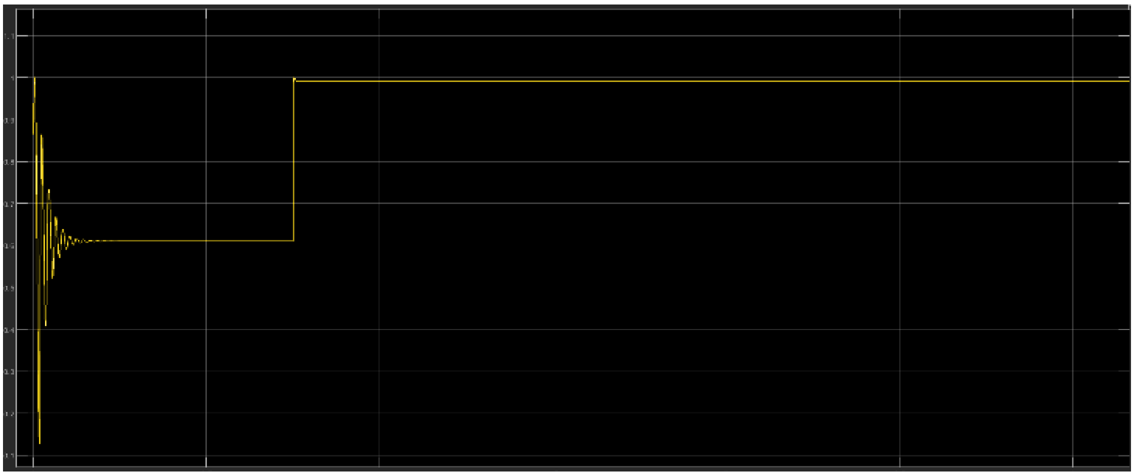

Figure.3. Response

4. Testing Methods

4.1. For Reactor

HV Test- It ensures its insulation integrity and performance under operation conditions key tests include the power frequency with stand test, lighting and switching impulse test, partial discharge measurement includes over voltage test This test verify the reactor ability to handle voltage stresses, detect insulation defects, and insure reliable operation.

Voltage Test- A voltage test for a reactor checks its insulation strength and insure safe operation under high voltage. It includes the power frequency withstand test, where a high AC voltage is apply to check the insulation and the impulse voltage test which simulates lighting and switching surges.

Continuity and Wiring Check- Verify all electrical connections as per wiring diagram check proper functioning of contactors, fuses.

Functional Testing- power factor setting in controller. Test manual capacitor Ensure correct voltage supply and proper boot up of the panel. Verify correct polarity and placement for accurate power factor correction. Set required switching and automatic correction.

Load Test- Run the panel under actual load condition. Check capacitor switching as per reactive power demand. Measure power factor before and after APFC activation.

5. Results and Discussions

Figure.4. Before turning on the capacitor bank our power factor is 0.896

Figure.5. Before turning on the capacitor bank our current is 5.2A

Figure.6. After turning on the capacitor bank our Power factor is 0.977

Figure.7. After turning on the capacitor bank our current is 1.3A

6. Calculations

Given

Connected load=3HP

Capacitor=1,2kVAR

Current Rating=5Amp

Voltage Rating=440V

Formula

1. TotalkVAR=MultiplyingFactor*Connected load
2. kVA=3Vph*Iph
3. Calculations for phase difference and cos ϕ
4. Time difference (Δt)=t1-t2
5. Phase Shift (φ)= 2πΔt/T
6. In Degree=0.6911*180/π
7. Q = P·tan(cos−1(PF))
8. Q compensation=Q initial – Q final

7. Conclusions

Automatic Power Factor Correction (APFC) panels monitor continuously and adjust the reactive power in electrical systems to optimize power factor and improve energy efficiency. When the power factor drops below a set threshold, the APFC panel activates capacitors to inject reactive power, counteracting inductive loads and bringing the power factor back to acceptable levels. The power factor correction device designed was able to improve the power factor under the test load conditions with the proper amount of reactive power compensation, the system capacity is released as there is a reduction in current drawn.

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