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Solar PV Based Electric Vehicle Charging Interfaced to a Single–Phase Grid for V2G and G2V Operations

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Abstract— **This paper presents a solar-powered battery charging system using boost DC-DC converter using Maximum Power Point Tracking control algorithm. The main objective is to increase the efficiency of energy transfer from photovoltaic panels to the battery under varying solar irradiance and temperature conditions. In this paper it is also discussed about electric vehicle charging systems through Vehicle-to-Grid and Grid-to-Vehicle operations,** which **helps in increasing grid stability and energy efficiency. This further helps in enabling controlled energy transfer from the grid to the vehicle during charging and from the vehicle back to the grid during discharging or when needed. This is done with the help of using bidirectional AC/DC converters.**

Index Terms—**Photovoltaic system, Boost Converter, Maximum Power Point Tracking, Battery charging, Electric Vehicles, Vehicle-to-Grid, Grid-to-Vehicle, Bidirectional Converter.**

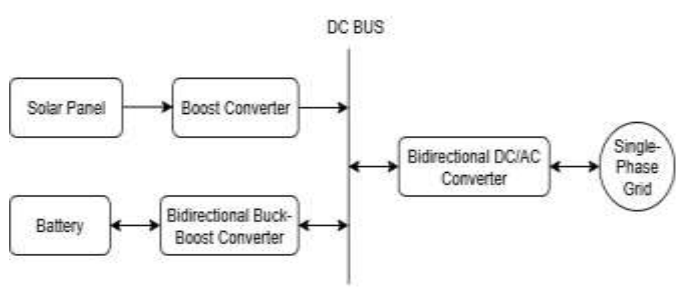
1. INTRODUCTION

There has been increase in adaptation of electric vehicle globally. It is due to its many benefits like reduce Greenhouse gas emissions. Electric Vehicle charging can also integrate with Renewable Sources such as Solar or Wind Energy which further improves Grid Stability and reduces dependency on fossil fuels. PV system consists of PV Array, Boost type DC/DC Converter, VSC type DC/AC inverter.[1]

Solar Panel is connected to Boost Converter through Maximum Power Point Tracking Controller using Perturb and Observe Algorithm. By using Solar Energy for Electric Vehicle charging can reduce load on Power Grid during daytime. Solar Panel output depends upon Irradiance and Temperature. Therefore, to utilize the maximum potential of Solar Panel, control techniques such as Maximum Power Point Tracking is used. PV Array and grid interfaced with V2G and G2V capabilities was researched by using a bidirectional buck-boost converter and MPPT control strategies to ensure Power-Quality under varying load and PV conditions.[2] This integrated system helps in efficient charging of Electric Vehicles with electricity generated from Solar Panel. The surplus energy can be stored in the battery or can be discharged to the grid. During the time when energy generated from Solar

Generation is low, energy stored in battery or power from grid can help in undisrupted charging process of vehicle. This configuration is G2V or Grid to Vehicle operation. Such systems contribute to energy sustainability, grid stability, and reduced operational costs, while promoting the broader adoption of electric vehicles and renewable energy technologies. This increasing awareness of renewable energy and decreasing price of solar panels have caused a boom in solar power applications. Among all the resources, solar energy is the winning contender due to unique features such as availability of sun on earth surface, ease of installation, ease of maintenance, no moving parts, negligible pollution level, etc.

