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Integrated bidirectional charger for seamless charging of electric vehicles

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Abstract— **The Integrated Bidirectional Charger for EVs using Solar and Grid Energy presents an advanced solution to efficiently charge electric vehicles (EVs) by harnessing both solar and grid power sources. This innovative system intelligently manages energy flow to ensure optimal charging while minimizing grid dependence. The primary mode of operation is to utilize solar energy for EV charging. When sufficient solar power is available, the bidirectional converter directs it to charge the EV's battery. However, in cases of low solar input or during the night, the system seamlessly transitions to grid power, ensuring uninterrupted charging. What sets this system apart is its ability to adapt to changing conditions. If the EV's battery is sufficiently charged (above 70%) and solar energy input is insufficient, the bidirectional converter can be shifted into a discharging mode. Excess energy stored in the EV's battery is inverted and sent back to the grid, providing valuable support to the grid infrastructure, and allowing for grid-tied energy storage. By prioritizing renewable energy sources and enabling bidirectional power flow, this integrated charger not only promotes sustainable EV usage but also contributes to grid stability and resilience. It is a promising step towards a greener and more adaptive energy ecosystem.**

Keywords— *Integrated Bidirectional charger, EV, Solar and Grid Energy, Optimal Charging, Minimizing Grid Dependence, Adaptive energy flow, Sustainable EV usage, Grid Stability, Renewable energy, Bidirectional power flow, green energy Eco-system, Seamless Charging*

I. INTRODUCTION

The transportation sector is undergoing a significant transformation with the increasing adoption of electric vehicles (EVs). This shift towards EVs is driven by the need to reduce greenhouse gas emissions, combat climate change, and decrease dependence on fossil fuels. As the EV market expands, it brings along with it a host of opportunities and challenges, particularly in the domain of charging infrastructure and sustainable energy utilization. The "Integrated Bidirectional Charger for EV using Solar and Grid Energy" is a forward-looking concept that addresses these challenges by offering an innovative solution for charging EVs efficiently while incorporating renewable energy sources. The primary objective is to create a dynamic system that optimizes energy utilization, thereby promoting sustainability in EV charging. This integrated bidirectional charger offers a seamless transition between solar and grid power, while also supporting grid stability through energy feedback when EVs are sufficiently charged.

II. METHODOLOGY

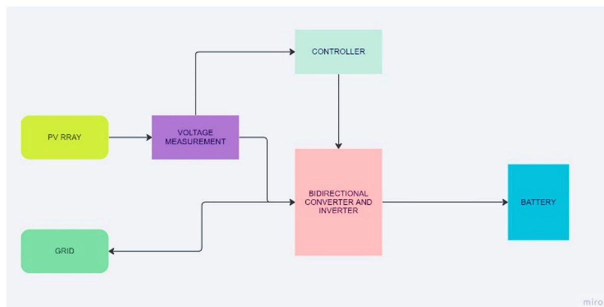

Fig 1. Block Diagram of the proposed system

A. Bidirectional Converter

At the core of this concept is the bidirectional converter, a critical component that manages the flow of energy between the EV, solar panels, and the grid. This device is responsible for directing the energy flow in multiple ways, depending on the prevailing conditions and system requirements.

In charging mode, the bidirectional converter primarily routes solar energy to charge the EV's battery. When the solar power supply is insufficient or unavailable, it smoothly transitions to drawing energy from the grid to ensure uninterrupted EV charging.

In discharging mode, the bidirectional converter operates when the EV's battery state of charge (SoC) is above a certain threshold, typically 70% or as predetermined. During this phase, it reverses its operation and converts the excess energy stored in the EV's battery back into electrical power. This power is then inverted and sent back to the grid, providing support to the grid infrastructure. This bidirectional flow of energy benefits the grid by offering grid-tied energy storage, which can help manage peak loads, reduce strain on the grid, and enhance grid resilience.

