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Dynamic Voltage Regulation using Solar Powered Synchro-Inverter

Chitra S [1], Archana Prasadini G S[2]

Associate Professor, Department of Electrical and Electronics Engineering,

Government College of Technology, Coimbatore, India[1]

P.G Scholar, Power Systems Engineering, Department of Electrical and Electronics Engineering,

Government College of Technology, Coimbatore, India[2]

Abstract: Voltage variations are a common issue in modern electrical power systems due to fluctuating load demand and increasing penetration of renewable energy sources. These variations can lead to voltage sag, swell, and power quality disturbances, which may affect the performance of sensitive electrical equipment. Maintaining a stable voltage level at the load terminal is therefore essential for reliable and efficient system operation.

This work presents a dynamic voltage regulation method using a solar powered Synchro-Inverter. The proposed system utilizes solar photovoltaic energy as the primary power source and incorporates a Maximum Power Point Tracking (MPPT) controller to ensure maximum power extraction from the PV array. A DC–DC boost converter is employed to regulate the DC link voltage, while a voltage-controlled Synchro-Inverter converts the DC output into AC power.

The inverter operates similar to a synchronous generator and dynamically adjusts its output voltage based on system conditions. A PID controller is implemented to maintain a constant load voltage by compensating voltage disturbances in real time. The inverter is connected to the distribution line through an injection transformer which enables effective voltage compensation.

The proposed system is modelled and simulated using MATLAB/Simulink. Simulation results demonstrate that the system effectively mitigates voltage fluctuations, improves voltage stability, and enhances the power quality of the distribution network.

Keywords: Dynamic Voltage Regulation, Solar PV, Synchro-Inverter, MPPT, PID Controller, Power Quality.

I. INTRODUCTION

Voltage stability is one of the important aspects in the operation of electrical power systems. A stable voltage profile ensures reliable power delivery and proper functioning of electrical equipment. However, modern distribution networks often experience voltage variations due to load fluctuations, fault conditions, and integration of renewable energy sources. These disturbances may cause voltage sag, swell, and other power quality problems that negatively affect system performance. To overcome these issues, several voltage compensation techniques have been developed. Among them, inverter-based compensation methods have gained significant attention due to their fast response and flexible control capability. With the growing demand for clean energy, solar photovoltaic systems are widely integrated into power networks. Solar energy provides an environmentally friendly and sustainable solution for electricity generation.in this study, a solar powered Synchro-Inverter is proposed for dynamic voltage regulation.

The Synchro-Inverter behaves similar to a synchronous generator and provides voltage support to the distribution system. It continuously monitors the system voltage and adjusts its output accordingly to maintain a stable load voltage. the photovoltaic system converts solar radiation into electrical energy through semiconductor devices. Since the output characteristics of the PV system depend on environmental conditions such as irradiance and temperature, the operating point of the PV array changes continuously. To ensure maximum energy extraction, a Maximum Power Point Tracking controller is used. The proposed system integrates a PV array, MPPT controller, DC–DC converter, Synchro-Inverter, and voltage control unit. The system improves voltage stability and power quality while utilizing renewable solar energy. MATLAB/Simulink simulation is used to evaluate the performance of the proposed system under different operating conditions.

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II. SOLAR PHOTOVOLTAIC SYSTEM

A solar photovoltaic system converts sunlight directly into electrical energy using semiconductor devices known as solar cells. When solar radiation strikes the surface of the PV cell, photons transfer energy to electrons in the semiconductor material, resulting in the generation of electric current. A single solar cell produces a small voltage. Therefore, multiple cells are connected in series and parallel to form a PV module or array in order to obtain the required voltage and power levels. The electrical power generated by a PV module can be expressed as

$$P = V \times I$$

where V represents the output voltage and I represents the output current of the PV array.

The performance of a PV module is influenced by environmental conditions such as solar irradiance and temperature. An increase in irradiance generally increases the generated current, whereas a rise in temperature slightly reduces the output voltage.

Because of these variations, the operating point of the PV array changes continuously. To maintain operation at the optimal point where maximum power is produced, a Maximum Power Point Tracking technique is required.

