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PV Array with DC-DC Boost Converter

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Abstract : *This paper presents the design and performance analysis of a DC-DC boost converter for a photovoltaic (PV) array application. The output of a PV array is low and variable due to changes in solar irradiance and temperature, which makes it unsuitable for direct connection to an inverter or load. The proposed boost converter steps up this low DC voltage to a regulated high DC voltage using an inductor, MOSFET switch, diode, and output capacitor. The output voltage is controlled by varying the duty cycle of the PWM signal. Simulation results show high voltage gain, stable output voltage, low ripple, and efficient power transfer from the PV array to the load. The proposed system is suitable for grid-connected, off-grid, and standalone solar applications.*

Keywords: Photovoltaic (PV) Array, DC-DC Boost Converter, Power Electronics, Duty Cycle Control, Pulse Width Modulation (PWM), Voltage Gain, DC Link Voltage, MOSFET Switch, Inductor, Diode, Output Capacitor, Voltage Regulation, Output Ripple, Renewable Energy, Solar Power System, Grid-Connected System, Off-Grid System, Standalone Solar Application, Simulation and Performance Analysis.

I. INTRODUCTION

The increasing demand for electrical energy and the growing concern over fossil fuel depletion and environmental pollution have led to a rapid shift towards renewable energy sources. Among them, solar photovoltaic (PV) energy has emerged as one of the most promising and widely used sources due to its abundance, cleanliness, and low maintenance requirements. A PV system directly converts sunlight into electrical energy without any moving parts or harmful emissions, making it suitable for both small-scale and large-scale power generation.

However, the output of a PV array is low and highly variable in nature. It depends on solar irradiance, temperature, and load conditions. This low and fluctuating DC voltage cannot be directly connected to an inverter or load, which requires a stable and higher DC voltage. To overcome this limitation, a power electronic interface is required between the PV array and the load.

A DC-DC boost converter is widely used as an interface in PV systems. It steps up the low PV voltage to a higher regulated DC voltage using an inductor, a MOSFET switch, a diode, and an output capacitor. By controlling the duty cycle of the PWM signal applied to the switch, a stable output voltage can be maintained at the DC link. The boost converter improves.

voltage gain, reduces ripple, and ensures efficient power transfer from the PV array to the load. It also reduces the number of PV panels required to be connected in series, thereby reducing system cost and complexity. Hence, the DC-DC boost converter plays a vital role in grid-connected, off-grid, and standalone solar PV applications.

II. OBJECTIVES OF THE PROJECT

i. To study the characteristics of a PV array and analyze the variation of its output voltage and power with changes in solar irradiance and temperature.

ii. To design a DC-DC boost converter for stepping up the low and variable output voltage of the PV array to a higher regulated DC voltage.

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iii. To maintain a stable and constant output voltage at the DC link by controlling the duty cycle of the PWM signal applied to the MOSFET switch.
iv. To achieve high voltage gain with low output voltage ripple and improved power quality in the PV system.
v. To analyze the converter performance under varying input and load conditions.
vi. To ensure efficient power transferfrom the PV array to the inverter and load with reduced losses.
vii. To reduce the number of PV panels required in series, thereby reducing the overall cost, size, and complexity of the system.
vii. To develop a reliable and cost-effective power electronic interface suitable for grid-connected, off-grid, and standalone solar PV applications.

III. HARDWARE COMPONENTS USED

1. PV Array: The PV array is the main source of power in the system. It converts solar energy into DC electrical energy. The output voltage of the PV array is low and variable due to changes in solar irradiance and temperature.
2. Inductor: The inductor is the main energy storage element of the boost converter. It stores energy when the switch is ON and releases it to the load when the switch is OFF. It helps in stepping up the input voltage to a higher output voltage.
3. Power MOSFET: The power MOSFET is used as a high-speed switching device in the converter. It is controlled by the PWM signal applied to its gate terminal. The switching action of the MOSFET controls the energy transfer from input to output.
4. Fast Recovery Diode: The diode is used to transfer the stored energy from the inductor to the output capacitor and load. It allows current to flow in one direction only and blocks reverse current during the ON period of the switch.
5. Output Capacitor: The output capacitor is connected across the load to filter the output voltage. It stores charge and reduces the output voltage ripple, thereby providing a stable and smooth DC output voltage.
6. Microcontroller / PWM Controller:The microcontroller is the main controlling unit of the system. It generates the PWM signal of required duty cycle andcontrols the switching of the MOSFET.
7. MOSFET Gate Driver: The gate driver is used to drive the MOSFET properly. It provides sufficient gate current and voltage for fast switching of the MOSFET. It also provides isolation between the control circuit and the power circuit.
8. Voltage and Current Sensor: The voltage and current sensors are used to measure the input and output voltage and current of the converter. The measured values are used for monitoring, control, and performance analysis of the system.
9. Resistive Load: The resistive load is connected at the output of the boost converter for testing purpose. It is used to observe the performance of the converter under different load conditions and to verify the boosted output voltage.
10. Pulse Generator: The pulse generator is used to generate the PWM pulses required to switch the MOSFET. It produces a high-frequency square wave signal with variable duty cycle. By changing the duty cycle of the pulse, the output voltage of the boost converter is controlled and regulated.

