Solar Power Generation System with Dual Buck Boost Inverter

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Abstract

The amount of electricity a solar panel system can produce changes a lot depending on the weather and other environmental factors, which can affect how stable and reliable the electricity supply in the grid is. This study introduces a solar power system that generates electricity using sunlight, and it also includes a feature to make the power flow more stable. The system being suggested includes a solar cell array, a group of batteries for storing energy, a dual-sourced DC–AC inverter with buck boost ability, and a boost based dc-dc converter. The dual-sourced DC–AC inverter with buck–boost ability is designed to handle increasing and decreasing voltage levels and also converts direct current into alternating current. The boost power converter acts as a middle step in charging the battery, helping move energy from the solar panels to the battery storage. In the suggested SPGS, the direct current power from either the PV array or the battery bank is turned into alternating current power using one stage of power conversion. The PV array can charge the battery bank using a single-stage power conversion method. This setup improves the overall efficiency of converting power for the PV panels, energy storage system such as battery, and also included with electricity grid. The battery group charges or releases energy based on quick changes in the power output from the solar cells, which helps reduce power variations and keeps the power from the SPGS steady. Moreover, the DIBBDAI can help reduce leakage currents that come from the extra capacitance present in the PV array. The suggested power conversion interface improves the efficiency of converting power, reduces changes in the output power, and lowers leakage currents in the SPGS. The system's performance is checked using simulations done in MATLAB/SIMULINK.

1. Introduction

Severe changes in the climate have led to global warming. To prevent serious and long-lasting effects on the environment, the United Nations supports international agreements to cut down on greenhouse gas emissions. Many countries are working hard to develop renewable energy technologies to reduce the harm caused by these gases. Solar and wind energy, which use proven technology, are widely used to produce electricity. Historically, renewable power generation was associated with high costs and relied heavily on government subsidies; however, advancements in manufacturing technologies have significantly reduced the cost of renewable energy production. In numerous countries, the cost of electricity generated from renewable energy sources has approached or fallen below that of fossil-fuel-based generation, Because of this, more renewable energy systems, like solar panels, are being connected to the electricity network. The amount of electricity these solar systems produce can change a lot depending on things like weather and sunlight. These conditions change depending on the weather and the time of year, and they are something we can't control. With the increasing penetration of SPGSs, rapid fluctuations in their power output can impact the voltage and frequency stability of the distribution network, potentially leading to power interruptions. These changes lower the quality of electricity in the distribution system. Different methods have been used to control the power conversion system in order to reduce the changes in power output from SPGSs. Nevertheless, these approaches typically compromise maximum power point tracking to limit power surges and are primarily effective in suppressing upward power fluctuations. Furthermore, the overall power output of the SPGS may be reduced. To

