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Solar Bidirectional Converter for Enhanced Power Management

D. Suresh [1], B. Deekshith kumar [2], M. Sai Chandra [3], P. Shashank [4], Mr. K. Srinivasa Rao [5]

U.G. Student, Department of Electrical and Electronics Engineering, Anurag University, Telangana, India. [1,2,3,4]

Assistant Professor, Department of Electrical and Electronics Engineering, Anurag University, Telangana, India[5]

ABSTRACT: The increasing need for renewable energy sources has led to a rise in research on efficient and sustainable power generation technology. Solar energy is one of the most widely used renewable energy sources, but in order to efficiently capture and manage the energy produced, it needs complex power electronics converters. Crucial components of this project work include the modelling of the solar PV array, the design of the bidirectional converter, and the development of trustworthy control techniques. The simulation's output demonstrates the converter's ability to regulate power flow in response to shifting solar and grid circumstances. A few advantages of the bidirectional converter system are enhanced grid stability, increased energy efficiency, and the ability to help with grid support tasks including voltage regulation and frequency control. The project also examines the effectiveness of the converter in different scenarios, such as rapid variations in solar irradiance and grid disruptions. This research supports on-going efforts in the field of renewable energy by offering a versatile and efficient way for integrating solar power into the current grid architecture. The results of the MATLAB-based simulation, which validate the feasibility and efficiency of the proposed bidirectional

I. INTRODUCTION

As the world's energy demand rises and carbon emissions must be reduced, the energy landscape has fundamentally moved towards renewable sources. Among these, solar energy is the most well-known and abundant. However, because solar power generation is sporadic, it presents a challenge to the seamless integration of solar power systems with conventional power systems. To overcome this, bidirectional power flow between solar photovoltaic (PV) arrays and the grid needs to be successfully managed by advanced power electronics technologies. MATLAB is the primary modelling tool used in this research, which offers a comprehensive analysis of the design, modelling, and implementation of a solar bidirectional converter control system. The fast growing number of solar energy installations emphasizes the need for sophisticated power management systems that can adapt to the variable nature of solar power generation. Conventional unidirectional converters can't completely utilize bidirectional power flow, which restricts how much solar energy they can use. A bidirectional converter can carry electricity to and from the grid efficiently, removing this restriction and enhancing the overall sustainability and dependability of the power system. Bidirectional converters, a crucial link between solar PV arrays and the grid, offer dynamic power transfer in response to fluctuating solar conditions and grid demands. Its ability to operate in both directions allows for the addition of excess energy generated during the hours of maximum sunshine to the grid and the removal of power during periods of low solar irradiation. This flexibility is required to balance energy supply and demand, enhancing power system stability. A validated bidirectional converter control system that effectively regulates the power flow between solar panels and the grid is one of the anticipated outcomes. The study's findings should benefit the renewable energy industry by providing a versatile means of enhancing solar power's integration into the networks that are in place today.

II. LITERATURE REVIEW

The approaches for bidirectional power flow regulation were analyzed, providing insights into the challenges and algorithms associated with grid integration. The extra contributions from literature review for the Solar Bidirectional Converter Control project include numerous research covering significant aspects of power electronics, bidirectional converters, and solar energy integration. Scholars such as Li, Kulkarni, and Guerrero have provided ideas for the research by having Siano look into bidirectional converters in electric automobiles and grid-connected PV systems. In addition, Patel and Tey's research elucidated the optimal dimensions, control strategies, and modeling elements for energy storage systems and solar installations. Venkatraman and Chen, on the other hand, dive into dynamic modeling and complex control mechanisms for renewable energy and solar systems; Blaabjerg's ideas expand the subject to wind power.

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The comprehensive study, which offers a variety of perspectives to address problems and enhance the field of solar power integration technologies, provides a solid foundation for the Solar Bidirectional Converter Control project. The breadth of the literature review is expanded by additional research, which deepens our understanding of solar energy integration and bidirectional converters. The study conducted by Acha et al. on power quality enhancement methods in renewable energy systems provides insight into lowering harmonic distortions and grid instability, two problems that are crucial for bidirectional converters. Lara-Moreno et al.'s evaluation of inverters for grid-tied solar systems covers regulation schemes and technological advancements, offering a comprehensive grasp of the shifting environment crucial to bidirectional power flow control. The study conducted by Liserre et al. on real-time simulation technologies for power electronics controllers provides valuable perspectives on testing and verifying bidirectional converter control algorithms to assure their efficacy in practical settings. El-Shatter et al.'s analysis of the patterns and challenges of incorporating renewable energy sources into the grid provides context for understanding the opportunities and challenges of bidirectional converter applications. Chakraborty et al.'s study of solar module smart inverters identifies traits that enhance grid stability and suggests potential synergies with bidirectional converter control methods. Sharma et al.'s examination of grid integration problems in photovoltaic power conditioning units provides information on control tactics for bidirectional power flow in solar energy systems. Shen et al.'s rigorous examination of current grid-connected inverter control approaches presents nuanced perspectives that are pertinent to bidirectional converters, especially in the context of solar energy applications. Hasanien et al.'s study on grid synchronization strategies for single-phase renewable energy systems offers valuable insights into bidirectional converters in grid-tied solar applications. Collectively, these studies broaden our understanding of the challenges and opportunities related to solar energy integration, which benefits the Solar Bidirectional Converter Control project, which is navigating the intricate problems of bidirectional power flow management within the context of renewable energy systems.