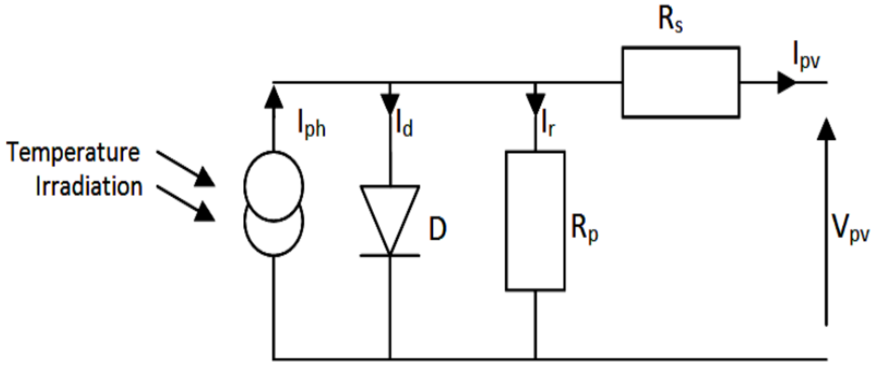

Fig. II. Solar Photovoltaic system

III. MAXIMUM POWER POINT TRACKING

The power output of a photovoltaic system varies depending on solar irradiance and temperature. The relationship between voltage and power in a PV system is nonlinear, which makes it difficult to obtain maximum power without proper control techniques.

Maximum Power Point Tracking (MPPT) is used to ensure that the PV array operates at the point where maximum power is available. Among various MPPT techniques, the Perturb and Observe algorithm is widely used because of its simplicity and reliability.

In this method, the controller continuously measures the voltage and current of the PV array and calculates the output power. The operating voltage is slightly perturbed and the resulting change in power is observed. If the power increases, the controller continues to move the operating point in the same direction. If the power decreases, the direction of perturbation is reversed.

This process allows the system to track the maximum power point even when environmental conditions change. The MPPT controller also adjusts the duty cycle of the DC–DC converter to maintain the optimal operating condition.

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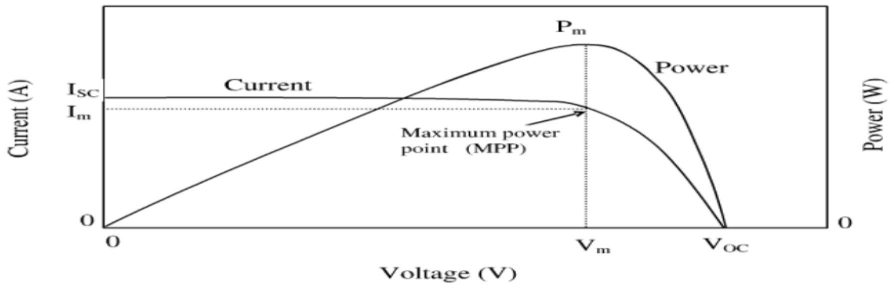

Fig. III. IV and PV characteristics of PV cell

IV. PROPOSED SYSTEM

The proposed system aims to regulate the load voltage dynamically using a solar powered Synchro-Inverter. The system consists of several components including a solar PV array, MPPT controller, DC–DC boost converter, inverter, injection transformer, and load. the solar PV array generates DC power from solar radiation. The MPPT controller ensures that maximum power is extracted from the PV array by controlling the duty cycle of the boost converter. The DC–DC converter increases the voltage level and maintains a stable DC link voltage.

The Synchro-Inverter converts the DC power into AC voltage and operates in voltage control mode. Unlike conventional inverters, the Synchro-Inverter imitates the behaviour of a synchronous generator and provides improved voltage regulation.

A PID controller is implemented to regulate the inverter output voltage. The controller continuously compares the measured load voltage with the reference value and produces an error signal. Based on this error, the controller adjusts the inverter modulation to maintain a constant load voltage. During voltage sag conditions, the inverter injects a compensating voltage in phase with the supply voltage. In the case of voltage swell, the injected voltage is controlled in such a way that the excess voltage is reduced. The injection transformer allows the inverter voltage to be added in series with the supply voltage and provides electrical isolation.