2. SYSTEM DISCRIPTION



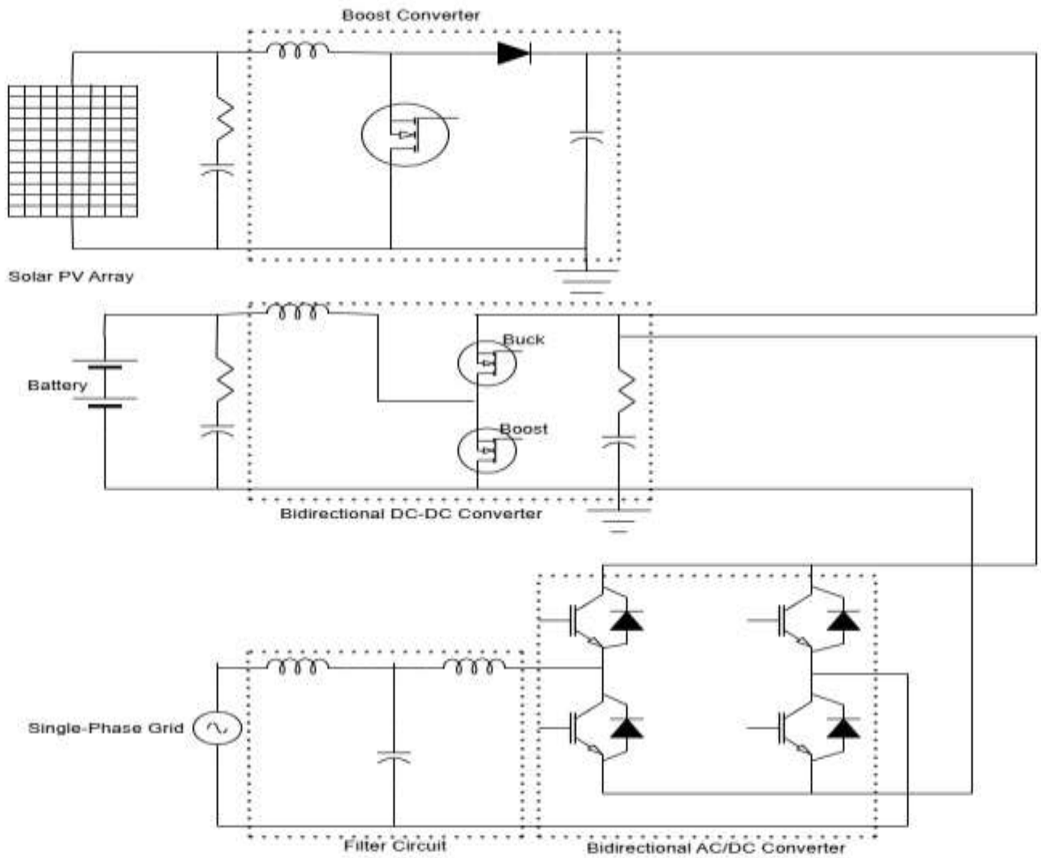


Figure 1. Block Diagram of system Integration

Block diagram of the system shows the method adopted in this work to charge batteries by sensing the battery charging current. To increase the maximum power output from the solar panel MPP tracking systems are used. Even though the temperature, irradiation and the load characteristics varies it helps in maintain the output of the solar PV panel constant. The insolation and temperature problems can be overcome by using P&O, this is effective, flexible and earliest control algorithm. In photovoltaic a proportion of radiation reflected or absorbed depends on the object's reflectivity. The insolation into a surface is largest when the surface directly faces the Sun. As the angle increases between the direction at a right angle to the surface and the direction of the rays of sunlight, the insolation is reduced in proportion to the cosine of the angle [3].

Figure 2. Circuit Diagram

During G2V mode it will act as a source by which the battery gets charged and during V2G mode, grid will act as a load and receive the power from the battery.

Solar Panel to Battery

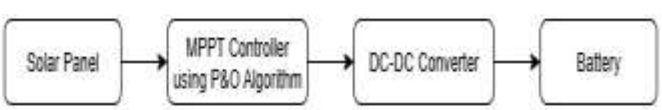
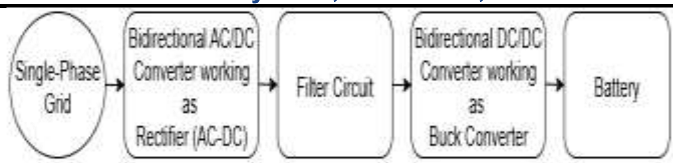


Figure 3. Charging from Solar Panel to EV Battery

In this configuration, Electric Vehicle battery is charging from Solar Panel. PV array is built of strings of PV modules which are connected in parallel. Each string consists of modules connected in series. These cells are generally made of Silicon semiconductor whose electrons get excited when sunlight falls on it. These electrons when passed through an external circuit generates electricity in form of direct current.[4] To extract maximum capacity of solar panel, MPPT Controller is used. It tracks the point of maximum power of the solar panel. Perturb and Observe technique is based on operating voltage and its effect on output power. In this case, it will adjust the duty cycle of boost converter which depends on its input voltage and will decide whether to continue in same direction or reverse it accordingly.[5][6] This way battery will be charge from solar panel.