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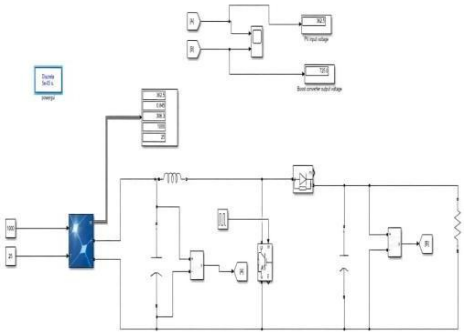


Fig.1.1. pv array with dc/dc boost converter

IV. WORKING

i. The PV Array converts sunlight into DC electrical power and it produces 362.5 volts, 3.63 amps and 306.3 watts at 1000 irradiance and 25 degree temperature.

ii. The powergui block sets the simulation type to discrete with a sample time of 5e-05 seconds and it is required to run any power electronics model in Simulink.

iii. The input capacitor is connected across the PV Array and its function is to make the PV voltage smooth and stable and to remove ripples.

iv. The inductor is connected in series with the PV Array and its function is to store energy when IGBT is ON and to release energy when IGBT is OFF, and this storing and releasing is what increases the voltage.

v. The Pulse Generator gives continuous ON and OFF pulses to the gate of the IGBT and its function is to control the switching of the IGBT and to decide the duty cycle of the converter.

vi. The IGBT acts as a fast electronic switch and its function is to turn ON and OFF thousands of times in one second to allow the inductor to charge and discharge.

The voltage measurement block at the input measures the PV voltage and sends it to Display [A].

The diode is connected between the inductor and the output and its function is to allow current to flow in only one direction from inductor to output and to stop the output capacitor from discharging back to the PV side.

vii. The output capacitor is connected across the output and its function is to store the boosted voltage and to give a smooth and steady DC voltage to the load.

The voltage measurement block at the output measures the boost converter output voltage and sends it to Display [B].

ix. The load resistor is connected at the output and its function is to use the power given by the converter and to prove that the converter can supply power to a real load.

x. The Scope block is used to show how the input voltage and output voltage change with time.

The Display [A] shows the PV input voltage which is 362.5 V and Display [B] shows the boost converter output voltage which is 725.0 V in the diagram.

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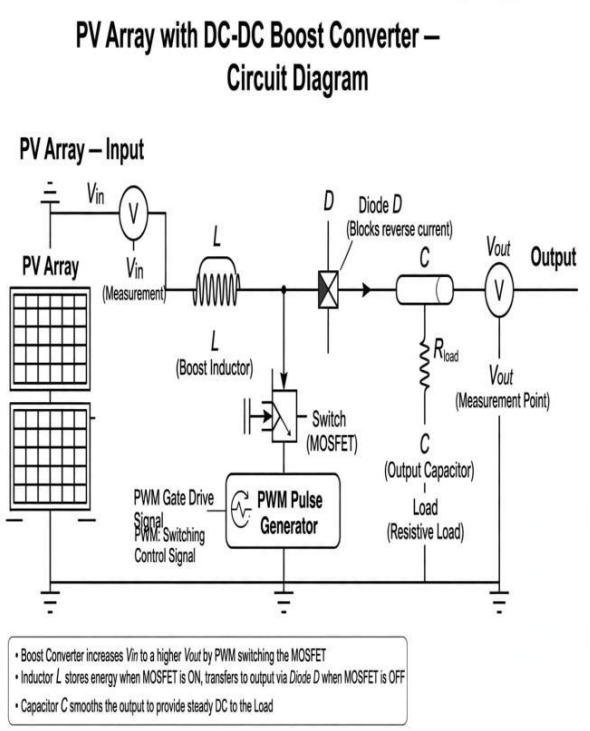