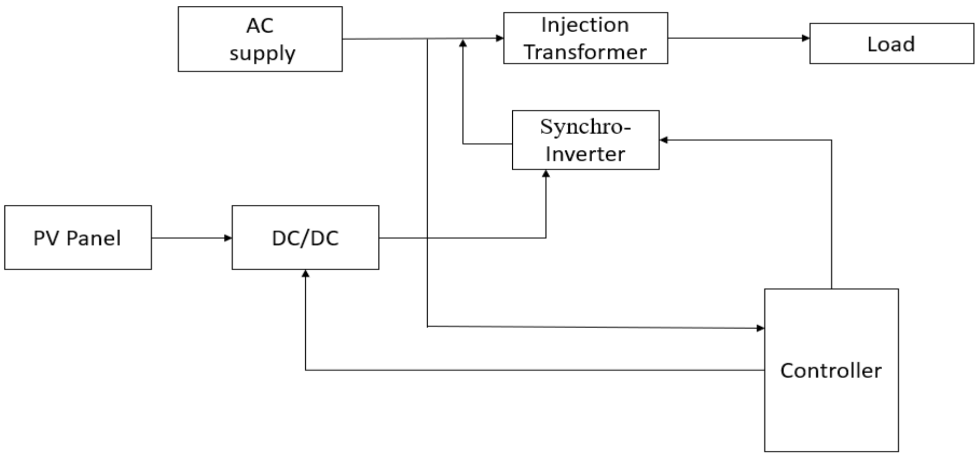

Fig. IV. Block diagram for the Proposed System

V. RESULTS AND DISCUSSION

A. SOLAR PV WITH MPPT

The solar PV subsystem generates DC power from the sunlight it receives and the temperature. To get the most power from the PV array, a Maximum Power Point Tracking (MPPT) algorithm is used. The Perturb and Observe (P&O) method is chosen because it is simple and responds well to changes. It constantly adjusts the operating voltage of the PV array and monitors the power changes to modify the converter's duty cycle. This keeps the PV array working at its maximum power point (MPP) even when sunlight conditions change.+

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The MATLAB/Simulink model of the PV subsystem created with MPPT control is shown below.

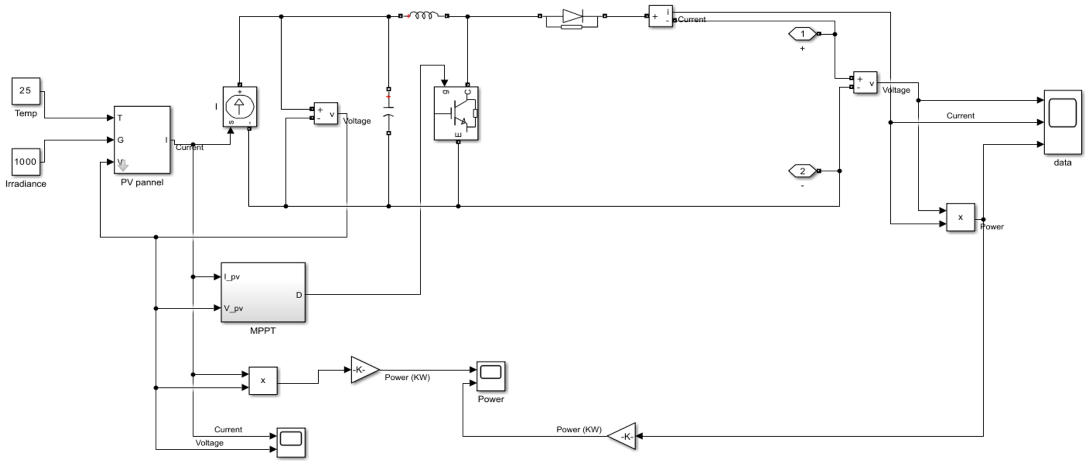

Fig. V.A. Simulink of Solar PV with MPPT

The simulated output waveform of the PV system is shown below. It represents the variation of PV power during MPPT operation as shown below

