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Maximizing Photovoltaic Power Extraction with Double Integral Sliding Mode MPPT Controll

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Abstract:

The sliding mode control system's efficient dynamic duty cycle ratio makes it ideal for solar panel power extraction in partial weather atmospheric circumstances. However, by combining single- and double-integral methods, the strategy for controlling sliding modes was improved. These methods increase the maximum power extraction from solar panels in partly cloudy conditions. The sliding mode control approach considers the weather conditions while choosing a sliding surface, allowing the DC/DC boost converter to operate with a sliding duty cycle ratio. Sliding mode control's duty cycle ratio is more efficient than multiple maximum power point tracking (MPPT) techniques since it is based on normal dynamic behavior. Achieving the solar panel's steady-state voltage inaccuracy in the least amount of time possible is the primary goal of the sliding-mode control system. The single-integral sliding-mode control method accomplishes the projected steady-state voltage error limit, however it is not long enough to meet the minimal settling time duration. We achieve both steady-state voltage error restrictions as quickly as feasible by expanding the single-integral sliding-mode control method and using a double-integral sliding-mode operation. This double-integral sliding-mode control method may be used to get a larger sliding-surface duty cycle ratio. After that, this signal may be used to operate the boost converter. This activates the more steady and dependable system working and closes the gap to the maximum efficiency of the solar panels under partial weather conditions. So, this article's goal is to show you how the DISM MPPT control system is made and how it works. By constructing and analyzing the model in MATLAB/Simulink, the outcomes of the performance evaluation of the suggested DISM MPPT control scheme are confirmed. In order to evaluate the performance of the various controller schemes, we compare the proposed DISM MPPT system against SMC and SISMC. According to the performance research, the proposed DISMC scheme outperforms the prior methods with a settling time of 0.035 s and an efficiency of 99.10%. In this larger field, you may find PV systems, methods for maximum power point tracking (MPPT), SMCs, and DISMCs, or double-integral sliding mode controllers.

Introduction

Smart lifestyle shifts, digitalized sectors, technological advances, etc., have all contributed to a meteoric rise in electrical energy use in recent years. Due to issues such as climate change and insufficient fuel capacity, existing power plants need supplementary power sources[1, 2]. Consequently, there has never been a more critical time to produce clean, socially and economically significant electricity from renewable sources [3]. Social factors must be considered in any nation's development. Among the potential societal benefits of renewable energy systems are the following: more consumer choice, improved health, more job opportunities, and the development of local jobs. We methodically collected data on the socio-economic implications of renewable energy projects utilizing solar, wind, and biofuels as case studies. It is important to take environmental, social, and economic factors into account when calculating the social and economic benefits of renewable energy projects (REPs). Several social factors determine whether renewable energy projects in any given area will be viable over the long term. The development of every country is mostly influenced by societal factors. It is possible that renewable energy systems will lead to many social benefits. Improved health, increased employment opportunities, more consumer choice, and new local jobs are all on the list. Local economies benefit from renewable energy systems because these systems hire people from surrounding rural regions, purchase from neighboring companies, have local stockholders, and utilize bank services. A trust fund will be established using the sales profits. Reinvesting power into the local economy is another way the community has profited from the development of renewable energy plants. Efforts to boost the utilization of renewable energy sources have not only brought more attention to the issue of climate change, but have also improved environmental outcomes by reducing emissions of carbon dioxide. In addition to being dynamic and eco-friendly, solar renewable energy stands out for its ability to create social and economic power. Among the numerous possible advantages of generating energy from fossil fuels without emitting greenhouse gases are the following: a decrease in air pollution, an increase in the number of available jobs in construction and manufacturing, a decrease in reliance on imported hydrocarbons, and a diversification of energy sources. Solar power is outpacing wind power in terms of renewable energy output growth [4-6]. The reason behind this is the abundance of solar panels found in nature. Solar energy is becoming more popular as a means of producing electricity, heating homes, and desalinizing water on a global scale. Solar energy may be converted into electricity more efficiently because to the grid's well-organized design. Current silicon solar cells are very efficient, last a very long time, and are relatively inexpensive. When it came to renewable power production, one of the biggest issues was how unreliable the resources were. The supply is unpredictable due to the variable amount of wind and sunshine, unlike supplies from fossil fuel facilities. There is an almost infinite number of applications for solar energy, including but not limited to: power generation, water heating, air conditioning, lighting, portable solar, and solar mobility. The energy utilization and peak power consumption issues in multi-core systems were proposed to be resolved by using a scheduling algorithm that considers both temperature and power [7]. Heuristic optimization methods enable the building or monitoring of a number of complex objects, which is a significant step towards

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artificial intelligence. Efforts were undertaken to reduce energy use, build energy storage systems, and execute integrated heat and power designs that relied on renewable energy sources [8]. The goal of developing a heuristic intelligent neural decision support system was to enhance estimating methods for both local energy production and demand. This technology employs an enhanced algorithmic method that is based on smart renewable energy systems [9]. Solar renewable energy has a limitless supply, but it is intermittent, which is a huge concern. Because it is so unpredictable, solar power is suitable for use as a backup power source. Maximum power point tracking (MPPT) schemes like perturbation and observation (P&O)[6], incremental conductance (IncCond)[7], variable step size open circuit voltage (VSSOCV)[8], parasitic capacitance (PC) [10], and the short circuit current scheme (VSSOCV)[9] were developed and implemented by researchers to address the problem. Most power point tracking (MPPT) systems are used to guarantee that photovoltaic (PV) arrays run at its MPP, thereby maximizing the power output of the arrays. By improving the efficiency and reliability of PV cell power output, maximum power point tracking (MPPT) revolutionized the solar power industry. Using MPPT algorithms, connected capacitors or multiple inverters control continual updating. In conclusion, while building programs utilizing the SASV-MPPT technique and Lyapunov conceptual design, the best ways keep in mind the PV program's potential to switch between features. A technique called maximum power point tracking (MPPT) was developed to reduce oscillations at the MPP utilizing artificial neural network (ANN) perturb and observe (P&O) technology. In order to calculate the MPP's current and voltage requirements, the ANN takes into account every conceivable combination of cell temperature and sun irradiation. One more common approach to PV system technology is the incremental conductance (INC) method. The MPP may be figured out by comparing the PV array's incremental conductance to its instantaneous conductance. Like the P&O approach, the INC method has an issue. The results would point to a symbiotic relationship between MPPT accuracy and executive function. Nothing of these devices does anything beyond maximum power extraction when confronted with partial darkness. In order to maximize power extraction in partly shaded settings, sliding mode controller (SMC) approaches have lately gained popularity. Systems dealing with shocks and uncertainties would have been wise to use SMC. You can trust this method to get you where you need to go. Additionally, the SMC method varies from previous discontinuous systems as its control inputs alternate between two restrictions.