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mitigate both upward and downward fluctuations, rapid power regulation techniques are necessary, enabling temporary energy storage and release to stabilize the system's power output. Due to its compact size, rapid charge–discharge capability, and operational flexibility, the battery bank shows a lot of promise as a tool for managing energy in the SPGS. Usually, the way to make the load power from the SPGS smoother is by using the battery storage system to make up for the difference between the power it produces at any moment and its usual average level. The average output power of an SPGS can be found using methods like low-pass filtering, operational average filtering, Savitzky–Golay filtering, or Operational regression filtering. Because the actual output doesn't often match the average calculation, the battery bank has to charge and discharge for longer periods of time. The electricity produced by a solar cell array is in direct current form, and the battery bank also stores energy as direct current. Because of this, a special power conversion system is needed to connect the solar array and battery system to the electrical grid, which requires converting direct current to alternating current. An SPGS along with a battery energy storage system can be set up in two main ways: one where the components are connected through an AC system and another where they are linked via a DC system. In the AC-coupled setup, the SPGS and the BESS each connect to the electrical grid on their own. Because of this, both the SPGS and the BESS need separate devices to modify DC to AC power, which makes the electrical design more cumbersome. In the DC-coupled configuration, both the Solar Photovoltaic Generation System and BESS share a mutual DC-to-AC converter, thereby simplifying the overall system architecture. The BESS typically functions by mitigating the fluctuations between the instantaneous power output and its mean value, consequently enhancing the stability and smoothness of the power delivered by the SPGS. Because the instantaneous output power of the SPGS rarely coincides with its average value, the battery bank experiences extended charging and discharging periods. The PV array generates power in the form of DC quantity, and the battery bank similarly reserves energy in DC quantity. Hence, a conversion system is required to connect the PV panels and battery system to the electrical grid by converting direct current to alternating current. The setup of a solar power generation system that includes a energy storage device such as battery can be designed in two main ways: either through an AC-coupled or a DC-coupled configuration. In the AC-coupled setup, the SPGS and BESS each connect directly to the electrical grid. Because of this, both systems need their own DC-to-AC converters, which makes the overall circuit setup more cumbersome. In the DC-coupled setup, the SPGS and BESS dispense the same DC-to-AC converter, which makes the circuit design simpler overall. Nevertheless, the output have more ripples values because of a DC offset. This causes the power electronic devices to need a higher voltage rating and experience more switching losses. Also, traditional Z-source and boost DC-to-AC converters do not work well for leakage current problems in SPGS applications. The bridge operates in synchronization with grid while the dc-dc converter regulates the voltage magnitude and controls the output current, ensuring stable and accurate power delivery. The conventional bridge topology may be substituted with a cascaded bridge framework. The buck–boost converter is commonly realized by connecting two power electronic switches in cascade structure. Alternatively, it can be implemented on the DC terminals of the bridge topology. Nevertheless, the overall power conversion efficiency is compromised, as the transferred energy must be temporarily stored in the inductor and subsequently released. Furthermore, these DC-to-AC converters are typically designed to accommodate only a single DC power source, limiting their flexibility in multi-source configurations. Photovoltaic (PV)-fed transformer less inverters are generally susceptible to leakage currents. To address this issue, numerous inverter topologies and control strategies have been developed by researchers. Nevertheless, PV sources with lower voltages necessitate a boost structure, which in turn diminishes the overall system efficiency. "Several studies have proposed buck-derived transformer less inverters; however, these configurations may be ineffective when the PV source operates at low voltage or under partial shading conditions. In this circumstances, it is evident that contemporary research has increasingly focused on the development of transformer less inverter topologies incorporating buck–boost functionality. Several buck–boost-derived transformer less inverter topologies have been proposed for photovoltaic (PV) systems to enable wide-range operation. However, existing topologies exhibit notable limitations. Although these topologies can operate over a wide range of PV conditions, they typically require eight power switches and a single input inductor, which reduces system efficiency and reliability while increasing overall cost. The proposed buck–boost-derived topology overcomes these limitations by minimizing the number of power switches to five, thereby improving efficiency, reliability, and cost-effectiveness. Another limitation of this topology is that the input PV voltage must exceed the desired output voltage. To address

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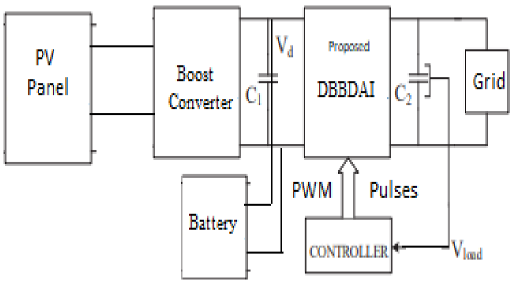
this, an alternative topology employing a coupled inductor has been proposed. This topology is capable of providing a high voltage gain at the output.