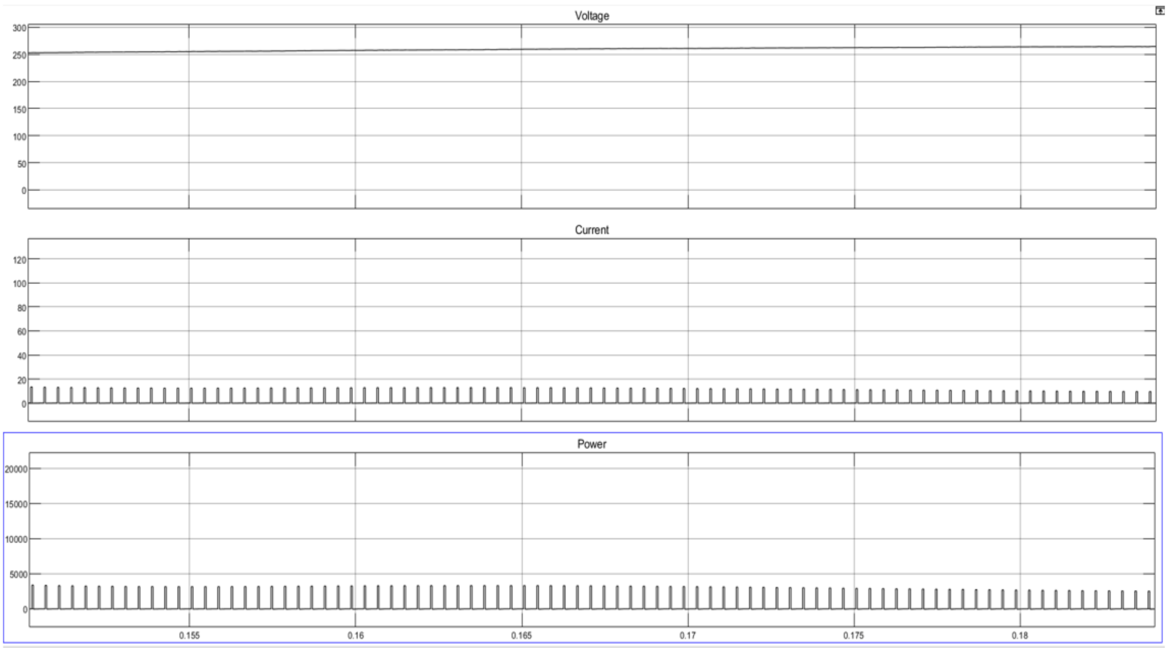

Fig. V.A. Output of Solar PV with MPPT

B.PID controller system

The PID controller regulates the injected voltage of the DVR and keeps the load voltage constant. It compares the measured load voltage with the reference value of 230 V and produces an error signal. The proportional part of the controller makes quick corrections for the error, while the integral part eliminates steady-state deviations. This setup ensures a quick and precise response to voltage changes, allowing for dynamic voltage regulation during both transient and steady-state conditions.

The closed-loop control system uses a PID controller to maintain voltage stability. The Simulink representation of the system is illustrated below

