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Innovative Problem Solving for Power Factor Improvement

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ABSTRACT--Advancements in power electronics technology have created opportunities for the exploitation of renewable sources in various configurations. However, the power quality of AC systems has become a major concern in recent years due to the significant increase in electronic equipment, power electronics, and high-voltage power systems. Large electrical loads in commercial and industrial installations are often inductive in nature, resulting in a lagging power factor that can lead to heavy penalties for consumers from electricity boards. To address this issue, power factor correction (PFC) can be used to absorb the reactive power produced by a load. While switching capacitors manually can correct the power factor for fixed loads, it becomes challenging for rapidly varying and scattered loads. This challenge can be overcome by using an Automatic Power Factor Correction (APFC) panel. In this paper, power factor measurement from the load is achieved using an ESP32 microcontroller, and the necessary energy is feeded through battery to compensate for reactive power and bring the power factor closer to unity.

KEYWORDS*:* power facor correction, ESP32 microcontroller, Reactive power compensation.

I.INTRODUCTION

Power factor improvement is a critical aspect of electrical power systems, as it directly impacts the efficiency and reliability of the power supply. A low power factor can result in increased energy losses, reduced system efficiency, and additional costs for both utilities and consumers. Therefore, finding innovative problem-solving approaches to improve power factor is of great importance.

In this context, there are several cutting-edge techniques and technologies that can be employed to address the challenge of power factor improvement. These include Active Power Factor Correction (APFC) techniques that utilize advanced control algorithms and high-speed switching devices, smart grid solutions that integrate communication, control, and monitoring technologies, energy storage systems such as batteries or capacitors, advanced power electronics devices such as multilevel inverters or STATCOMs, load management techniques, and the use of artificial intelligence (AI) and machine learning (ML) for data analysis and decision-making.

Reactive power compensation plays a crucial role in ensuring the smooth functioning of electrical power systems, particularly in industrial and commercial settings where inductive loads are common. Without proper compensation, reactive power can cause voltage drops, equipment malfunctions, and increased energy costs.

II. PROPOSED SYSTEM

The topology of the proposed reactive power compensation system is shown in Fig.1. It consists of an IHQRR at the front-end, a full bridge dc/ac inverter at the back-end, a battery charger/discharger, and a battery bank. The boost integrated flyback rectifier/energy storage dc/dc (BIFRED) converter, which is part of the IHQRR, consists of a DCM boost converter. The controlled dc link voltage from the output capacitor of the BIFRED features voltage source function for both the inverter and bidirectional dc/dc converter. The dc/ac inverter consists of a dc-link bus capacitor Cout, switches SI1 to SI4, and an output low-pass LC filter. It operates in a high frequency pulsewidth modulation (PWM) pattern to provide a high quality sinusoidal output voltage. The charger/discharger is a bidirectional dc/dc converter, which consists of switches S1b and S2b as well as a dc inductor Lb. The switch S2b cuts the high dc-link voltage Vdc and steps it down to low battery voltage Vbat during the normal operating mode and charges the battery bank. Therefore, it eliminates problems associated with the high battery voltage such as space, cost, reliability, and safety issues. During the energy-stored mode, the Boost converter steps up the low battery voltage Vbat to high dc-link voltage for proper operation of the back-end inverter.

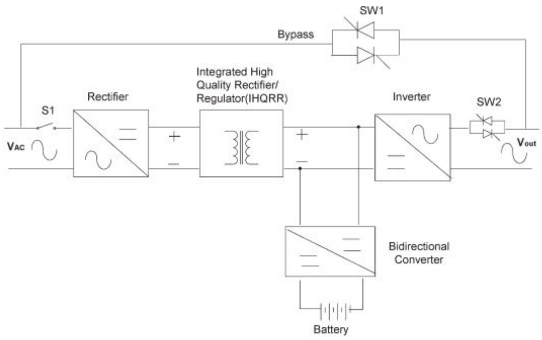

Fig 1:Configuration of the proposed system

III. PROBLEM STATEMENT

Many electrical systems suffer from a low power factor, resulting in increased energy consumption, reduced system efficiency, and additional costs. Traditional power factor correction methods lack real-time monitoring and control, leading to suboptimal power factor correction. Complex load behaviors require adaptive response for effective power factor improvement. Limited integration with smart grid solutions hinders system performance. Insufficient data analytics and decision-making capabilities limit the optimization of power factor performance. Innovative approaches utilizing the capabilities of the ESP32 microcontroller are needed to address these challenges and provide efficient and effective solutions for power factor improvement.