G2V Mode

Figure 4. Charging of EV Battery from Grid

In G2V mode, vehicle battery is charged by single-phase grid. During rainfall, night time or in foggy conditions when solar panel cannot work up to its full potential then power is extracted from grid to charge the battery.

In this configuration, Single-Phase grid is connected to a bidirectional AC/DC converter which is working as a rectifier to convert AC into DC. Filter Circuit with capacitor and inductor is connected to remove ripples from the current so that more stable DC output can be obtained. A bidirectional DC-DC converter is connected which will work as a Buck Converter in this configuration. It will reduce the DC voltage to the level of Battery charging voltage and will regulate battery voltage and current. In this mode, care should be taken that so many vehicles should not charge from a single grid because this can put strain on the Power System. Yilmaz and Krein studies and observed the ill effects of uncontrolled G2V charging and gave some techniques to maintain balance between energy generation and energy consumption which help in grid stability [7].

V2G Mode

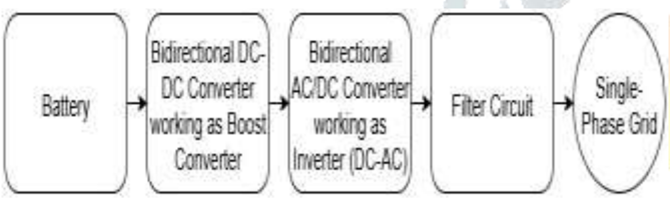


Figure 5. EV Battery supplying Power to grid

In V2G Configuration, Battery discharges its power to the grid. Stored energy in battery can help during peak loads or during grid's power outage or equipment damage.

Vehicle battery is connected to bidirectional DC-DC converter which will now work as a boost converter which will level up the voltage to supply power to the single-phase grid. Bidirectional AC/DC converter will work as an inverter to convert DC to AC. Filter circuit consisting of capacitors and inductors is connected along with single-phase grid to help in converting non-sinusoidal AC output into sinusoidal waveform. This filter circuit will further help in reducing unwanted harmonics from the current and cancelling noise from the circuit. Study conducted by Kempton and Tomic show that even small part of electric vehicle battery helping in V2G mode could help in increasing the grid stability and power quality [8].

All these configurations are interconnected by using a common DC bus.

3. RESULT AND DISCUSSION

Case 1- When EV Battery is charging from Solar Panel

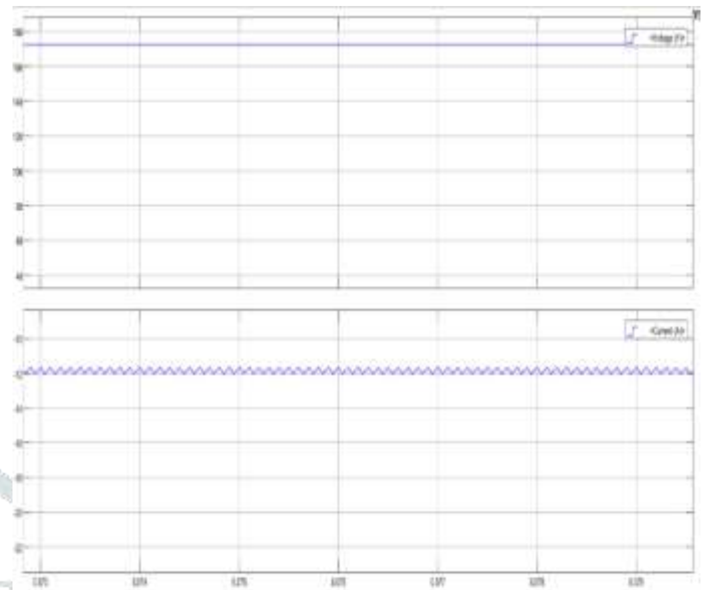


Figure 6. Battery Voltage and Current

It is shown in this graph that EV Battery is charging at 170 V and current is -12A. The simulation results indicate that the battery charges at a regulated voltage of 170 V. The presence of minor ripple in current is due to switching action in the boost converter, and the system maintains steady-state operation without any transient spikes or instability, confirming the effectiveness of the MPPT control strategy.