III. DESIGN OF BIDIRECTIONAL CONVERTER

For this project, the non-isolated DC-DC converter has been selected. First, we are aware of the two modes of operation for this converter. Here, bidirectional actions are made possible by replacing the diodes with controlled switches. While switch S2 is triggered for backward operation in Boost mode, switch S1 is actuated for forward operation in Buck mode. The converter functions in the manner described below:

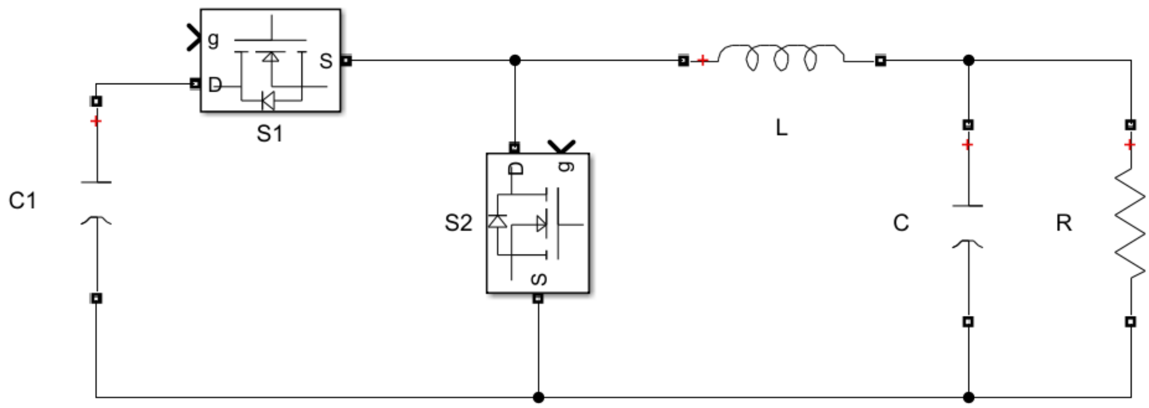

Fig 1 Bidirectional Converter

Buck mode (Forward operation): When switch S1 is turned on, the input current rises and passes through S1 and L. The inductor current decreases until the next cycle when S1 is turned off. Battery charging works by using the energy that is stored in inductor L. The output voltage is lower than the input voltage when using the Buck mode. As shown in Fig., switch S1 is turned on and switch S2 is left off in order to charge the battery from the DC grid.

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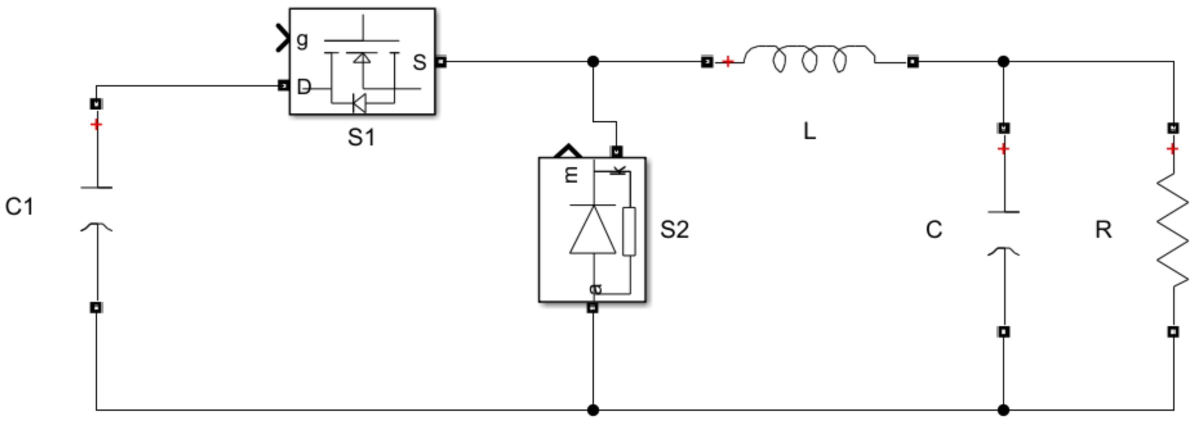

Fig 2 Bidirectional Converter In Buck Mode

Boost mode (Backward Operation): When the boost mode is on, the output voltage is higher than the input voltage. The battery discharges power to the load when switch S1 is off and switch S2 is tripped. The operation of this mode is shown in Figure. When switch S2 is turned ON, the input current increases through inductor L and switch S2. Up until the next cycle, when S2 is turned off, the inductor current drops. The energy contained in inductor L is applied to the load.