IV. METHODOLOGY

The block diagram for reactive power compensation using batteries consists of several components including a supply, comparator, battery, inverter, current and voltage sensors, load, and a microcontroller (such as the ESP32). The supply provides power to the system, while the comparator compares the grid voltage and current with a reference value to determine the reactive power demand of the grid. The battery serves as the energy storage component and stores electrical energy, charging or discharging based on the demand determined by the comparator. The inverter converts the DC voltage from the batteries into AC voltage that is synchronized with the grid, and controls the flow of power between the batteries and the grid to compensate for the reactive power demand and maintain power quality. The current and voltage sensors measure the grid and battery parameters, providing feedback to the microcontroller for monitoring and control of the system. The load represents the electrical load connected to the grid that requires reactive power compensation. The microcontroller, such as the ESP32, acts as the main control component, implementing control algorithms and making decisions on the operation of the batteries and inverter to optimize the reactive power compensation. Overall, this methodology involves monitoring the grid parameters, determining the reactive power demand, controlling the batteries and inverter, and compensating for the reactive power demand of the grid to maintain power quality and stability.

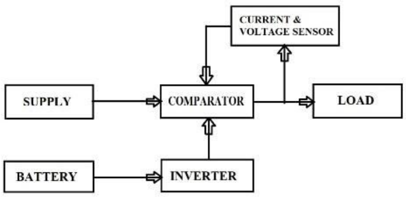

Fig 2: Block diagram of reactive power compensation

V. FUNCTIONAL PARTITIONING

The project comprises two components: Hardware and Software. The ESP32 Microcontroller was utilized in this project, and as a result, the Arduino IDE was used. The hardware components employed in the project are listed below.

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1. ESP32 Microcontroller

The ATmega328 microcontroller is integrated into the Arduino UNO board, which serves as a versatile platform for developing and implementing projects that require microcontroller functionality. The board features 14 digital input/output pins, with 6 of them being analog input pins. Additionally, it has a power jack, a USB connector, a reset button, an ICSP header, and other necessary components that enable its operation and utilization in a project.

2. ZMCT103C AC Current Sensor

The ZMCT103C AC current sensor module is a small and low-cost device used for non-invasive current sensing applications. It can measure AC currents up to 5A and provides a proportional output voltage that is linearly related to the current. The module includes a ferrite core, a primary winding, a secondary winding, a load resistor, a potentiometer for output voltage adjustment, and an LED indicator for status. It is typically interfaced with a microcontroller or other processing device to measure and process the output voltage.

3. ZMPT101B AC Voltage Sensor

The ZMPT101B AC voltage sensor module is a small and low-cost device used for non-invasive voltage sensing applications. It can measure AC voltages up to 250V and provides a proportional output voltage that is linearly related to the voltage being measured. The module includes a transformer, a primary winding, a secondary winding, a load resistor, a potentiometer for output voltage adjustment, and an LED indicator for status.
It can be calibrated to match the specific voltage range.

4. 12V Lithium-Ion battery

An 18650 battery is a lithium-ion battery. The name derives from the battery's specific measurements: 18mm x 65mm. The 18650 battery has a voltage of 3.6v and has between 2600mAh and 3500mAh. They have a high energy density, meaning they can store a lot of energy in a small size and weight. They should be handled and stored carefully to prevent overheating, short-circuits, and explosions, as they contain flammable and hazardous materials.