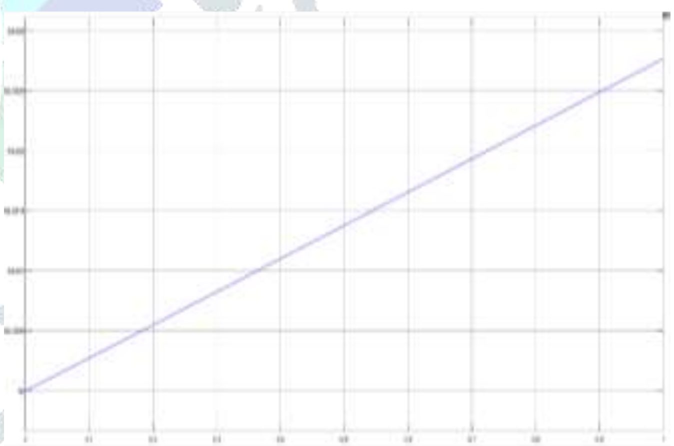


Figure 7. SOC of battery increasing when charging by Solar Panel

SOC of the battery is increasing which indicates battery is charging from Solar PV Array.

Case 2 – G2V Mode

When vehicle's battery is charging from grid

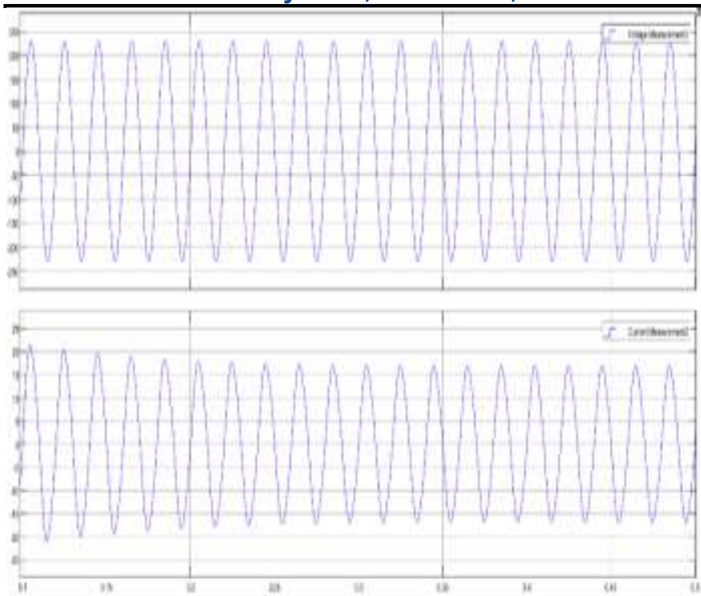


Figure 8. Grid Voltage and current

In G2V mode, Grid is supplying power to charge EV Battery. While charging, grid voltage is stabilized at 240 V. Both voltage and current are in phase which indicates grid is supplying power and acting as a source in this case.

Figure 9. SOC of EV Battery while charging from grid

State of Charge of battery is shown increasing which means battery is in charging mode.

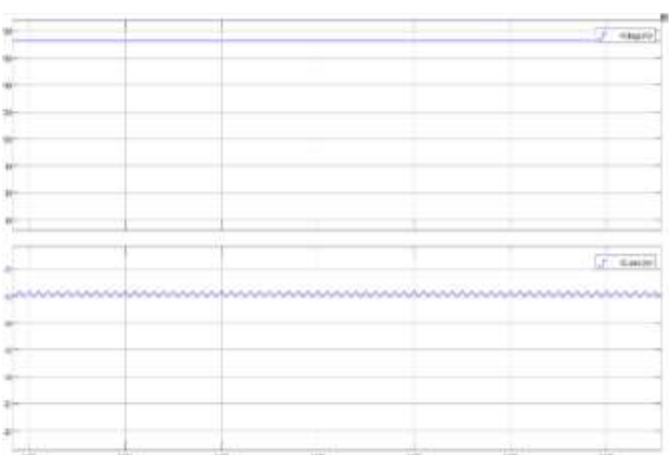


Figure 10. EV Battery voltage and current while charging from grid

From this graph battery is charging at 170 V and current is -12 A which shows the charging state of battery.