B. *Modes of working of the converter*

1. Solar Power Utilization (Charging Mode):

During the charging state, the bidirectional converter is set to charge the EV's battery using solar power. Solar panels generate direct current (DC), which is then fed into the converter. To ensure efficient power transfer, the solar DC voltage is boosted to match the battery voltage. When the battery is fully charged, the power flow to the battery is cut off, and it is transferred to the grid via the inverter. The transistor Q2 is ON, and the transistors Q1 and Q3 are in OFF mode in mode 1 of operation. In this mode, current flows from PV to a Q2 MOSFET and then to the battery via the inductor to charge the battery. The model circuit is given to show the flow path and the components of the circuit.

Table 1. Status of the switches in mode 1

SWITCH	STATE
Q1	OFF
Q2	ON
Q3	OFF

Diode is forward biased in this mode. This is achieved by using a boost converter, and the equation for DC-DC conversion efficiency ($\eta_{dc\text{-}dc}$) is given by:

$$\eta_{dc\text{-}dc} = (V_{out} * I_{out}) / (V_{in} * I_{in})$$

where:

- Vin is the input voltage from the solar panels.
- Vout is the output voltage required for the battery.
- Iin is the input current from the solar panels.
- Iout is the output current to charge the EV battery.

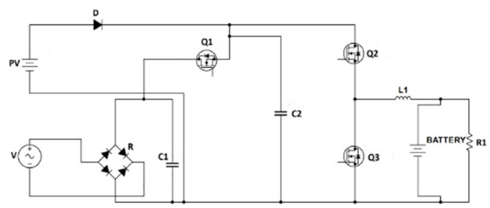

Fig 2. Mode 1 of the converter.

2. Grid Power Utilization (Charging Mode):

In cases where solar power is insufficient, the bidirectional converter switches seamlessly to utilize grid power. Grid power is alternating current (AC) and needs to be rectified into DC before being used to charge the EV battery. Here, the transistor Q1 is turned on, and the transistor Q2 remains turned on as in the previous mode. Like mode 1, the transistor Q3 remains off in this mode. Here, the current flows from the grid to transistors Q1 and Q2 and then to the battery via the inductor to charge the battery. The converter contains a rectifier, which converts AC to DC. In this mode, the rectifier output is smooth and steady, and then it is allowed to charge the battery. The efficiency of this conversion ($\eta_{ac\text{-}dc}$) is given by:

$$\eta_{ac\text{-}dc} = (P_{out}) / (P_{in})$$

where:

- Pin is the input power from the grid.
- Pout is the output power used to charge the Electric vehicle's battery.

Table 2. Status of the switches in mode 2.

SWITCH	STATE
Q1	ON
Q2	ON
Q3	OFF

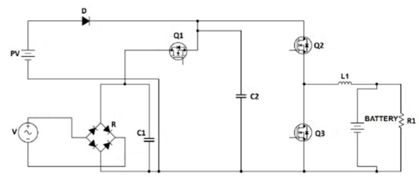

Fig 3. Mode 2 of the converter.

3. Transition to Discharging Mode:

The system continuously monitors the state of charge (SoC) of the EV battery. If the EV battery's SoC exceeds a predefined threshold (e.g., 70%), and there is insufficient solar power and grid power is not needed for charging, the system transitions to discharging mode. In this mode, the energy is transferred to the grid. Here, the transistor Q2 is turned off, and the transistor Q1 is turned off. Practically, this should be done based on the grid power generation and the battery SoC, besides the willingness of the person who owns the electric vehicle. For discharging, another MOSFET named Q3 is used, and it is to be turned on by giving a pulse to its gate. Here, the power from the battery is transferred via the inverter. The SoC can be varied as per the requirement in the case of simulation.