Methods based on SMC seek to maximize power extraction by initiating effective sliding surface switching operations under partial shadow conditions[11, 12]. Among the many problems with SMC systems are their low power harvesting efficiency from partial shadow, incorrect continuous steady-state voltage, lengthy steady-state settling time, and poor dynamic sliding surface duty cycle ratio. To get around these limitations, an architecture called SISMC was built using the SMC design. These days, electric drive devices' speeds are controlled via sliding mode control. Having a high level of transient reaction, being resistant to changes in environmental factors, and being insensitive to changes in plant variables are all desirable qualities. The reliability of SMC is unparalleled among nonlinear algorithms. The systematic manufacturing procedure of the product provides a straightforward solution to the input signal issue. One of the several benefits of this product is how well it withstands comparable external shocks and sudden changes in its properties. In order to decrease the steady-state error voltage compared to the SMC scheme, the sliding-surface duty cycle ratio was increased and the settling time was improved with the single integral implantation in SMC. We investigate the modulus criterion optimized controller's steady-state error with a sinusoidal input signal. Increasing the switching frequency and making use of several integral components in the controller are two approaches to decrease stable-state failures [13]. Although it can achieve a low steady-state error voltage, the SISMC system has limits. As the settling period of the steady-state error voltage lowers, the long-term instability of the system grows. You can't maximize its potency when there's partial shade. To circumvent this limitation, we created and tested a double integral SMC approach, which shortened the time it took for the system to settle while keeping the steady-state error voltage constant. If you would want your solar panels to function better in partially shadowed areas, the DISMC system is worth considering. This approach improves the sliding duty cycle ratio via a dynamic sliding switching operation, building on prior research[14,15]. In order to prove that the DISMC scheme is worth implementing, this research will create and run a performance analysis comparing it to existing schemes such as SMC and SISMC. As a standard procedure, one may verify the accuracy of a prospective distributed Monte Carlo program's analytical conclusions by comparing them to other computational methods or empirical research. Objective definition, standard development, system implementation, result comparison, risk assessment, and validation against multiple standards are all potential processes in ensuring functional testing of the proposed DISMC system. The MPPT system regulates the switching frequency of the DC-DC converter so that it may be controlled. Prior to modifying the switching frequency, it is crucial to calibrate the frequency response. For this, you may utilize the insertion loss of a DC-DC converter or the resistance of solar PV. In this research, we examine three distinct methods for making green hydrogen, which may be used at refueling stations that use photovoltaic (PV) panels. Finding the best course of action is possible by comparing the three possibilities and making use of the optimal findings of the levelized hydrogen cost (LHC), which are found using techno-economic methods. An affordable solution for sustainable gas production was a 3 MW grid-connected PV system, which cost 5.5/kg [16]. Graphene oxide nanoparticles were added to freshwater at mole fractions of 0.10%, 0.15%, and 0.20%, with concentrations ranging from 0.35 percent to 0.45% and 0.25 percent, respectively, to create a nanofluid. The flat plate solar collector (FPSC)—riser tube was used to evaluate the temperature distribution and viscosity at 25˚C, 30˚C, 35˚C, 40˚C, 45˚C, or 50˚C. In order to provide accurate predictions under all conditions, we analyze data using fuzzy logic and artificial neural network systems, and then we choose the alternative with the lowest chance of error. In relation to the input data, the predictions produced by the fuzzy expert system were clearly quite accurate [17]. What follows is a summary of the paper's major points: A double integral SMC approach was developed and tested in this work to address the issue of insufficient steady state error voltage in a minimum amount of time for system settling. To improve the efficiency of solar panels while they are partially shaded, the DISMC system raises the sliding duty cycle ratio. The proposed DISM MPPT control system's performance assessment was tested using a MATLAB/Simulink model. The paper's general format is as follows: After outlining the research, the DISMC, the results of the proposed method, and our analysis of the work, Section 5 presents the conclusion.

Double Integral Sliding Mode Control

A DC-DC boost converter supplied from a solar PV panel was part of the DISMC scheme of the MPPT approach [14,15]. The pulse width modulation data is received by an integrator-equipped holding circuit. After each positive pulse, the integrator generates a ramping response whose magnitude is inversely proportional to the pulse length. By implementing the increased sliding surface switching actions, the constant potential to the DC-DC boost converter can be obtained by the effective sliding surface duty cycle ratio; this can be seen in the schematic view of the operation of the proposed DISMC scheme in Image 1. Two kinds of DC-DC conversion modes exist: linear and switching. You may get switching DC-DC converters or continuous DC-DC converters. In contrast to a linear DC-DC converter, which generates and controls a production value by resistive power dissipation, a switched-mode DC-DC converter routinely stores the necessary energy and then transfers it to the output at higher voltages. The output of a linear DC-DC converter may be controlled and produced.

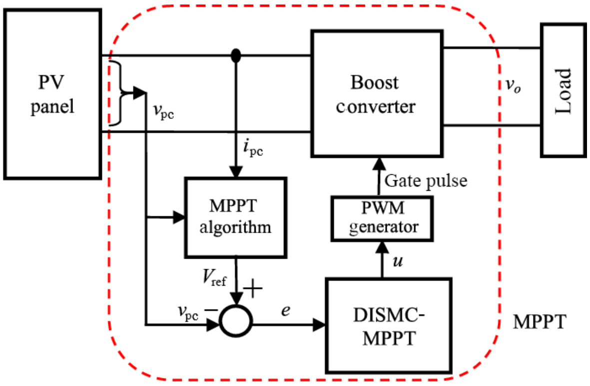

Fig. 1Schematic view of solar PV system model with DISMC.