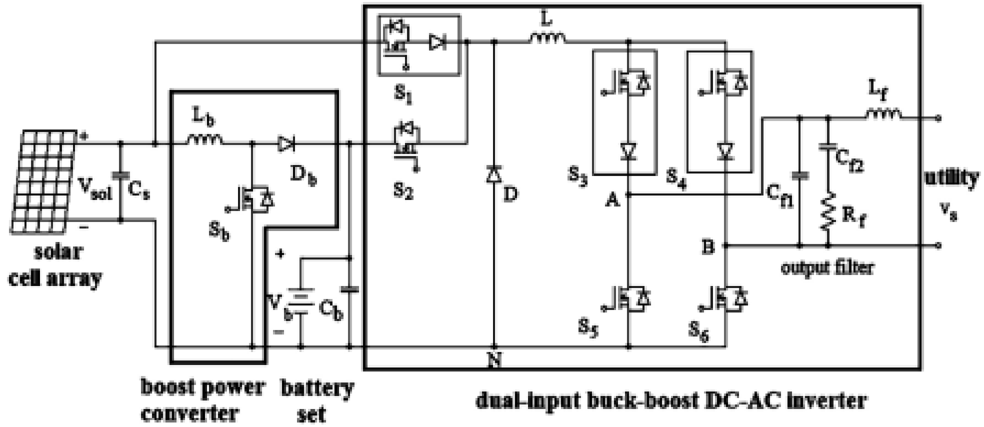
This study presents a solar photovoltaic generation system (SPGS) with improved power-smoothing capabilities. The proposed SPGS employs a dual-sourced buck–boost DC–AC inverter (DIBBDAI) in combination with a boost power converter (BPC) to interface a PV array and an energy storage system such as battery for grid-connected power injection. The DIBBDAI is specifically designed to efficiently integrate and manage two independent DC power sources. In this configuration, the DC power from likewise the PV array or the energy storage system such as battery is converted to AC power exclusively through the DIBBDAI, while charging occurs with the battery bank via the BPC from the PV array. The battery bank charges or discharges in response to significant fluctuations in the solar array's output, thereby smoothing the overall power delivered by the SPGS. Moreover, the PV array effectively reduces leakage currents caused by the parasitic capacitance of the array.

2. Proposed Dibbdai Inverter

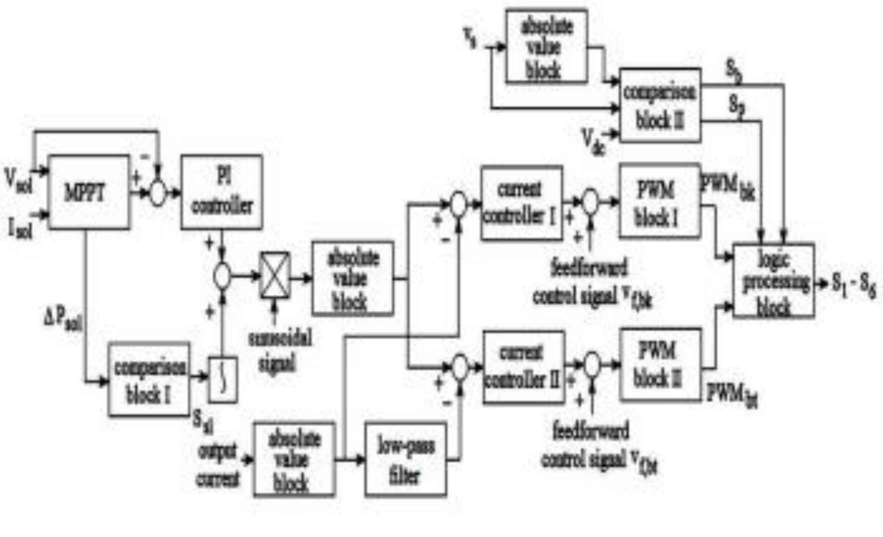
The configuration of the proposed inverter is illustrated below



The proposed SPGS comprises a PV array, a battery bank, and a power conversion system. It comprised of an inverter (DIBBDAI) and a boost converter (BPC). The BPC regulates the energy harvested from the PV panels and direct it to the battery for charging. To reduce the required capacity of the battery bank, it operates only when the power fluctuations from the PV array exceed a predefined threshold, thereby enhancing system efficiency and extending battery lifespan. The battery bank is charged exclusively by the PV array, resulting in unidirectional power flow through the boost power converter. The dual-input buck-boost DC-AC inverter is used to increase or decrease voltage and convert direct current to alternating current. The DIBBDAI and the battery power controller work at the equivalent time. The DIBBDAI takes power from the PV array to send to the ac grid, while the BPC uses power originating the battery bank to charge the battery. The DIBBDAI operates in two modes: boost and buck, with its input terminals interfaced through S1 and S2. Given that the PV cell voltage is lesser than that of the battery voltage, preventing the battery voltage from influencing the operating voltage of the PV array. The S1 and S2 act as the primary switching elements in buck mode. When the solar cell array is active and the battery bank is idle, S1 conducts while S2 remains off. In a configuration where the grid is connected to both DC input terminals—one from the battery bank and the other from the PV array. When the grid voltage exceeds the voltage of the PV array, the DIBBDAI operates in boost mode. During this mode, S1 remains continuously on, while S4 and S3 are operated using PWM control during the positive and negative half-cycles of the grid voltage, respectively. Switches S6 and S5 operate according to the polarity of the grid voltage. When the DIBBDAI is supplied using the battery bank, switch S2 is turned on and switch S1 is turned off. In this situation, the DIBBDAI works in the same way as it does when it is supplied using the PV array, so there is no need to explain it again.