Case 3 – V2G Mode

When EV Battery is discharging to grid

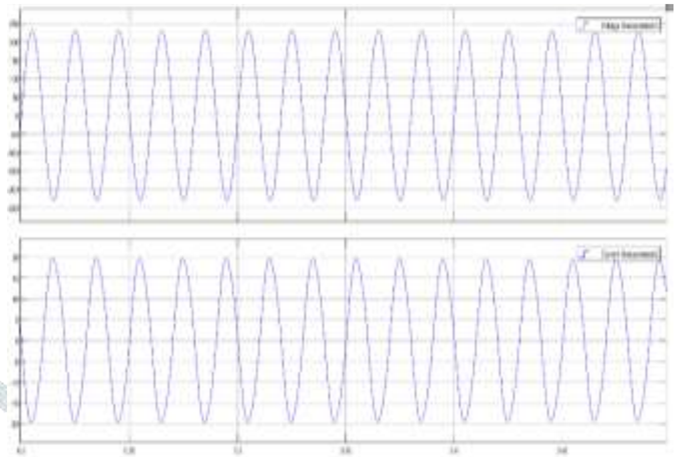


Figure 11. EV Battery is discharging to grid

Grid voltage is 240 V and current is 20 A and voltage and current waveforms are out of phase which shows Battery is supplying stores energy to grid.

Grid Voltage and Current when charging from EV Battery

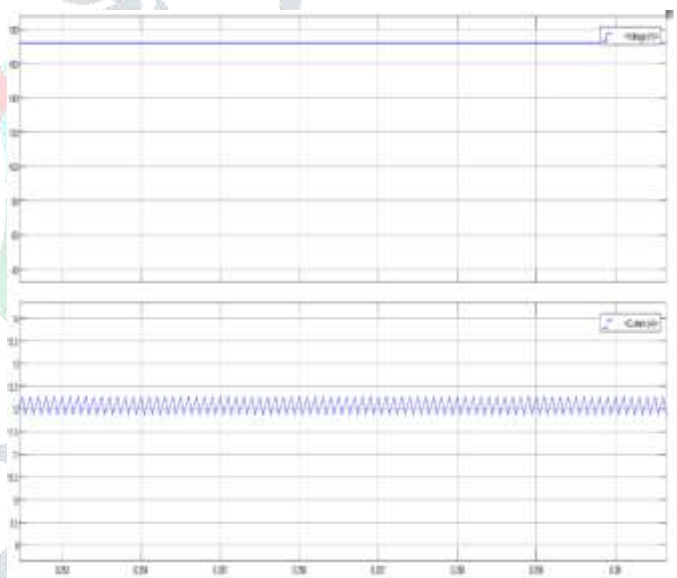


Figure 12. Grid Voltage and Current when charging from EV Battery

Battery is charging at 170 V at -12A which is given as a reference value.

EV Battery Voltage and Current when discharging to grid

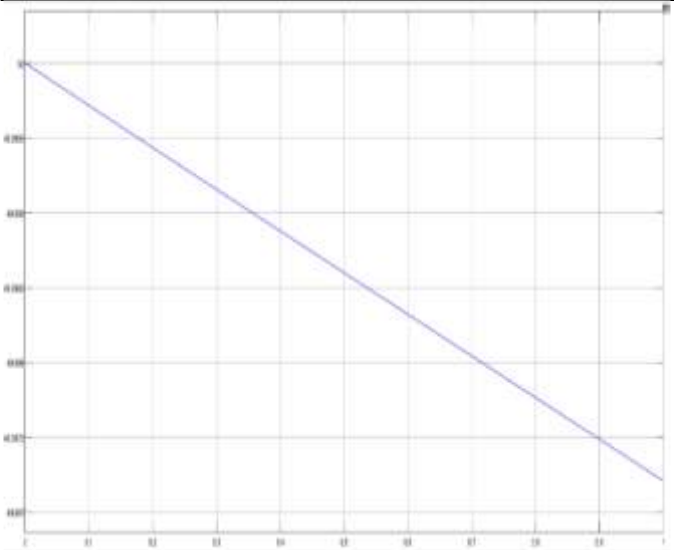


Figure 13. SOC of the EV Battery decreasing while discharging to grid

EV Battery Voltage, current and SOC is shown in these graphs. Battery current is +12V which is given as reference when battery is in discharging state.

SOC of the battery is decreasing which shows battery is discharging. The battery's stored energy level reduces as it supplies power back to the grid. This indicates that EV Battery can discharge its stored energy when required.