Instead of using a resistive voltage drop, as is done in a linear converter, a switched-mode DC-DC converter converts voltage by periodically holding input energy and then releasing it to the output at a variable voltage. Capacitors, inductive loads, or transducers are used by high-energy converting circuits known as direct current (DC) converters to control DC outputs and eradicate voltage variations. One important thing that DC-DC converters can do is keep an eye on the maximum power point (MPP). The goal is to maintain full capacity operation of the solar energy system at all times. Even in partially shaded areas with little settling time required, the DC-DC boost converter—which depends on a constant input—provides the required power supply for the load. Therefore, the effective dynamic sliding surface duty cycle ratio is a direct proportional to the efficiency of solar panels. In order to enhance and maximize the production of solar energy, one may use several techniques such as temperature management, monitoring systems, concentrating solar cells, anti-reflective coverings, oxide layer coatings, reverse connection modules, and others. For DC-DC boost converters (DDBCs) fed by constant power loads (CPLs), this nonlinear controller composite combines backstepping with sliding mode controllers. Voltage regulation refers to a DC-DC converter's capacity to keep the output voltage constant despite variations in the input voltage. The inductance in the series resistance is responsible for the DC-DC conversion's ability to introduce an unanticipated change to the input signal. With the switch in the on position, the inductor absorbs electricity from the input and stores it as electromotive force. It is possible to remove electricity by opening the valve. You may use the buck/boost conversion to get voltage outputs that are either lower, higher, or exactly the same as the source voltage. With the help of the charge controller, you may achieve the goal of producing more power than you use. In order to keep the load power constant, P = VI, a continuous power load is engineered to continuously regulate the power flow in a proportional relationship to the voltage waveform. The fundamental advantage of PWM for evaluating model performance is the exceptionally low power loss in switching components. As a switch is turned off, there is almost no current flowing through it. When turned on, power is transmitted to the load with almost no voltage drop across it. Similar to that of a changing-type electrical supply, this inverse feature of a continuous power load is often used to express the output current of a solar panel as ipc.

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$$i_{pc} = I_{pc} - I_0 \left[\exp\left(\frac{v_{pc} + i_{pc} R_s}{N_{sc} V_{th}} \right) - 1 \right] - \frac{v_{pc} + i_{pc} R_s}{R_{sh}} v_{pc} \text{ with}$$

$$i_{pc} = (I_{sc} + K_1(T - 298)) \frac{H}{1000} \quad (1)$$

$$V_{th} = \frac{a k_b}{e} T \quad (2)$$

$$I_0 = I_{0,\text{ref}} \left(\frac{T}{298} \right)^3 \exp\left(eE_g \frac{eE_g}{k_b N_{sc} V_{th}} \left(\frac{1}{298} - \frac{1}{T} \right) \right) \quad (3)$$

modeling the temporal dynamics of parameter value using dynamical systems. The dynamical systems method examines the reactions to these issues or transformations and how they depend on the variables or initial conditions. A DI-SMC, which stands for DC microgrid, is a nonlinear, decentralized controller. The use of two integral parts in the DISMC program guarantees the elimination of any steady-state error that may occur, whether it be due to disturbances or modeling uncertainty. A combination of battery and supercapacitor energy storage technologies makes up this DCMG's hybrid energy storage system. Solar photovoltaic (SPV) devices are able to provide enough power to fulfill the load need [19]. Instead of lowering voltage or current, pulse width modulation (PWM) changes the ratio of on to off time, which lowers average current and voltage. This reduces overall energy, and the combination of the two determines instant authority. Modeling, comparison with existing MPPT methods, simulation results, and risk assessment are all that's needed to verify the effectiveness of the proposed DISMC-based MPPT system. By comparing the SISMC system's performance to that of the SMC approach, we can see how much better the SISMC system is. To reduce the steady-state error voltage of the PWM generator, the suggested DISMC scheme employs two integral blocks. Equations relating to this scheme are provided below to derive the constant current and potential under non-linear load consideration circumstances. in which initial state current (I0), solar panel current (ipc), temperature (T), resistance series (Rs), irradiation (I), short circuit current (Isc), number of series-connected cells (Nsc), and thermal voltage (Vth) are all given. This picture was created by an Ipcis sensor. The photovoltaic voltage across the diode current is abbreviated as vpc. There is a current in the shunt and acceleration. The charge of an electron is 1.602 × 10—19C. At zero point, the reference current is I0,ref. As for the gate voltage, it is Egis. The energy partition of an atom, which stands for the Boltzmann factor, is expressed by the Boltzmann constant. The statistical concept of entropy and the word used to describe thermal voltage in semiconductor physics are both significantly affected by it. Entropy is one of the most fundamental concepts in both statistical mechanics and astronomy. One common way to measure the degree of disorder in a material or living thing is by looking at its entropy. The more unknown a process is, the more unpredictable it is likely to be. An very low-resistance resistor is called a shunt resistance. The main component of the shunt resistor is a material that has a low-temperature coefficient of resistance. It runs parallel to the ammeter, the range of which needs improvement. Furthermore, the modes of operation of the DC-DC boost converter are shown in Figure 2 for the purpose of generating the necessary power supply for nonlinear loads in circuit representation mode [5,19]. Motors, capacitors, and transformers are all examples of linear loads. When there is no linear relationship between inputs and outputs, we say that the process is non-linear. An electromagnetic demand is provided by an alinear load.