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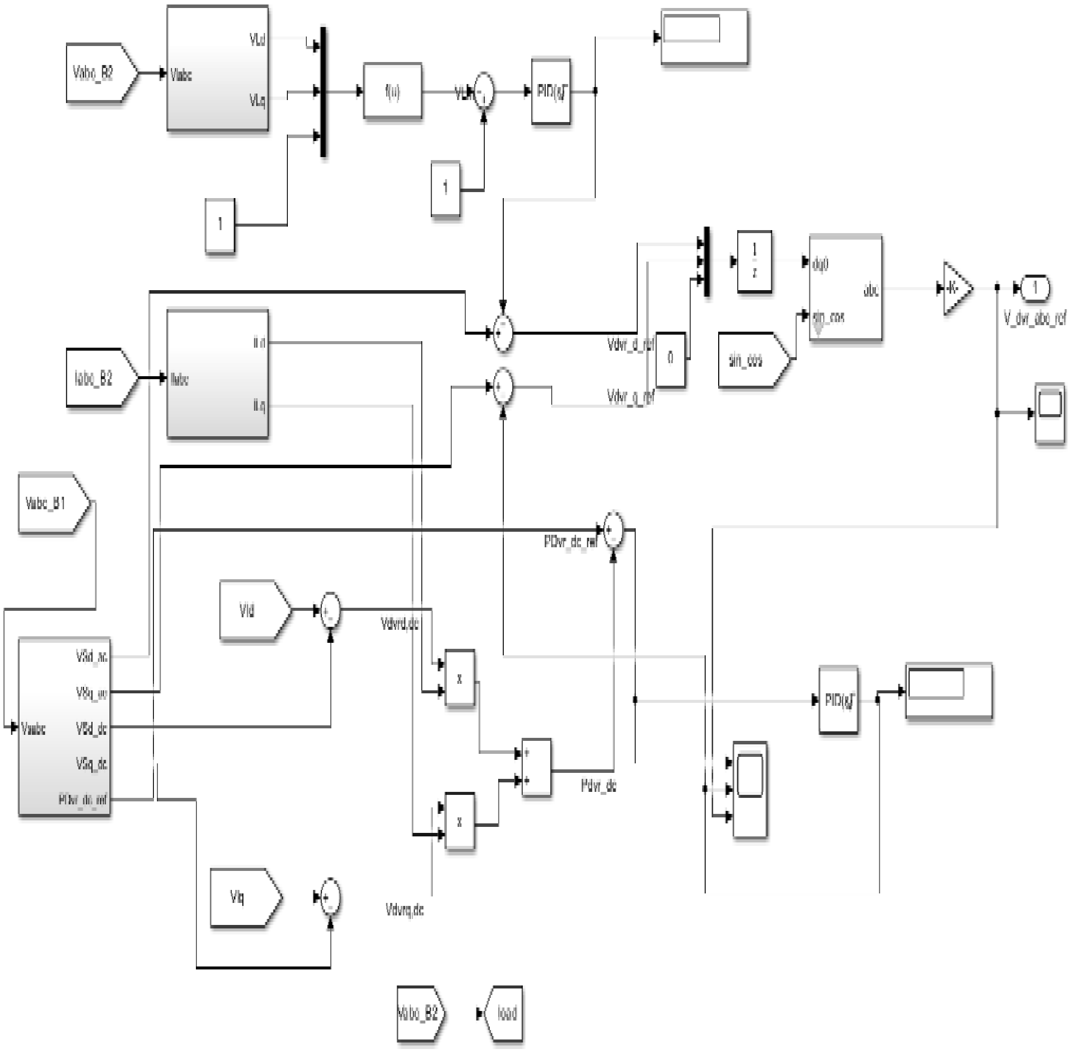

Fig. V.B. Simulink of PID controller system

C.The Dynamic Voltage Restorer (DVR)

The Dynamic Voltage Restorer (DVR) is the main subsystem that keeps voltage stable at the load terminal. The DVR connects in series with the distribution line through an injection transformer. It continuously checks the supply voltage. When it detects a voltage drop or fluctuation, it adds a compensating voltage in series to bring the load voltage back to its rated value. The injected voltage comes from a voltage source inverter (VSI) powered by a solar-fed DC-link. A filter circuit is placed at the inverter output to clean up harmonics and create a smooth sinusoidal voltage waveform. The complete DVR Simulink model connected to the distribution network is illustrated below.

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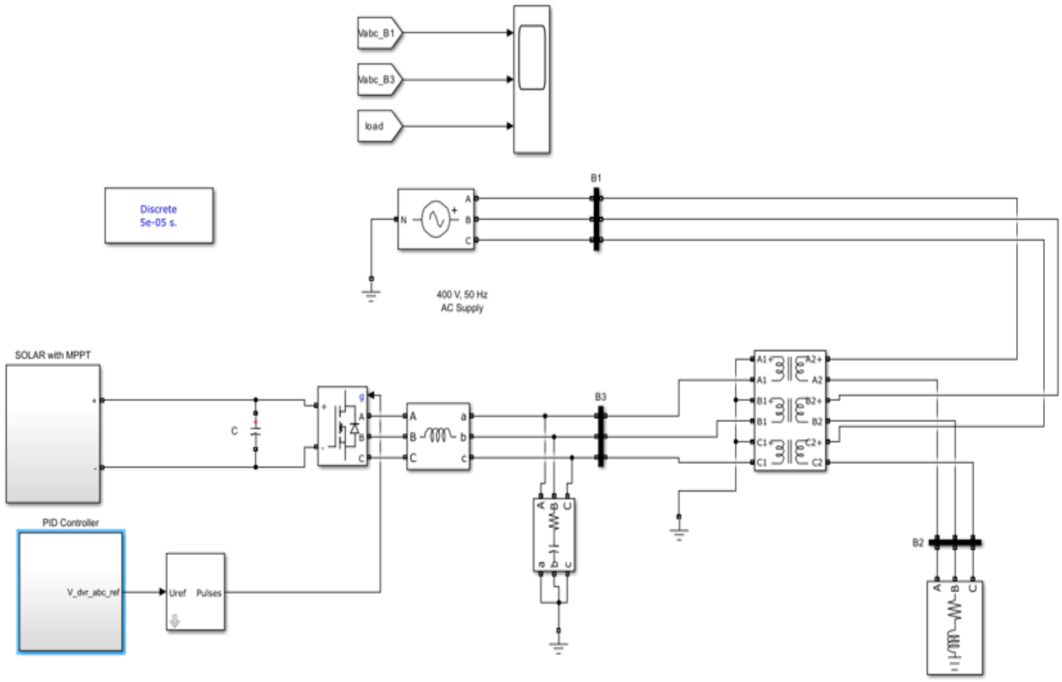