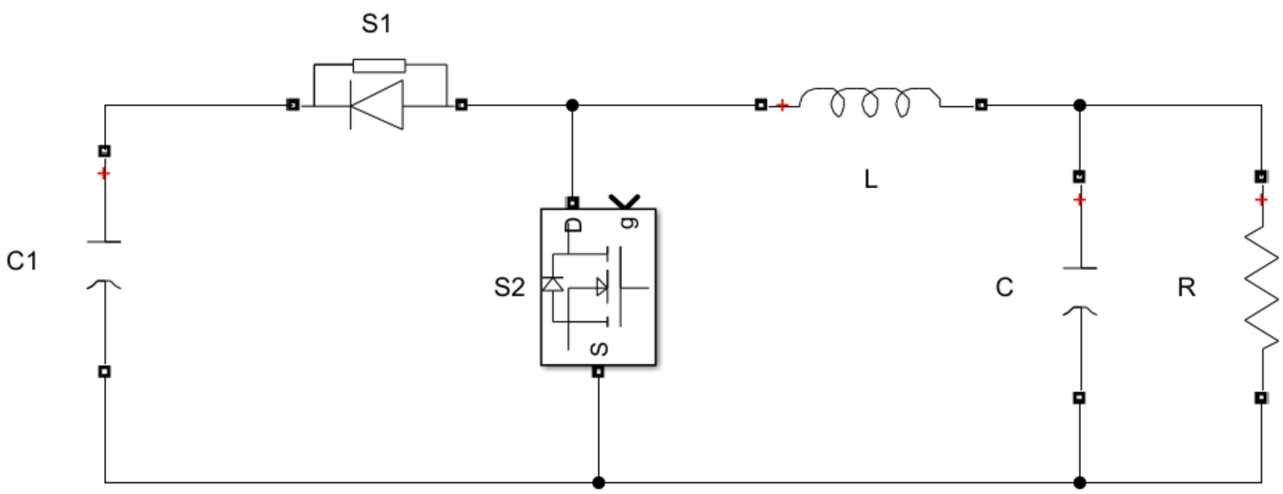

Fig 3 Bidirectional Converter In Boost Mode

IV. MPPT ALGORITHM

INCREMENTAL CONDUCTANCE:

The P-V curve's slope is found using the incremental conductance algorithm, and the MPP is found by looking for the curve's peak. For MPPT, this technique makes use of the incremental conductance (dI/dV) and the instantaneous conductance (I/V). The PV module's operating point in the P-V curve can be found based on the relationship between the two values, as stated in (1)–(2). That is, (1) indicates that the PV module operates at the MPP, while (2) and (3) indicate that it operates at the left and right sides of the MPP in the P–V curve, respectively.

$$\frac{di}{dv} = VI\text{---}\ (1)$$

$$\frac{di}{dv} > VI\text{---}\ (2)$$

$$\frac{di}{dv} < VI\text{---}\ (3)$$

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The above equations are obtained from the concept where the slope of the P–V curve at MPP is equal to zero, i.e;

$$\frac{dp}{dv} = 0\text{---}(4)$$

By rewriting (4), the following equation is obtained:

$$I+V\left(\frac{di}{dv}\right) = 0\text{----}\ (5)$$

The MPPT controller senses the voltage and current of the PV module, and the classic incremental conductance algorithm uses (5) to get the MPP. In the event that (2) or (3) are satisfied, the duty cycle of the converter has to be decreased; in the event that (5) is satisfied, on the other hand, the duty cycle stays the same.

An increase in solar radiation may confuse the standard algorithm. As shown in Fig., the MPPT algorithm adjusts the duty cycle to ensure that the PV system operates at load line 2 and that the MPP (point B) is tracked while the irradiation is at 0.4 kW/m2. Even after solar irradiation reaches 1.0 kW/m2, load line 2 keeps the duty cycle constant. Therefore, point G—which corresponds to the power at point C in the P–V curve—will be found using load line 2 in the I–V curve of 1.0 kW/m2. Using the conventional incremental conductance method, it is found that the gradient between sites B and C is positive.

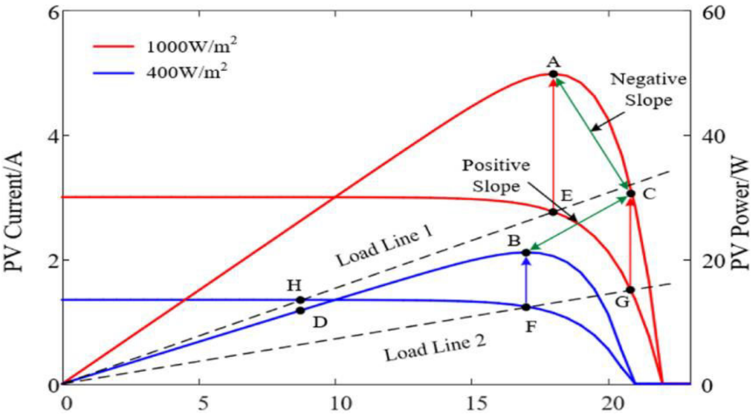

Fig 4 P-V curve's slope

The gradient of 1.0 kW/m2 between point C and the MPP (point A), however, has a negative value. The usual algorithm boosts the PV module's voltage without detecting the difference when solar irradiation levels vary from low to high, which results in an inaccurate first step change. However, this problem does not occur when sun irradiation decreases from high to low levels. The reason for this is that, in the P–V curve, the gradient is positive between points B and D and between points E and H, or from points A to D.