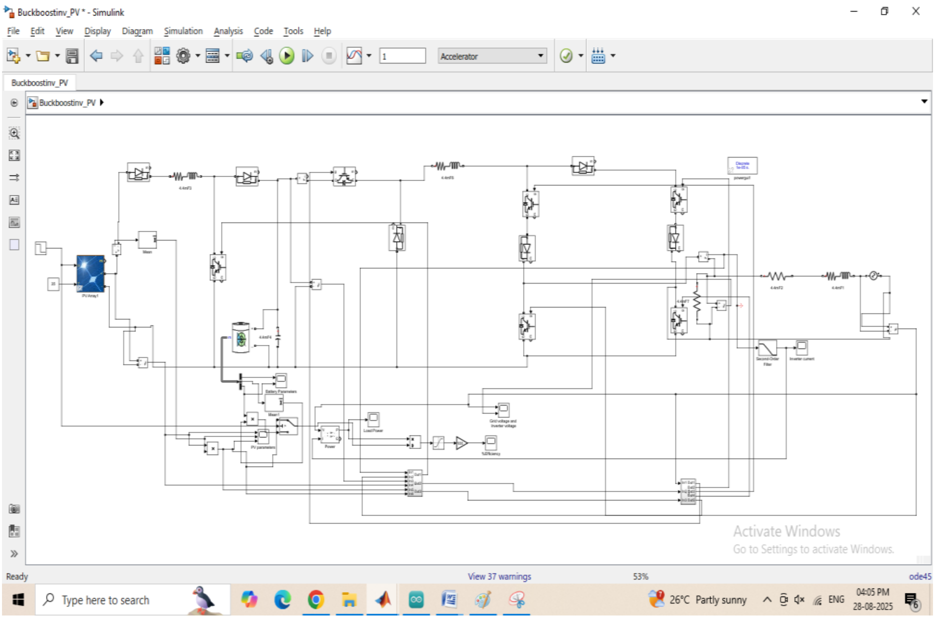


The SPGS smooths its output power when the power change from the PV array, called ΔP_PV, goes beyond a set limit, P1. The value of P1 is chosen depending on how much power variation you want to control. The DIBBDAI continues to be supplied by the solar cell array, while the BPC performs maximum power point tracking (MPPT) using the perturb-and-observe (P&O) algorithm. Consequently, the output current of the DIBBDAI is regulated to increase linearly according to a predefined slope, resulting in a corresponding linear rise in the SPGS output power (Pout_\text {out} Pout. Under this condition, the divergence between the photovoltaic power variation (ΔPPV\Delta P_\text {PV} ΔPPV) and Pout_\text {out} Poutremains positive. This excess power is automatically directed to the battery bank through the BPC, thereby increasing the battery's state of charge. When the output power, P_out, is greater than the solar power change, ΔP_PV, by a certain amount called P2, the DIBBDAI controls the output current to keep it steady. The BPC keeps trying to get the most power from the solar panels, which is called MPPT. In this case, the divergence between ΔP_PV and P_out turns negative, meaning the system is using more power than it's getting from the solar panels. This shortage of power is then covered by the battery bank, which lowers its charge level. If the solar power change stays the same, the BPC stops working when the battery's charge drops to 60%. The DIBBDAI continues to perform maximum power point tracking (MPPT). At this stage, the output power variation is denoted as P2, which must not exceed P1 to ensure compliance with the allowable regulation limits.