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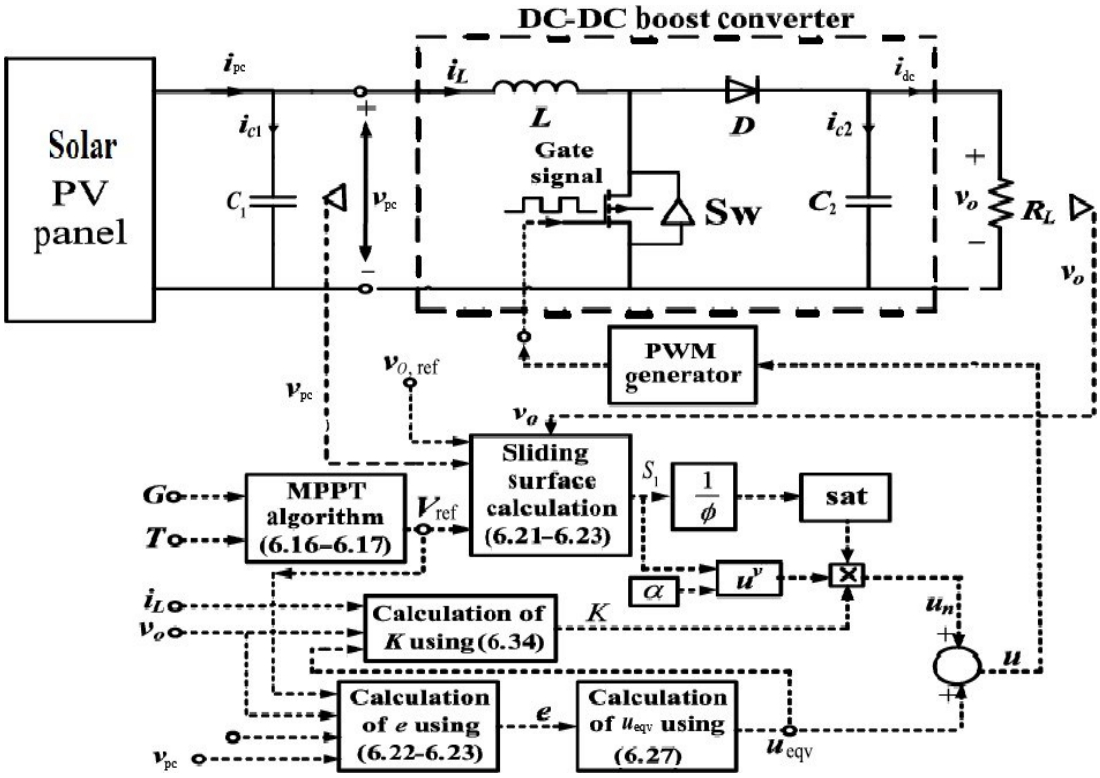

Fig.2DISMC-basedMPPT design.

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It draws power from both real and perceived electrical sources at a voltage of 1 volt. In addition to the original AC current, the non-linear application's active power is less than 1 volt, which causes it to generate harmonic components. In a non-linear load, the current fluctuates based on the intermittent load impedance and is not directly proportional to the voltage. A non-linear load is one whose impedance changes in response to changes in the applied voltage. The nonlinear load causes voltage distortions at the numerous system bridges as a consequence of current harmonics generated by element drops across the network's characteristic impedance. The current drawn by the load will not be sinusoidal, even when the non-linear load is connected to a sinusoidal voltage, due to the changing impedance. Fatigued pressures may vary from the lowest possible limit to the most possible benefit, and they are described as loads of the same kind (tension or compression). Since electrical charges are usually linked together, increasing the capacity (or resistance) causes the external load (or impedance) to be connected in parallel to the prior weight. In many cases, a parallel connection may reduce the equivalent resistance. This causes the current to increase.

Solar photovoltaic arrays, charge controllers, battery banks, inverters, efficiency meters, and electrical grids are the six main components of a photovoltaic system. Among these factors are the following: the kind of PV material, the quantity of sunlight absorbed, the cell heat, freeloading defenses, the effects of clouds and other colorings, the efficacy of the alternator, sand, module alignment, module placement, and many more. The correct installation of each of these parts affects the efficiency of solar panels. Factors like as pollution levels, shadowing, time of day, Azimuthangle orientation, and location are crucial to the effectiveness of solar panel installations. Using the provided equivalent circuit, one can determine the open circuit potential by

$$V_{\mathrm{oc}} = N_{\mathrm{sc}} V_{\mathrm{th}}((\ln i_{\mathrm{pc}} + I_0)/I_0) \qquad (4)$$

The reference voltage for boost converter is calculated using open circuit voltage, and is given by

$$V_{\mathrm{ref}} = M_{\mathrm{oc}} \cdot V_{\mathrm{oc}} \qquad (5)$$

in which Depending on the intended solar PV module's assembly and material, the solar PV panel material coefficient (Moc) is determined. Photovoltaic design, load impedance, sunlight intensity (module orientation and inclination), temperature differential, shadowing, dirtiness, panel mismatches, transformer-converter loss, and other variables are the primary determinants of component performance. Hence, the design panel must ensure that the open circuit potential and reference potential are of equivalent magnitudes, as required by Eqs. (4) and (5). Despite their differences in nomenclature, open circuit energy and corroded perspective mean the same thing. The oxidation potential is the angle that an electrode maintains independent of the external power source. One passive approach is the "open circuit potential" (OCP), which goes by many names: "open circuit voltage," "zero-current potential," "corrosion potential," "equilibrium potential," and many more. In the corrosive industry, knowing the possibility for open circuits is vital for predicting whether certain metals would take an interest in specific electrochemical processes in a given configuration. Its primary function is to determine the costs and remaining potential of a system. IGBT powering is simple and provides a lot of power. Industrial motors, main motor controllers for cars, and inverter applications to increase the efficiency of common domestic appliances like refrigerators and air conditioners all make use of IGBTs. In order to help save energy and reduce power bills, there are a number of ways to enhance the performance of household appliances. When considering the placement of the data in relation to the sliding manifold in Control method components in nonlinear adaptive systems often rely on a switching function to decide whether to use data specific time. It follows that the duty cycle ratio of the sliding switching surface Ss(y) is given by, which is the basis for future investigation. It is possible to assess the passive membrane potential of these species.