FLOW CHART OF INCREMENTAL CONDUCTANCE:

Fig. shows the suggested algorithm in a flow chart. Changes in the irradiance will cause variations in the voltage and current as well. Thus, this technique utilizes the instantaneous voltage and current fluctuations in the PV modules. Unlike the standard incremental conductance method, which determines the position of the system operating point, the enhanced incremental conductance algorithm makes a choice based on the directions of power, voltage, and current. When the system is working in the positive direction (dv > 0), as shown when examining the system on the left side of the MPP, the duty cycle will continue to move in the direction of the disturbance from the previous step.

The duty cycle will continue to move in the opposite direction of the disturbance from the previous step as long as the system is operating in a negative direction (dv 0). On the other hand, the duty cycle will continue to move in the same direction if the system is operating in a negative direction (dv<0). This resolves the system misjudgement problem in the traditional technique since the algorithm can accurately and precisely estimate the direction of disturbance of the next working point step. The incremental conductance algorithm establishes the starting values of the voltage (V), current (I), and power (P) to determine the system parameters. The program monitors power and voltage differences once it is in a loop. Firstly, the incremental conductance (dP/dV) inside the loop is calculated by measuring the rate at which power changes in relation to voltage. Next, the procedure is applied to compare this computed number to zero. In the event that dP/dV equals zero, indicating that the system is at the MPP, the procedure maintains the system at its current operating point. Conversely, the algorithm confirms if dP/dV is not negative. If dP/dV is positive, then the voltage needs to be raised in order for the system to approach the MPP. The algorithm adjusts the voltage in accordance with changes made to the power and current figures. If dP/dV is negative, the system has to lower the voltage, and the algorithm makes the necessary adjustments.

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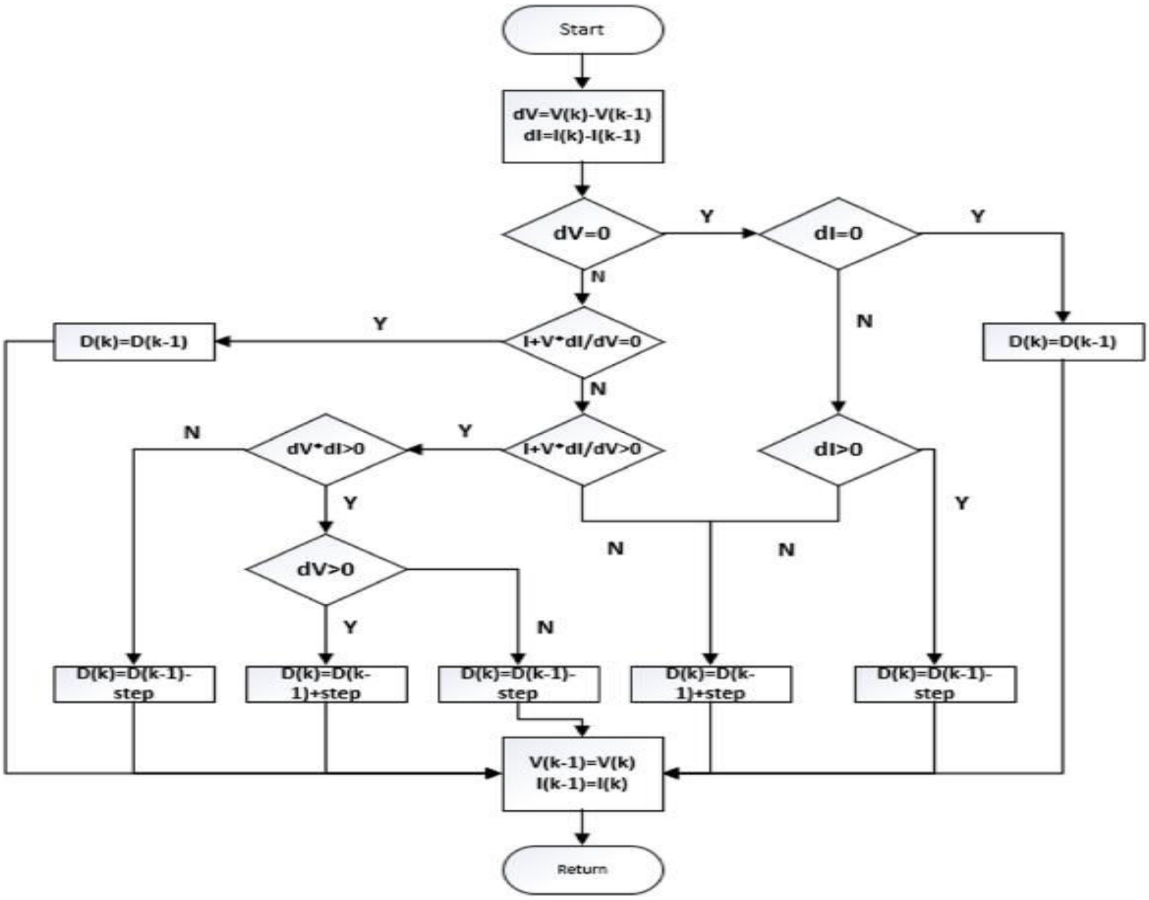