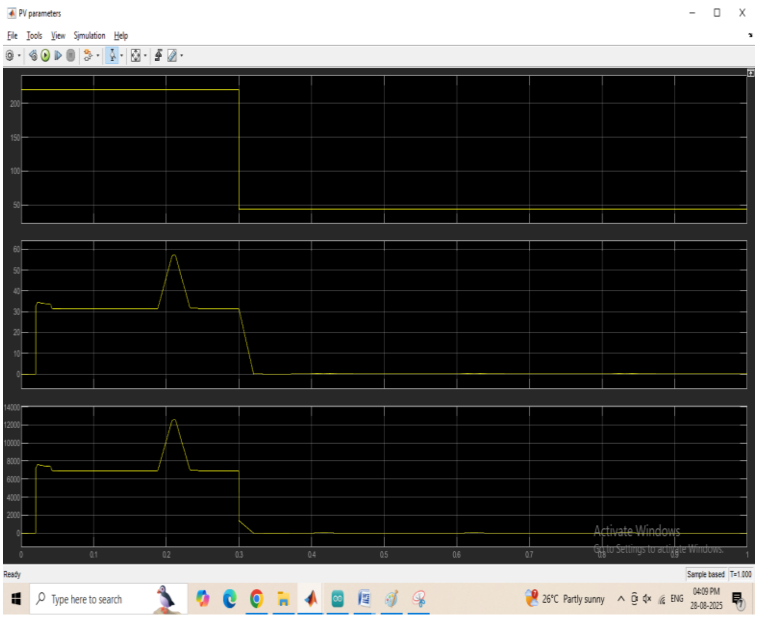


3. Simulation Results

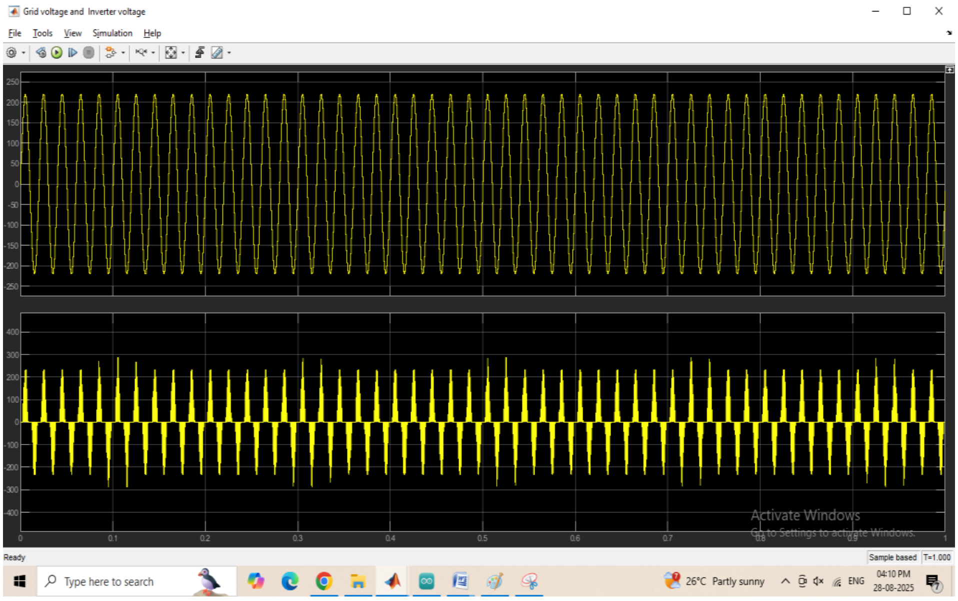
The schematic of the simulation circuit is illustrated below:



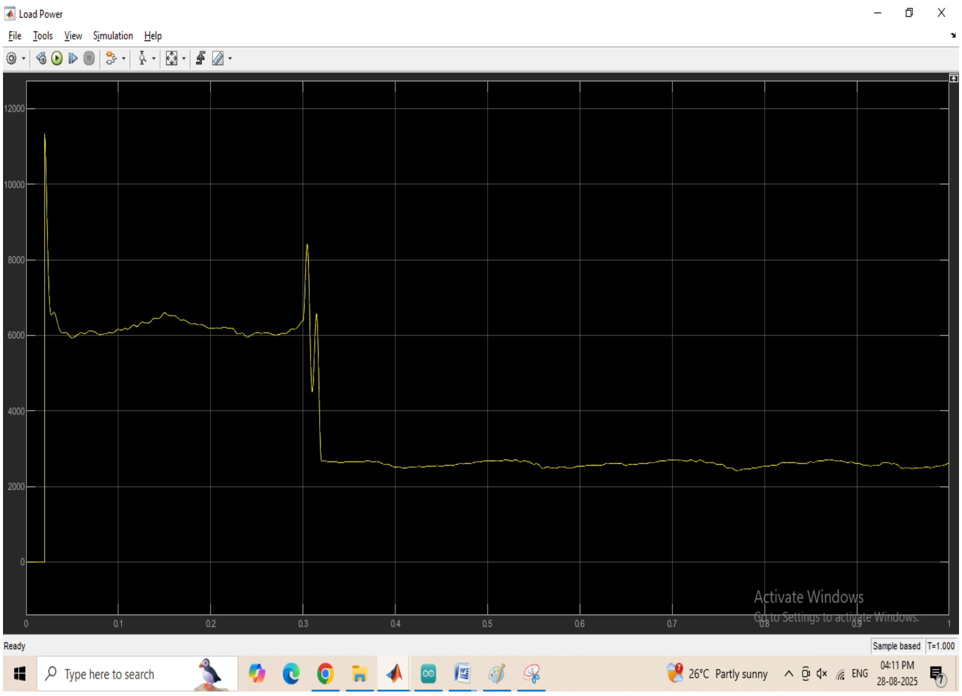
In this configuration, a PV source rated at 105 V and 7200 W supplies power to the inverter, which steps up the voltage to 230 V for injection into the grid. A battery with a voltage of 192 V and a capacity of 4.5 Ah serves as a secondary power source. The PV voltage, current, and power characteristics are presented below:



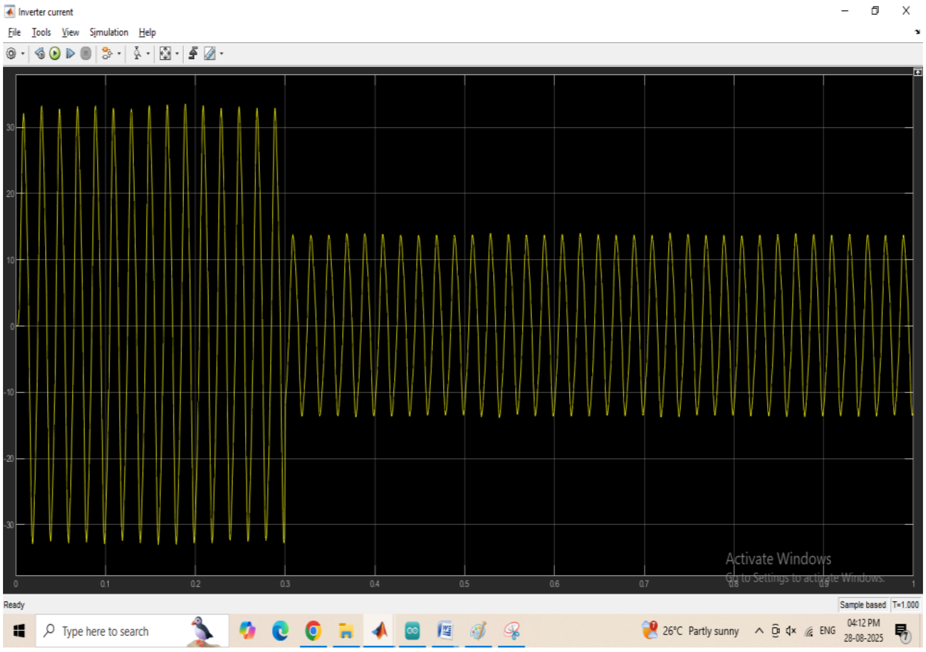
The PV converter operates at approximately 240 V with a current of 30 A, delivering a power output of approximately 7100 W. The grid voltage and inverter output voltage are depicted in the following figure:



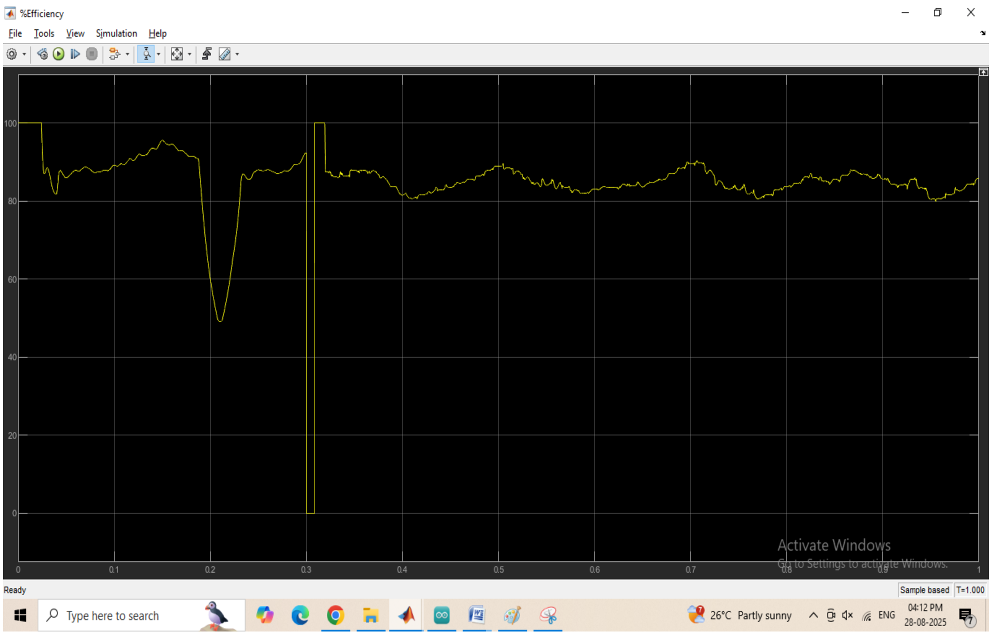
The inverter output voltage is approximately 240 V, while the grid voltage is around 220 V. The load power is illustrated in the following figure:



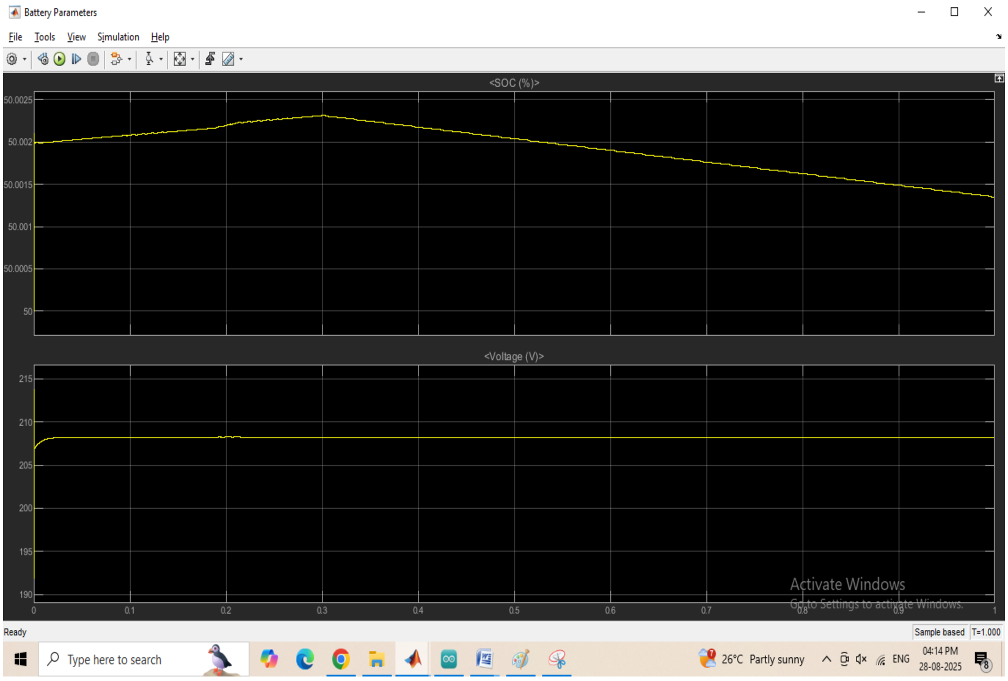
The load power is around 6600W. The load current is provided below:



The inverter current is around 32A. The efficiency of the proposed inverter is provided below:



The efficiency is around 88%. The battery %SOC and voltage is provided below:



In this the battery is charging until t=0.3s when PV source is available and %SOC is increasing and when PV is not available, battery is discharging and SOC is reducing.

4. Conclusion

In this, both the modes with PV as source and with battery as source is analysed and the simulation is done and results are discussed. The battery acts as load when PV is available and acts as source when PV is not available and the overall efficiency is achieved around 88%.

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