$$S_s(y) = \left\{ \frac{\mathrm{d}}{\mathrm{d}t} + \beta \right\}^{j-1} e(y) \qquad (6)$$

with the addition of a sensor to the device. The predicted remaining voltage for cardiomyocytes is -90 mV. The amount of specific potassium routes is usually the most important factor when regulating the reference voltage. Electric polarization across the cell surface is caused by certain ion exchangers, such as the Na+/K+-ATPase, and this may also have an effect on membrane permeability. Two types of signaling mechanisms, the sodium-potassium compressor and the sodium and potassium overflow streams, maintain the stability of relaxing cell wall possibilities. When there is no external load and the terminals of a circuit are separated, this voltage is present. Figure 2 was used in the design of the proposed DISMC system in order to achieve the same potential magnitudes [5]. Figure 2 shows the plan for the IGBT-based boost converter switch's sliding surface duty cycle ratio signal as a gate signal. Inverter circuits, which convert DC to AC, often employ IGBTs to power motors of varying sizes. Inverter circuits, which convert DC to AC, often use IGBTs as a switching component to power everything from small to large machinery. It is utilized to improve their efficacy. where s represents the state space of the vector of the proposed solar PV system design, j is the forcing to achieve the steady state error potential, β is a constant, and e(y) is the representation of the controlling error. The position constant (Kp), velocity constant (Kv), and acceleration constant (Ka) are the three constants that are associated to a steady-state error. In a steady-state mistake, the greatest difference between a service's intake (request) and production approaches infinity as time approaches infinity. Both the software setup and the intake type determine the steady-state error (0, I, otherwise II). To determine whether a system has a limited steady-state error, users need to know the systemtype and the values of these constants. The main reason for the steady-state inaccuracy is the kind of input utilized to activate the control system. An extra part of the system type, as shown by the transfer function's structure.

$$J = 1 \text{ obtains } S_s(y) = e(y) \quad (7)$$

The controlling error e given in the boost controller is

$$e(y) = e(y_1) + e(y_2) + e(y_3) \quad (8)$$

where $e(y_1) = V_{\text{ref}} - v_{\text{pc}}$, $e(y_2) = \int (V_{\text{ref}} - v_{\text{pc}})\mathrm{d}t$, $e(y_3) = \iint (V_{\text{ref}} - v_{\text{pc}})\mathrm{d}t$.

their average daily energy use. As a result, they get a grade from A to G, where A is the most effective item in its category and G is the least successful. The IGBT offers advantages when compared to the power of MOSFETs or BJTs. Its low ON-state power loss and excellent ON-phase conductance make it an attractive option. This allows for the use of a smaller die area, which might lead to decreased productivity. Hence, the double integral concept arrangement projected from Eqs. (7) and (8) is used in the proposed DISMC MPPT strategy to minimize the steady-state error voltage e(x).

Result

A 1 kW solar PV panel based on the DISMC system was constructed in MATLAB/Simulink software to verify the proposed DISMC MPPT control mechanism. The graphical editor, programmable block libraries, and solvers that make up Simulink make it an ideal tool for modeling and simulating dynamic systems. Thanks to its MATLAB compatibility, users may import MATLAB methods into their models and export simulation data for further analysis in MATLAB. We also build and compare the SMC and SISMC schemes with the proposed DISMC system to verify its performance analysis. Thus, Figure 3 displays the MATLAB/Simulink model of the proposed DISMCMPPT method. The SMC and SISMC methods were both tested using modified versions of the same design model control algorithm.

PV array: 1 parallel and 1 series connected module per string;

Maximum rated power: 60.003 W;

Potential at open circuit terminal: 22 V;

Current at a shorted terminal: 3.8 A;

RL load: Load active power 1000 W; reactive power 200 Vars.

An array of photovoltaic (PV) modules and panels is a complete device for electricity production. Most solar photovoltaic (PV) modules and arrays are graded according to their maximum DC power output (W) under STC. First case study: maximum power point tracking (MPPT) system simulation findings The suggested DISMC MPPT system is validated by testing the simulation design model for an SMC based MPPT scheme at the ratings stated above. Figure 4 displays the load output power and its source panel output power changes, which help to understand the performance efficiency of the SMC-based MPPT approach. Additionally, fluctuations in the load potential and solar panel potential may be detected in Image 5. Potential loads are one source of second-order stress in the body. It's the load that the second-order potential causes. When added to the quadratic load, it produces the entire QTF. Figure 5 shows that at a load output power magnitude of 41.78W and a panel output power of 44.15W, the efficiency was 94.63%. The magnitudes of the load potential and current are 46.26V and 0.9031A, respectively. Furthermore, the settling time and sliding surface duty cycle ratio of the SMC-based MPPT scheme were found to be 0.1s and 72.26%, respectively, suggesting that the sliding surface switching mode operation was inefficient. The observed magnitudes of sliding surface duty cycle ratio and settling time demand a lack of stable dependable operation in the long term, even if the SMC-based MPPT scheme supports the dynamic performance of sliding surface switching actions under partial shade situations. Results of a single integral sliding mode control simulation (Case Study 2) MPPT algorithm In addition to the aforementioned SMC system, the SISMC scheme is also evaluated to confirm the performance of the planned DISMC-based MPPT scheme. The SISMC system achieved a load and sourcepanel efficiency of 96.8%.