Fig 5 Flow Chart of Incremental Conductance

CODE OF INCREMENTAL CONDUCTANCE

```
function D=DutyRatio(V,I,Din)
Dmax=0.75;
Dmin=0;
Dinit=0.05;

persistent Vold Pold Dold;
if isempty(Vold)
    Vold=0;
    Pold=0;
    Dold=Dinit;
end
P=V*I;
dV=V-Vold;
dP=P-Pold;
D=Dold;
Di=Din;
if dP~=0
    if dP<0
        if dV<0
            D=Dold-Di;
        else
            D=Dold+Di;
```

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```
        end
    else
        if dV<0
            D=Dold+Di;
        else
            D=Dold-Di;
        end
    end
end

if D>=Dmax
    D=Dmax;
elseif D<Dmin
    D=Dmin;
end
Dold=D;
Vold=V;
Pold=P;
```

SIMULATION CASE STUDY:

The simulation case study for the Solar Bidirectional Converter Control project involves a thorough evaluation of the bidirectional converter system's performance under various conditions. To show the system's adaptability to dynamic variations in the amount of solar radiation, the simulations offer scenarios that range from sunny, bright days to partially surrounded circumstances. The study also examines the bidirectional converter's response to dynamic weather, assessing its resistance to sudden variations in the environment. Grid disturbances such as voltage sags and frequency fluctuations are simulated in order to evaluate the system's contribution to grid support functions and its response to external disturbances.