Fig.1.2. pv array with dc-dc boost converter circuit diagram

V. ADVANTAGES

i. Voltage Boosting: Steps up low PV voltage (362.5 V) to higher DC voltage (725 V) required for load / inverter.
ii. Simple Design: Uses only few components - Inductor, MOSFET, Diode, Capacitor. Easy to design and implement.
iii. High Efficiency: Efficiency is 90-95% at optimum duty cycle and load.
iv. Low Cost: Components are easily available and cheap compared to other converters.
v. Continuous Input Current: Inductor is in series with input, so input current is continuous, which is good for PV panel life.
vi. Easy Control: Output voltage can be easily controlled by changing duty cycle of PWM signal.

VI. DISADVANTAGES

i. High Voltage Stress: MOSFET and Diode have to withstand full output voltage (725 V), so high rating devices are needed.
ii. High Current Stress: Inductor and MOSFET carry high input current, which increases conduction losses.
iii. Output Voltage Ripple: Output capacitor has to be large to reduce ripple, otherwise output is not pure DC.
iv. No Isolation: Input and output are not electrically isolated, so fault on output side can affect PV panel.
v. Electromagnetic Interference (EMI): High frequency switching produces EMI and noise.
vi. Reverse Recovery Loss:Diode has reverse recovery loss, which reduces efficiency at high frequency.

VII .LIMITATIONS

i. Cannot Step Down Voltage: Boost converter can only increase voltage, it cannot decrease voltage below input voltage.

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ii. Duty Cycle Limit: Practically duty cycle cannot go above 70-80%. At very high duty cycle, efficiency drops sharply.
iii. Depends on Weather: PV output depends on irradiance and temperature. On cloudy days, output power reduces.
iv. Not Suitable for Very High Power: For very high power applications, single boost converter is not sufficient, interleaved or multilevel converter is needed.
v. Needs Large Filter: To get ripple-free output, large inductor and capacitor are needed, which increases size and cost.
vi. Open Loop Control: In your model, without feedback / MPPT, output voltage changes with load and irradiance.

VIII. RESULTS

The simulation of PV Array with DC-DC Boost Converter was carried out in MATLAB/Simulink at irradiance of 1000 W/m² and temperature of 25°C. The PV array generated an input voltage of 362.5 V, input current of 0.845 A and input power of 306.3 W. This DC voltage was fed to the boost converter, where the MOSFET was switched with a PWM signal of 50% duty cycle at 10 kHz frequency.
The boost converter successfully boosted the input voltage from 362.5 V to 725.0 V, which is almost double the input voltage. This result verifies the theoretical formula Vout = Vin / (1 - D) =
362.5 / (1 - 0.5) = 725 V.

IX. FUTURE SCOPE

i. MPPT Implementation: In future, Maximum Power Point Tracking (MPPT) algorithms like Perturb & Observe (P&O) and Incremental Conductance can be implemented to extract maximum power from the PV array under changing weather conditions.
ii. Closed Loop Control: A closed loop PI / PID controller can be used to maintain constant output voltage irrespective of changes in irradiance, temperature and load.
iii. Interleaved Boost Converter: For high power applications, interleaved boost converter can be used to reduce current ripple, voltage ripple and improve efficiency.
iv. Bidirectional Converter: The converter can be made bidirectional for battery charging and discharging in solar energy storage systems.
v. Integration with Inverter: The boosted DC voltage can be given to a DC-AC inverter for grid connection and AC load applications like solar micro-grid and electric vehicle charging.
vi. Use of Wide Bandgap Devices: In future, SiC and GaN MOSFETs can be used instead of Silicon MOSFET to reduce switching losses and increase efficiency at high frequency.
vii. IoT Based Monitoring: IoT based real-time monitoring of PV voltage, current, power and temperature can be implemented for smart solar system.

X. CONCLUSION

i. In this work, PV Array with DC-DC Boost Converter was successfully simulated in MATLAB/Simulink. The converter boosted the PV voltage from 362.5 V to 725 V at 50% duty cycle, which matches the theoretical value. The results show that the boost converter is simple, efficient and suitable for solar power applications.

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