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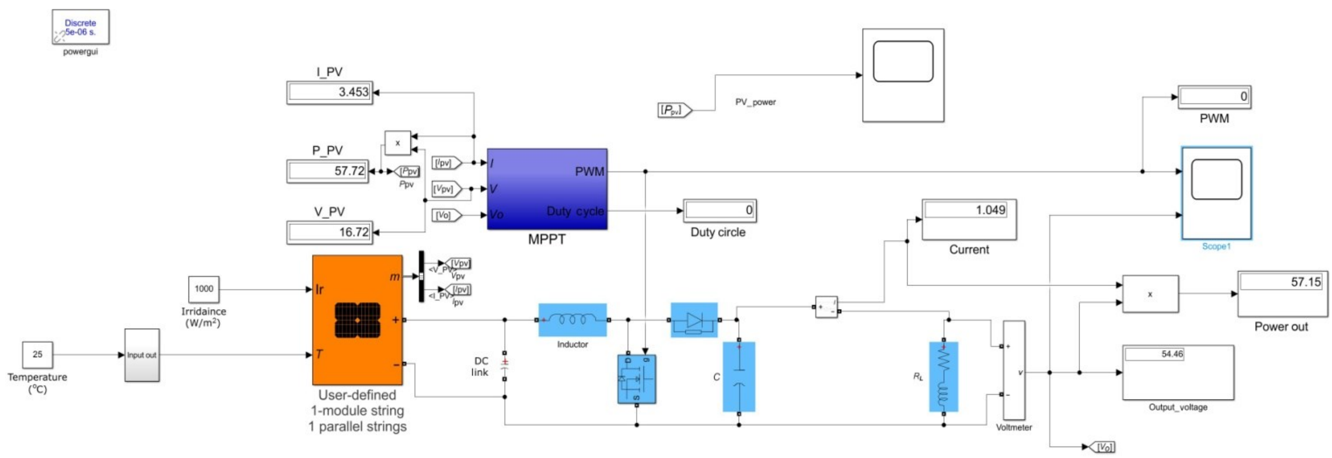
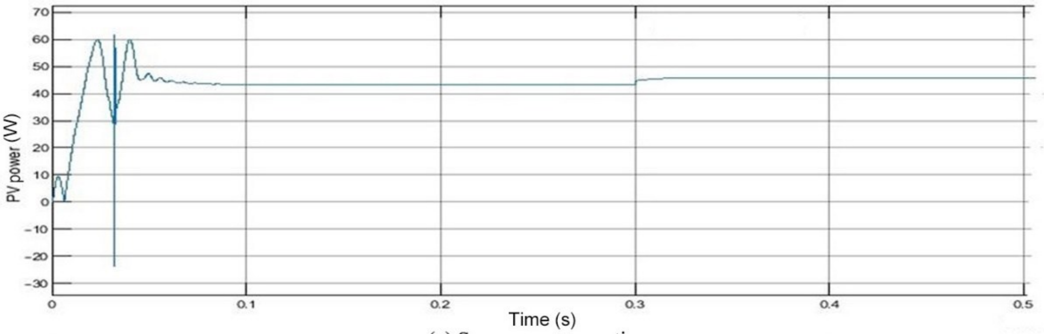
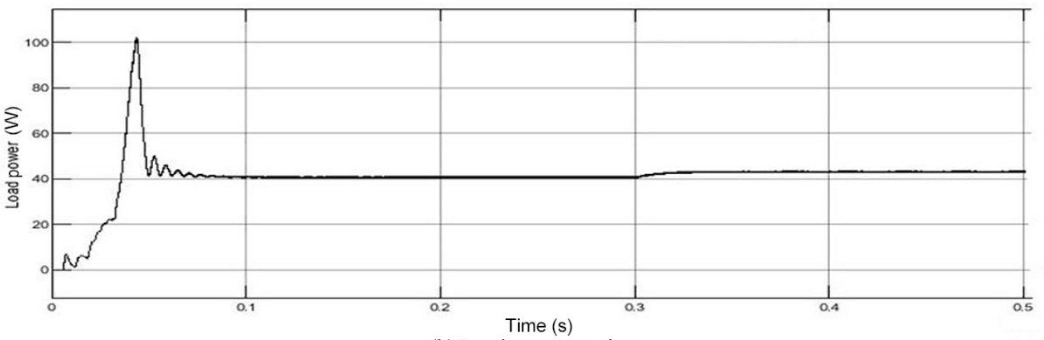


Fig. 3 MATLAB/Simulation design model of proposed DISMC MMPT scheme-based PV system.

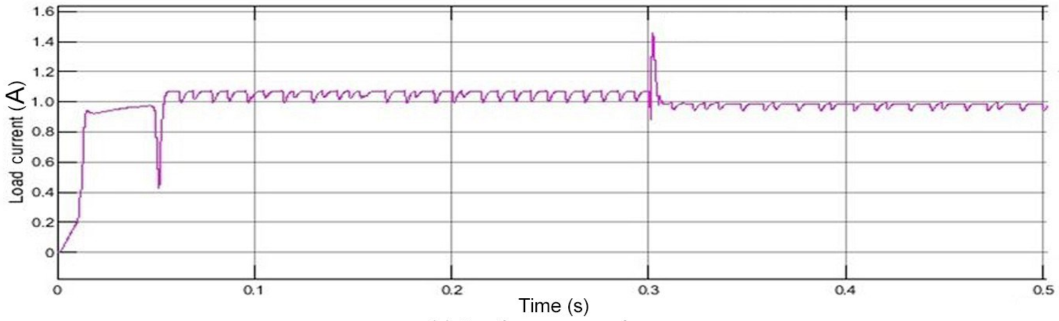


(a) Source power vs. time

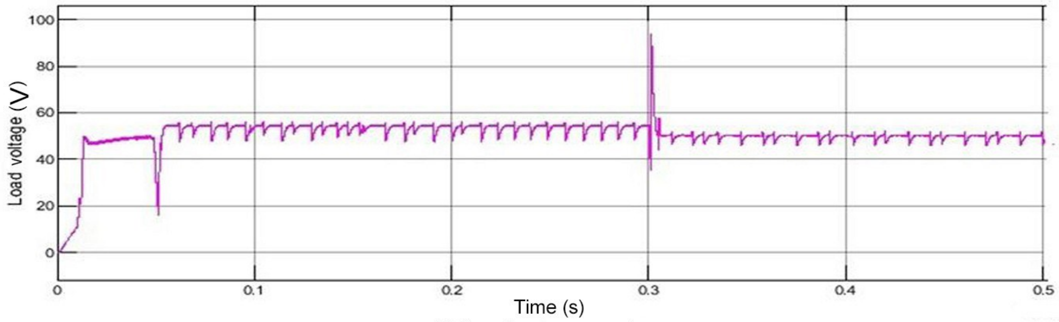


(b) Load power vs. time

Fig. 4 Source and load output power variations under SMC-based MPPT scheme.