Various scenarios of load variability are provided in order to assess how the bidirectional converter manages power flow while modifying to changing load demands. Peak solar generation and low output periods are simulated in order to assess the system's efficiency in sending electricity to the grid and withdrawing power during periods of low solar production. To determine how successfully the bidirectional converter can maximize energy storage and consumption, simulations of its interactions with energy storage devices, if any, are included in the study. To provide precise control over the two-way power flow and stable operation, the control algorithm's adaptability is put to the test under a variety of conditions.

The study also covers grid-tie operation scenarios to examine the bidirectional converter's seamless synchronization with the grid and compliance with grid standards. Efficiency evaluations are conducted in a variety of operational environments to determine overall performance. Every scenario is fully documented in the case study, giving a detailed analysis of the input conditions and observed outcomes. Furthermore, by introducing simulated fault and failure scenarios, the fault tolerance and protection mechanisms of the bidirectional converter are evaluated, ensuring the system's dependability even in uncommon situations. This comprehensive simulation case study is a useful resource for learning how the bidirectional converter behaves in a range of real-world scenarios, offering suggestions for enhancements, and optimizing its performance for practical application in solar energy integration.

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V. CIRCUIT DIAGRAM

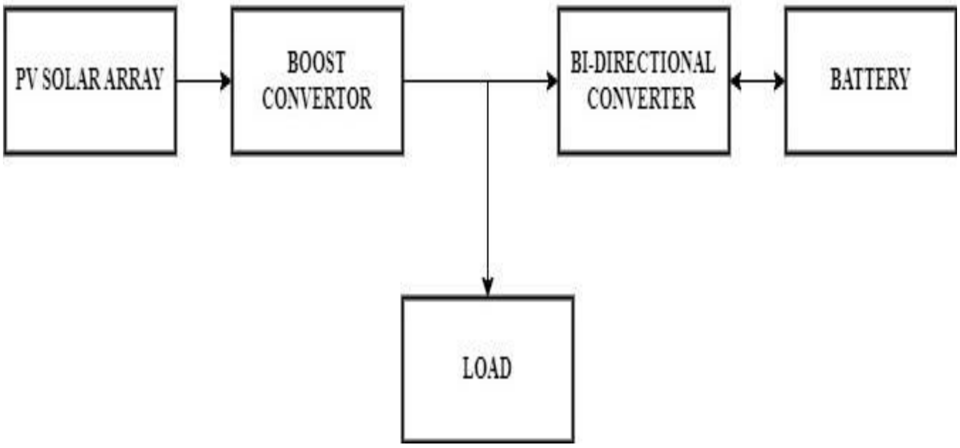

Fig 6 Block Diagram of Solar Bidirectional Converter For Enhanced Power Management

SIMULATION MODEL:

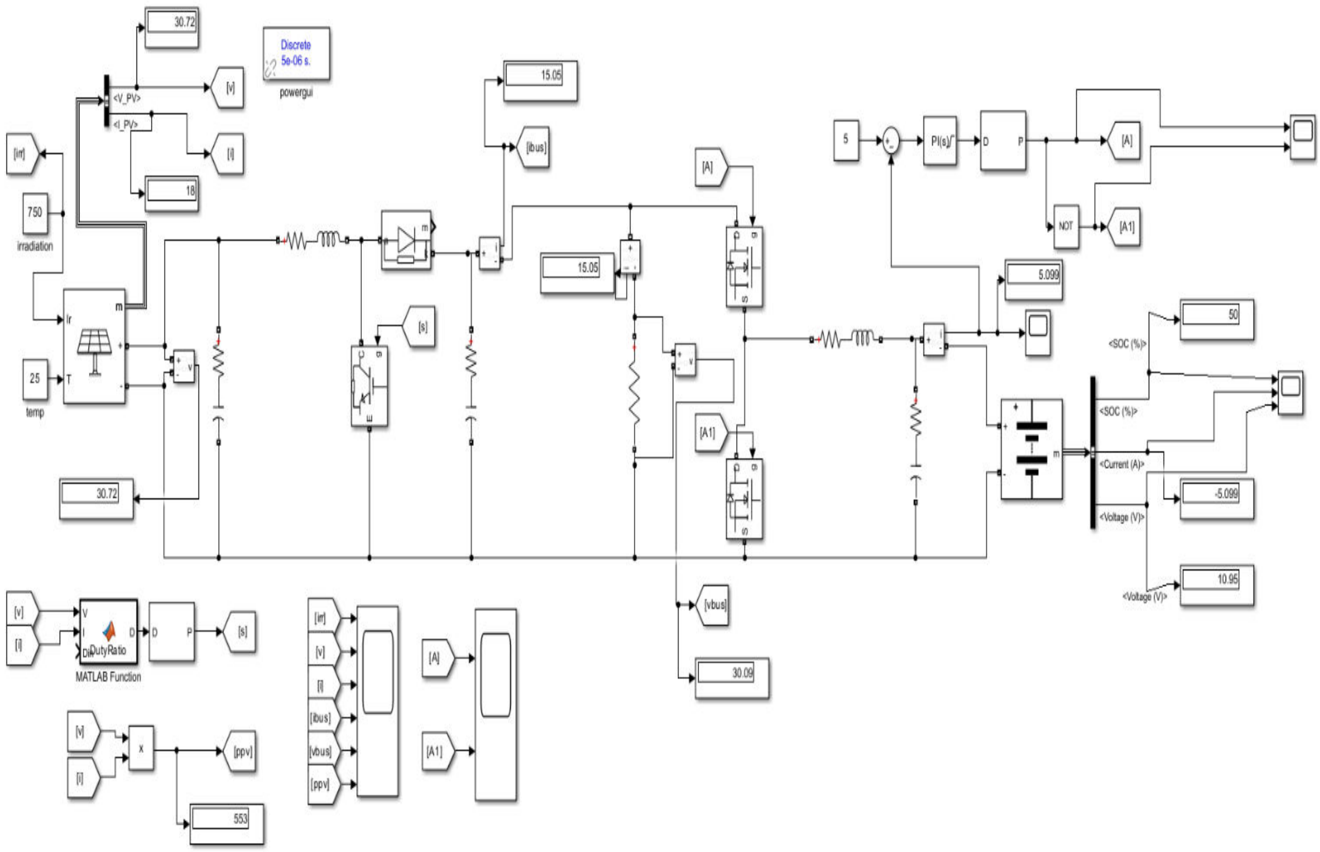

Fig 7 Simulation Model of Solar Bidirectional Converter for Enhanced Power Management

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SIMULATION RESULTS:

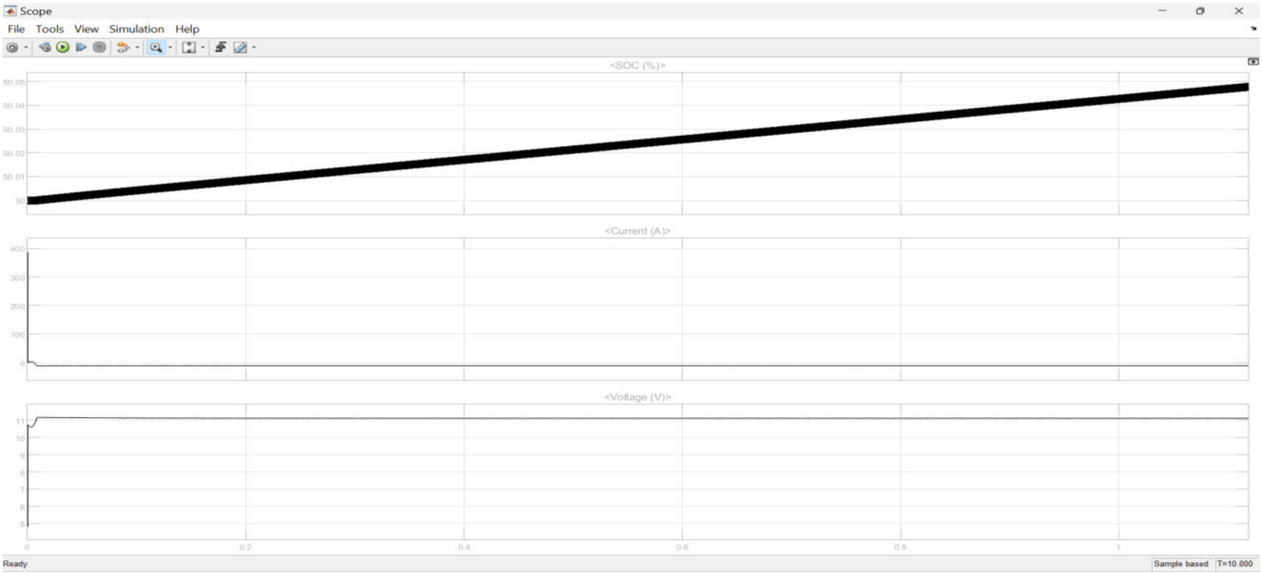

Fig 8 Graphical representation of SOC, Voltage &Current

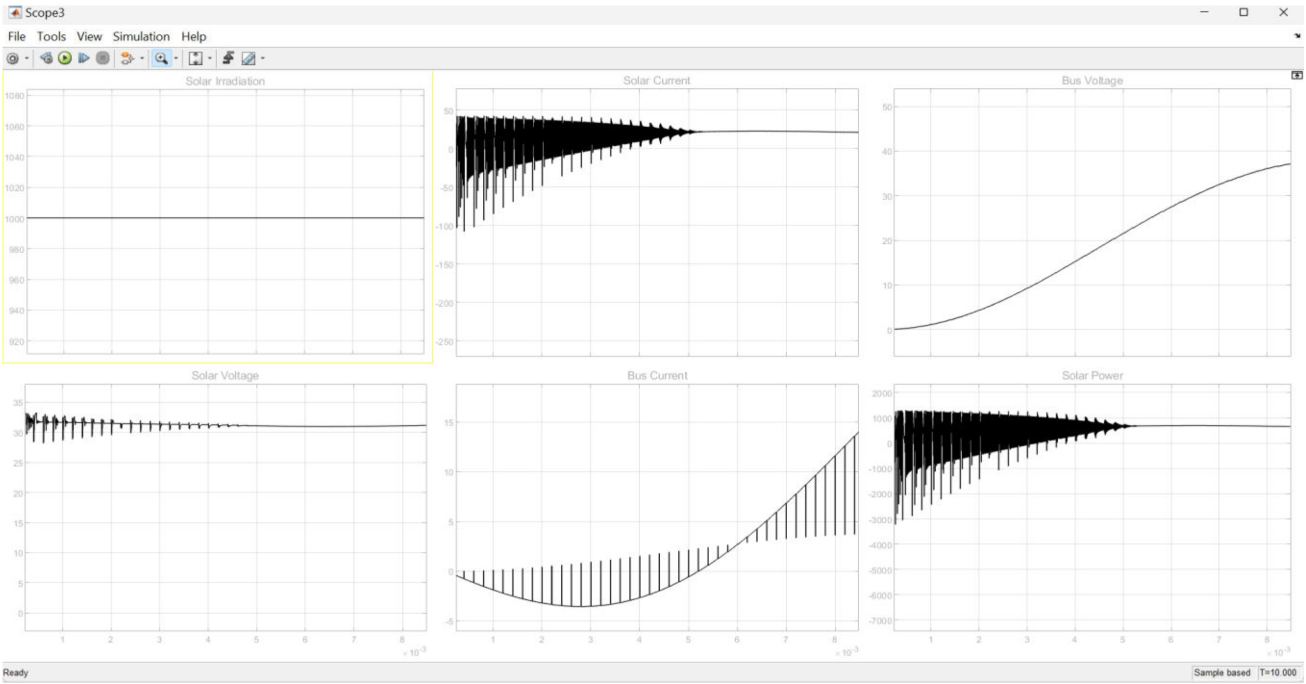

Fig 9 Graphical representation of Solar Irradiation, Solar Voltage, Solar Current ,Solar Power, Bus Voltage , Bus Current

VI. CONCLUSION AND FUTURE WORK

This study finds that the Solar Bidirectional Converter for Enhanced Power Management project is a significant step toward effective power management and sustainable energy solutions. By utilizing solar energy through bidirectional conversion, the system optimizes the utilization of renewable resources and enhances power management abilities.

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Ensuring optimal energy storage and utilization, the bidirectional converter enables seamless energy transfer between the solar panels and the power grid. The system's ability