Table 3. Status of the switches in mode 3

SWITCH	STATE
Q1	OFF
Q2	OFF
Q3	ON

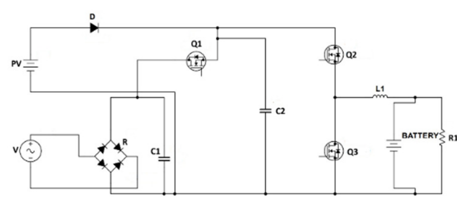

Fig 4. Mode 3 of the converter

4. Discharging Mode:

The converter switches to this mode when the battery SoC reaches 100 or when no charging is needed, where the power from PV is transferred to the main grid via the inverter, which supports the grid and reduces its stress. In the discharging state, the bidirectional converter reverses its operation. MOSFET Q2 is turned on, and MOSFET Q3 is adjusted using the PWM controller to control the output voltage, allowing energy to flow from the PV to the grid via the inverter, which supports the grid and helps to maintain the load balance. This mode is like power generation using photovoltaic cells. The bidirectional converter now acts as an inverter, converting DC from the PV into AC to supply power back to the grid. The efficiency of this conversion ($\eta_{dc\text{-}ac}$) is given by

D = Ton / (Ton + Toff)
η_dc-ac = (Pout) / (Pi)

Table 4. Status of the switches in mode 4

SWITCH	STATE
Q1	OFF
Q2	ON
Q3	ON

The inverter operation ensures that excess energy from the EV battery is returned to the grid.

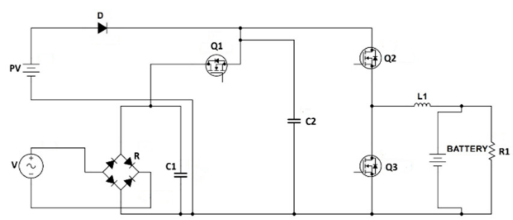

Fig 5. Mode 5 of the converter

III. MATLAB SIMULATION

MATLAB Simulink is used to simulate the model. Since Simulink is built over MATLAB the circuit is switched between the sources with the help of the MATLAB functions.

The circuit is built, all four modes of operations are simulated, and the output graph has been obtained.

IV. SIMULATION RESULTS

A. Mode 1

Power from PV is enough to charge the EV. Hence, the battery is charged via the PV array. The simulation graph is plotted between SoC and time. The X axis is the SoC of the battery in percentage, and the Y axis is the time taken in minutes to charge from the initial SoC to the final SoC. You can see that once the SoC reaches 100, charging is stopped, and the SoC becomes constant. The simulation result is shown below.

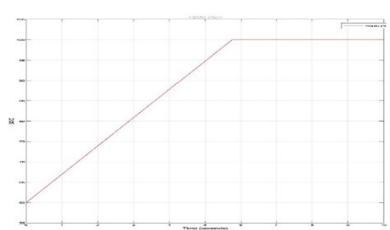

Fig 6. Simulation result for mode 1

B. Mode 2

In this mode, the power from PV is insufficient to charge the battery, so it is charged via the grid. The simulation result for this mode is shown below. Switching is done via the switching device using a MATLAB function for PV power output and compared with the optimum power to charge the battery. Like the above simulation graph, the X axis is SoC in percentage, and the Y axis is time in minutes. Charging stops when the battery SoC reaches 100%.

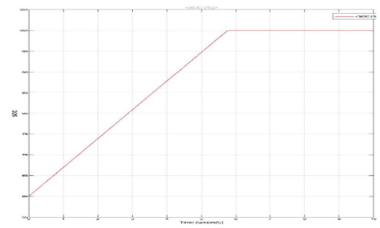

Fig 8. Simulation result for mode 2

C.Mode 3

In this mode, if the battery SoC is above a threshold level say.70% of the bidirectional converter acts as an inverter and the energy flows to the grid via the inverter from battery. Figure 8 shows the discharge graph between SoC of battery in percentage at X axis and time in minutes at Y axis. Figure 7 shows the inverter output voltage where x axis is voltage in volts and y axis is time in minutes. We obtained a sinusoidal output like the grid voltage. The simulation result of mode 3 is shown below.