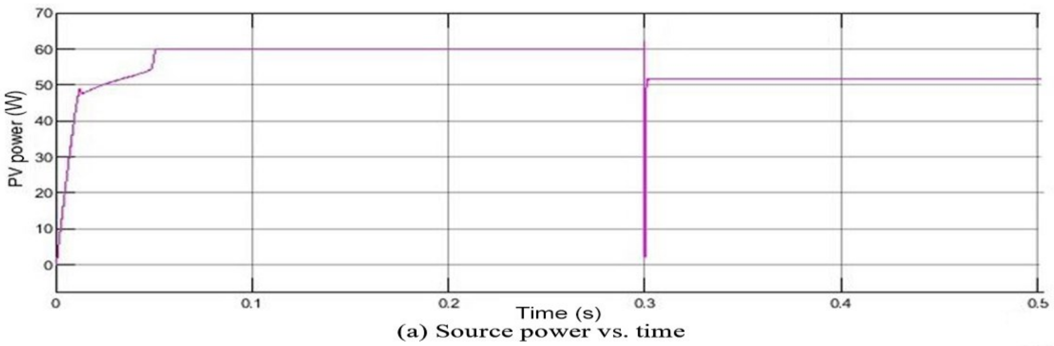
(a) Load current vs. time



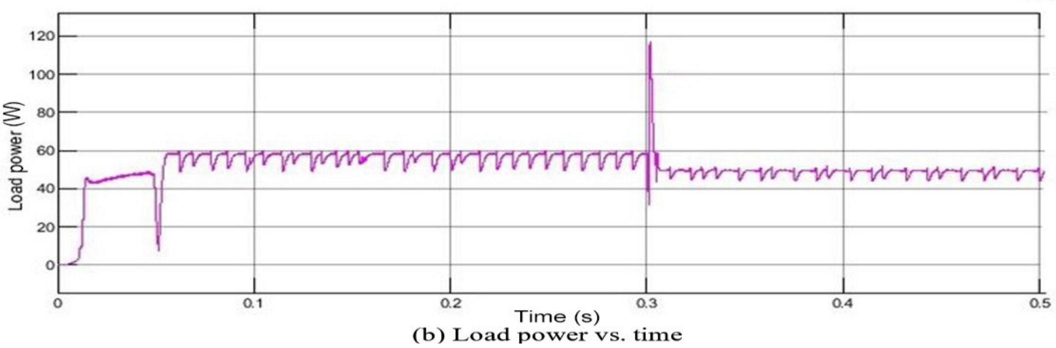
(b) Load voltage vs. time

Fig. 5 Voltage and current variations of the SMC-based MPPT scheme.

Fig. 6 shows the fluctuations in the output powers of 55.92W and 57.74W, respectively. Similarly, the SISMC system showed fluctuations in load potential and current magnitudes, as shown in Fig. 7, with values of 53.44V and 1.046A, respectively. In addition, the sliding surface duty cycle ratio was 0.921, which is much better than the SMC scheme and proves that the dynamic sliding surface switching operation is better with just a 0.05 s settling time. Figures 6 and 7 make it quite evident that the performance analysis of the SISMC-based MPPT scheme was superior to



(a) Source power vs. time



(b) Load power vs. time

Fig. 6 Source and load output power variations under SISMC-based MPPT scheme.

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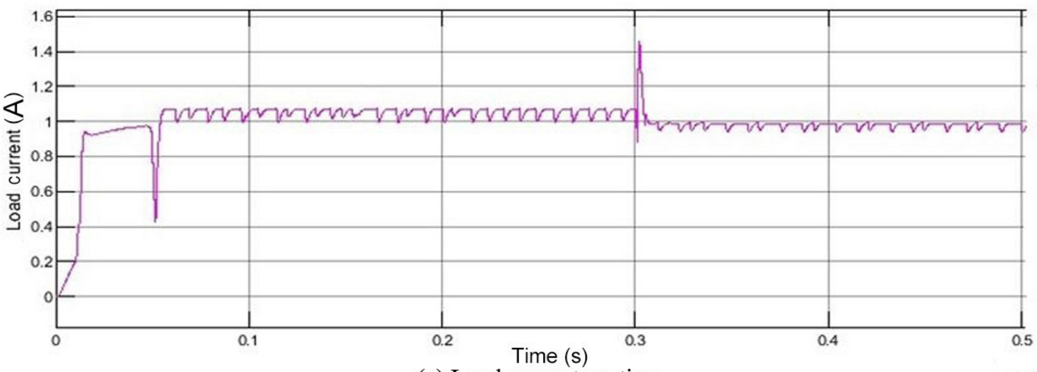
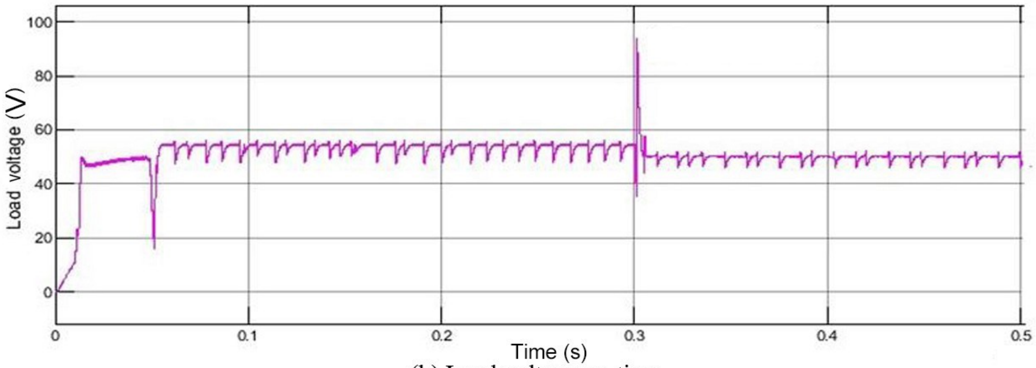