to exchange energy in both directions allows it to draw electricity when needed and contribute excess energy to the grid when it is available. This flexibility contributes to grid stability and builds a more resilient and adaptable energy system. The study also highlights how important it is to employ green technologies in order to address the growing issues associated with environmental sustainability. Because solar energy is clean and sustainable, it plays a critical role in reducing carbon emissions and mitigating climate change. The project's demonstration of bidirectional converter technology demonstrates how solar electricity may be logically integrated into existing power systems, so contributing to a more sustainable and ecologically friendly energy landscape. The successful implementation of the Solar Bidirectional Converter for Enhanced Power Management for EV Applications paves the door for the wider deployment of related technologies in a range of settings, including residential and commercial buildings as well as industrial complexes. As we look into new approaches to improving the environment, this study demonstrates the potential of bidirectional converters to transform power management and support the creation of a more sustainable energy ecosystem.

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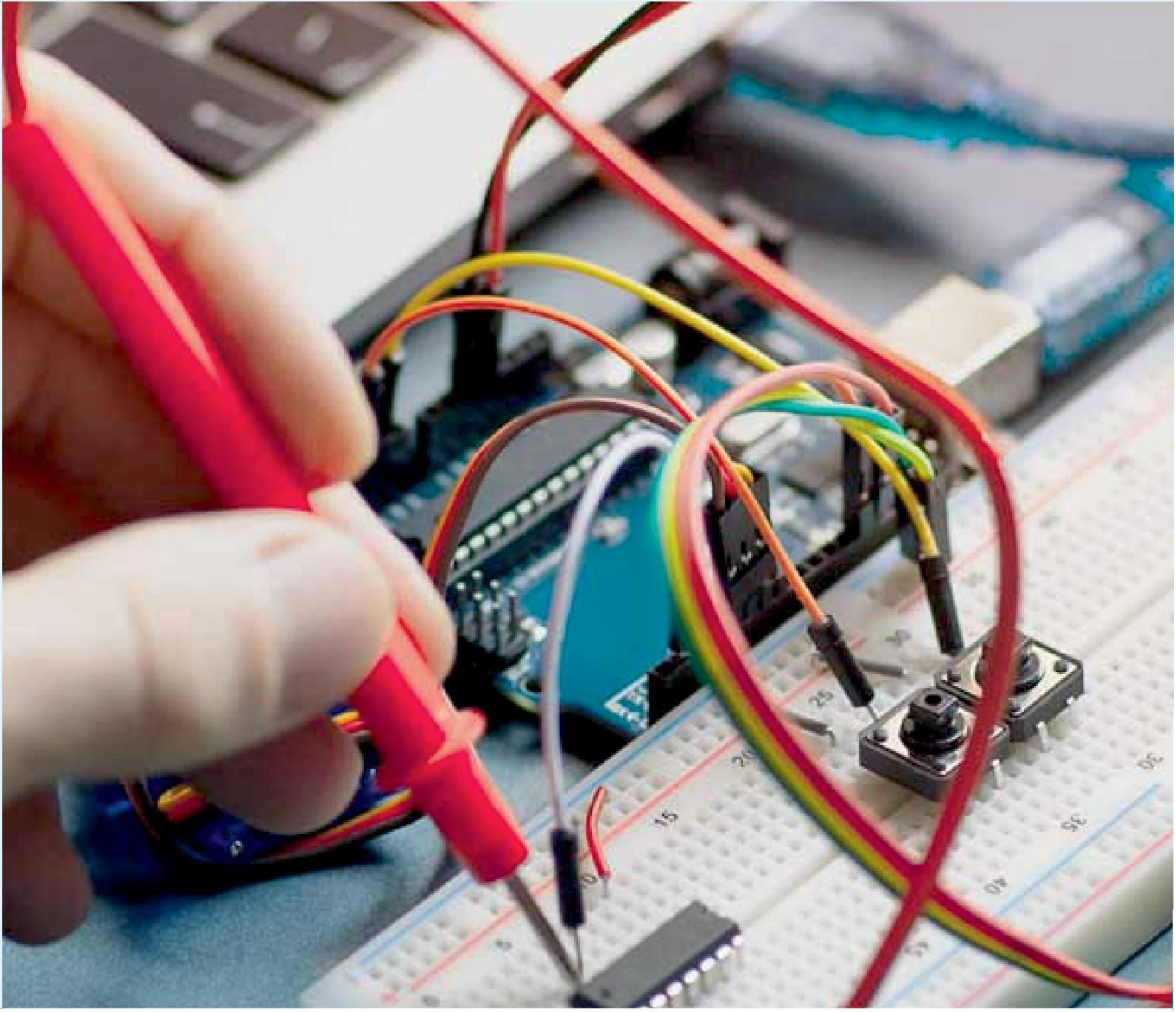

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