Fig. V.C. 1.Simulink Model of DVR

The waveform below shows voltage restoration performance during sag conditions. he compensating voltage injected by the DVR to stabilize the load voltage is shown below.

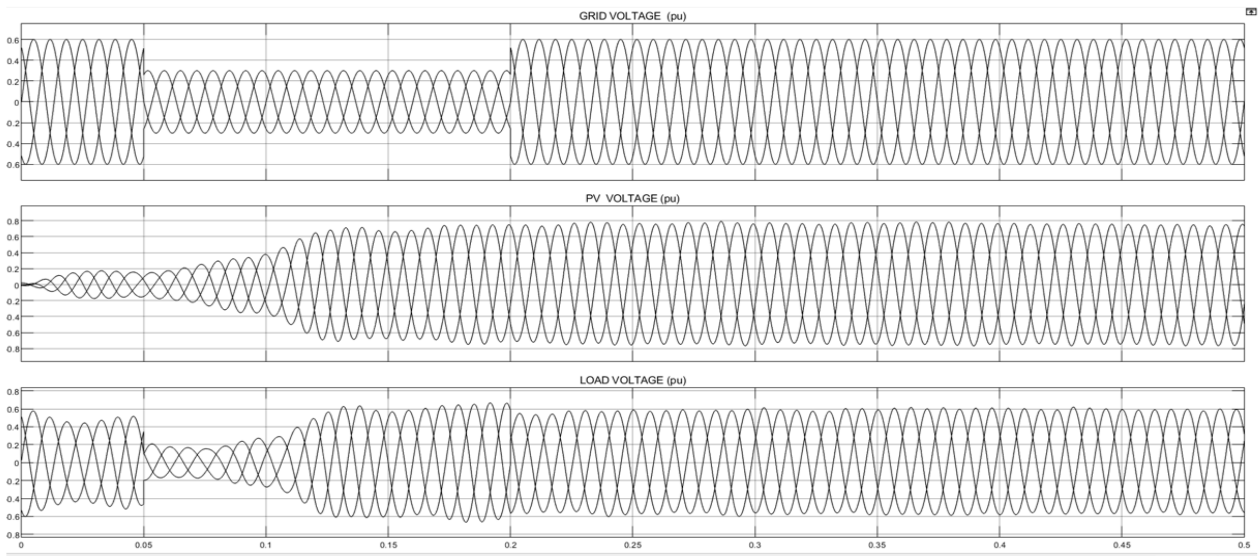

Fig. V.C.2. output of Dynamic voltage Regulation

VI. CONCLUSION

This work presented a solar powered Synchro-Inverter system for dynamic voltage regulation in distribution networks. The proposed system integrates a photovoltaic energy source with MPPT control and inverter-based voltage compensation The system was modelled and simulated in MATLAB/Simulink to evaluate its performance under different operating conditions. Simulation results demonstrate that the proposed method effectively regulates the load voltage and reduces voltage fluctuations.

The PID based control strategy enables fast response and accurate voltage regulation during disturbances. The use of solar energy also makes the system environmentally friendly and suitable for modern renewable energybased power

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systems. Overall, the solar powered Synchro-Inverter provides an efficient and reliable solution for maintaining voltage stability and improving power quality in electrical distribution systems.

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