5. Inverter

An inverter circuit is an electronic circuit used to convert DC power into AC power. The circuit uses electronic switches, such as transistors or MOSFETs, to rapidly switch the DC power on and off, creating a high-frequency AC waveform. The waveform is then filtered and shaped to produce a clean sine wave, square wave, or modified sine wave output suitable for powering AC loads. Inverter circuits are used in a wide range of applications, including power backup systems, renewable energy systems, motor drives, and uninterruptible power supplies. Efficiency is an important consideration in inverter design, as high-efficiency circuits use advanced switching techniques to minimize power losses and maximize efficiency. The inverter circuit is an essential component of many modern electrical systems, providing a reliable and efficient means of converting DC power into AC power.

6. Ardino Uno

The Arduino Uno is a microcontroller board based on the ATmega328P microcontroller that is widely used for building electronics projects in robotics, automation, and other areas of electrical engineering. It features 14 digital input/output pins, 6 analog inputs, a 16 MHz quartz crystal, a USB connection for programming and power, and can be powered by a USB connection, an external power supply, or a battery. The Arduino software provides a simple and intuitive interface for writing and uploading code to the board, making it an ideal platform for hobbyists and students learning about electronics and programming. Overall, the Arduino Uno is a versatile and affordable microcontroller board that has become a standard in the electronics industry.

7. LCD Display

An LCD (Liquid Crystal Display) display is a type of visual display that uses liquid crystal molecules to control the amount of light that passes through it. They are commonly used in electronic devices such as calculators, watches, and digital cameras, as well as in industrial and automotive applications. LCD displays have several advantages over other display technologies, including low power consumption, high contrast, and a wide viewing angle. They can be controlled by a microcontroller and can display a variety of information, making them a versatile and widely used technology that has changed the way we display information in electronic devices.

V. ADVANTAGES

- Voltage stabilization: Reactive power compensation using batteries can help stabilize voltage levels in power grids or microgrids.By compensating for reactive power with batteries, voltage fluctuations caused by reactive power can be mitigated, ensuring a stable and reliable power supply.

- Improved power factor: Power factor is a measure of how efficiently electrical power is used. A low power factor means that a significant portion of the power drawn from the grid is reactive power, which increases the strain on the power grid and reduces the overall efficiency of the electrical system.

- Grid support: Batteries can quickly respond to changes in reactive power requirements, providing reactive power when needed to maintain grid stability, and absorbing excess reactive power when demand decreases. This can help prevent grid disturbances, voltage sags, and other power quality issues.

- Renewable energy integration: They can be particularly useful in renewable energy systems, such as solar or wind farms. These energy sources are typically characterized by variable and intermittent power generation, which can result in fluctuations in reactive power. Batteries can help smooth out these fluctuations, ensuring a stable and reliable power supply to the grid.

- Cost savings: In some cases, using batteries for reactive power compensation can result in cost savings compared to traditional compensation methods. For example, batteries can be more flexible and faster in responding to changing power requirements compared to traditional compensation devices such as capacitors or inductors.

- Environmental benefits: Battery-based reactive power compensation can have environmental benefits as well. By reducing the need for traditional compensation devices that rely on reactive components, such as capacitors or inductors, batteries can help reduce the use of raw materials, energy consumption, and waste generation associated with manufacturing and maintaining these devices.

VI. CONCLUSION

The reactive power compensation using batteries can be a valuable solution for improving power factor and enhancing the efficiency of electrical systems. It can help mitigate penalties associated with poor power factor, optimize energy consumption, and provide fast response times for dynamic load profiles. However, careful consideration of factors such as the cost of batteries, their capacity, efficiency, maintenance requirements, and lifespan is crucial in determining the feasibility and economic viability of using batteries for reactive power compensation. Proper planning, analysis, and consultation with experts may be necessary to ensure that the benefits outweigh the costs and that the solution aligns with the specific requirements and goals of the electrical system in question. Overall, while reactive power compensation using batteries can offer advantages, it should be evaluated on a case-by-case basis to determine its suitability and effectiveness in a given application.

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