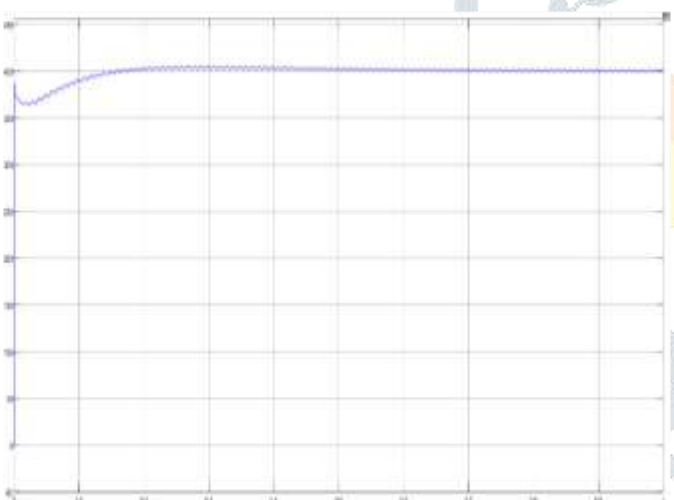


Figure 14. Output Voltage of DC Bus is maintained at 400V under all modes

Maintaining a steady 400V output at the DC bus in a solar-powered, grid-connected EV charger is essential for ensuring the system runs smoothly, efficiently, and reliably. This constant voltage helps the power converters—such as DC-DC converters and grid-tied inverters—operate within their ideal performance range. As a result, it improves overall efficiency and reduces the risk of issues like overvoltage or undervoltage, which could otherwise disrupt the charging process.

A stable DC bus also provides a consistent and safe charging voltage for electric vehicles, supporting reliable battery performance. Additionally, it allows for seamless power flow between the solar PV system, the grid, and the EV, even when solar input or grid conditions fluctuate. This stability is key to ensuring uninterrupted operation and maximizing the use of available renewable energy.

THD CALCULATION

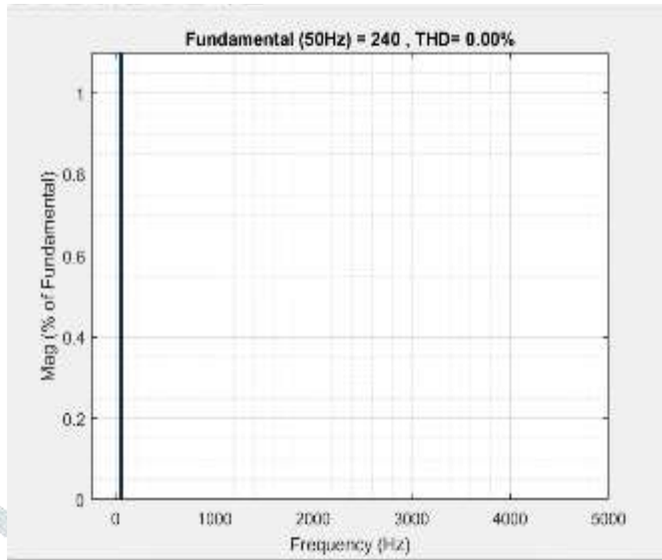


Figure 15. Graph showing THD of Grid Current

THD of grid current is 0.00%. It is an ideal pure sine wave of current with no higher frequency harmonics present.

4. CONCLUSION

Solar PV Based Electric Vehicle Charging Interfaced to a Single–Phase Grid for V2G and G2V Operations model was created have been successfully tested under different conditions. Boost Converter connected with Battery and Solar PV Array will charge battery at 170 V. MPPT Controller is using Perturb and Observe Algorithm whose codes are written in MATLAB Function. This algorithm is tracking maximum power point by adjusting duty cycle of boost converter which gives pulses to MOSFET. EV Battery is charging from the power extracted from Solare PV Array. In this model, EV Battery is integrated with single-phase grid. This integration makes this model more flexible and reliable. During G2V mode, grid is supplying energy to charge EV Battery. This will make balance between supply and demand and increase grid stability. During V2G mode, EV Battery will discharge its stored energy back to the grid during high demand or when some faults occur in grid. By connecting Renewable sources such as Solar Panel will further help in voltage regulation and frequency.

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