(a) Load current vs. time



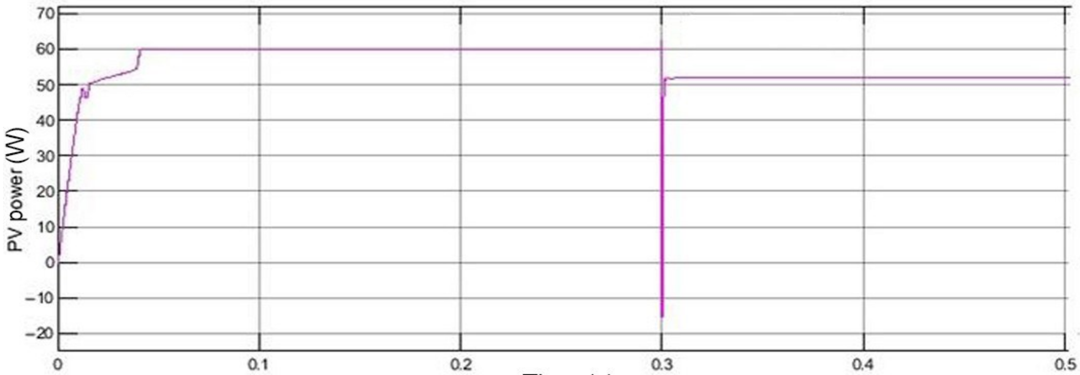
(b) Load voltage vs. time

Fig. 7 Voltage and current variations of the SISMC scheme.

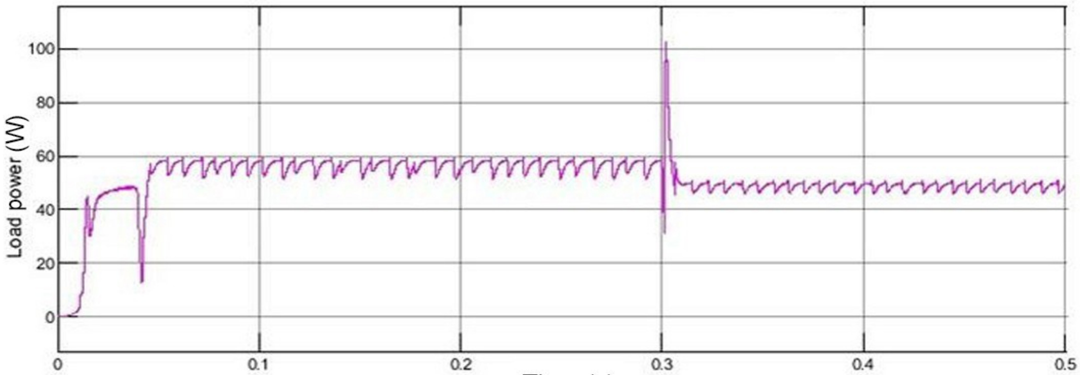
returning to the earlier SMC-based MPPT plan. Case Study 3: Results of the Double Integral Sliding Mode Control Maximum Power Point Timing (MPPT) Scheme The equipment configuration mentioned in the previous sections was used to construct the suggested double-integralsliding-mode control method. Figure 8 shows the variation waveforms of the proposed DISMC MPPT system, which was determined to have an efficiency of 99.01% for the load and source panel output powers of 57.15W and 57.72W, respectively. The magnitudes of the load potential and current waveforms are 54.46 V and 1.049 A, respectively, as shown in Figure 8. With a settling time of under 0.02 s, the sliding surface duty cycle ratio was also confirmed and measured at 0.985, which is almost equivalent to unity. In comparison to the other two SMC and SISMC systems, the suggested DISMC MPPT method achieves an improved efficiency of 99%. In order to test the efficacy of the suggested DISMC MPPT scheme, Table 1 compares it to three existing MPPT schemes—SMC, SISMC, and P&O—based on performance metrics including efficiency, settling time, and sliding surface duty cycle ratio [22].

Discussion

According to Table 1 and Figures 3–8, the proposed DISMC MPPT system achieves higher solar panel efficiency than SMC MPPT and SISMC MPPT. Although the P&O MPPT scheme is more efficient than the SMC MPPT scheme, the performance study in the literature shows that this advantage is only apparent in partial shadow situations[23, 24]. When faced with partial shading, sliding surface mode control moves to the concept of effective dynamic switching operation, which exhibits acceptable and reliable performance. Dynamic power is a component of peak power and the king of circuit switching losses. It is determined by three things: the supply voltage, the output load, and the switching frequency. Switching is the main component of dynamic power.



(a) Source power vs. time



(b) Load power vs. time

Fig. 8 Source and load output power variations under DISMC-based MPPT scheme.

Table 1 Comparison of performance analysis of DISMC with SISMC and SMC MPPT schemes and P&O scheme reported in the literature[20, 21].

Scheme	Settling time (s)	Efficiency (%)	Sliding surface duty cycle ratio	Load potential (V)	Load current (A)
P&O MPPT	0.3	96.16	–	–	–
SMC MPPT	0.07	94.60	0.7466	46.26	0.9031
SISMC MPPT	0.055	96.8	0.921	53.44	1.046
DISMC MPPT	0.035	99.10	0.985	54.46	1.049

power as well as short-circuit power [25,26]. Users may improve the overall thermal performance of their systems and decrease average power usage by using dynamicswitching. In recent years, this sliding-mode surface control scheme has gained popularity owing to its effective dynamic sliding switching actions that conform with human-made dynamic switching operations. It is complex and uses both single- and double-integral sliding-mode control schemes. The DISMC MPPT scheme verifies this with a sliding surface duty cycle ratio of 0.985 in under 0.02 seconds of settling time. Effective dynamic sliding surfaceswitching operations with increased solar panels and a very quick settling time of just 0.03 seconds are therefore provided by the suggested DISMCMPPT method.

Our next steps can include incorporating new methods into the suggested approach to make it more efficient and reduce its settling time.

Conclusion

We created and tested the DISMC MPPT scheme in MATLAB/Simulink for the 1 kW rated solar PV model in Fig. 1. In addition, we construct and assess the SMC MPPT scheme and the SISMC MPPT scheme in order to confirm the results of the performance study for the suggested DISMC system. Results of the Multi-Purpose Test for Learning (MPPT) with DISMC, SISMC, and SMC

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