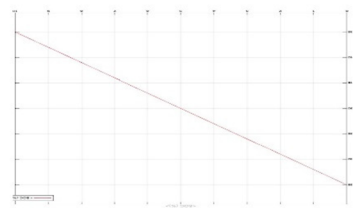

Fig 9. Simulation result for mode 3.

Fig 10. Simulation result of mode 3

D. Mode 4

In this mode, if there is no EV or no charging is required, the power from the PV array flows to the main grid via the bidirectional converter, which here acts as an inverter. The graph is plotted between voltage on the x axis and time on the y axis. The converter switches to mode 4 when no charging is required or the SoC reaches 100. The output is nearly sinusoidal, but it must be properly sinusoidal to transfer it to the grid since the grid is pure sinusoidal. Simulation result is shown below for mode 4.

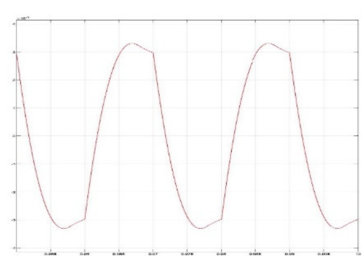

Fig 7. Simulation result of mode 4

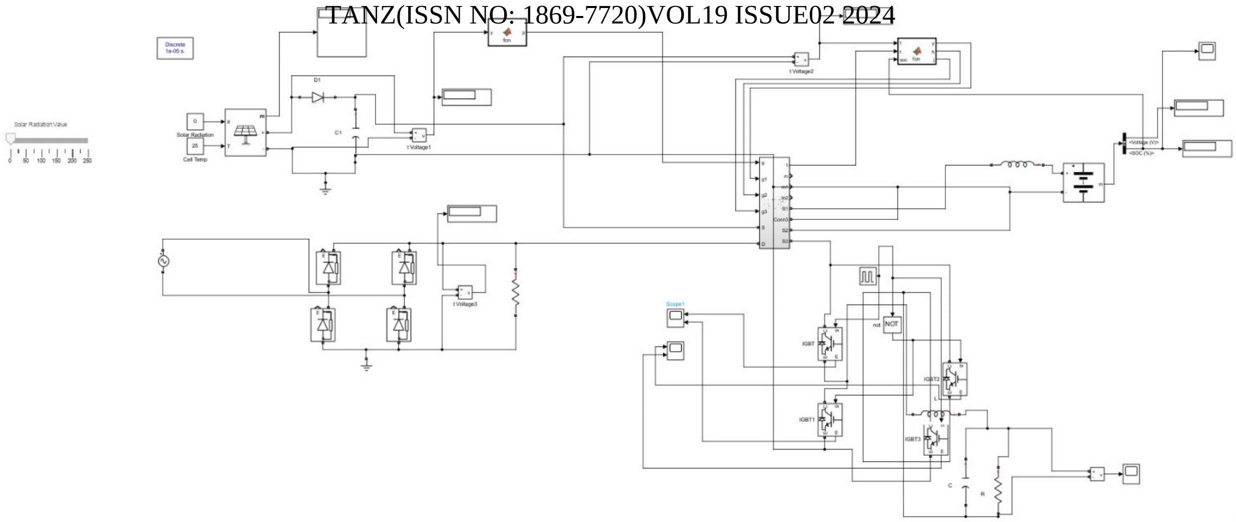

Fig 11. Simulation model of the proposed bidirectional converter.

V. FUTURE SCOPE

Electric vehicles are heavy loads for the grids to maintain. Imagine a company employee having EVs charge their vehicles at a time which results in an exponential increase in power consumption. This problem shall be rectified by using these converters hence using this converter helps in stabilizing the grid besides charging. This technology can also be improved to make a smart charging system that monitors the grid and PV power levels and charges the vehicles according to it. Integrate this converter with a smart monitoring system that monitors grid load levels and varies. the output power to charge the vehicle besides providing grid stability. This system interfaces with vehicles and smartphones. As clean energy initiatives gain momentum, the integration of bidirectional charging systems like this is expected to become an essential component in the continued growth of electric mobility and the optimization of renewable energy utilization.

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