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Research Article

AN MPPT-ENHANCED BATTERY CHARGING REGULATOR FOR HYBRID SOLAR-WIND ENERGY SYSTEMS INCORPORATING SUPPLEMENTARY ALGORITHMS

K.Parthasarathy[1], S Vijayaraj[2]

[1]Research Scholar, Department of EEE, Vels Institute of Science, Technology & Advanced Studies (VISTAS), Chennai, India. – 600117

[2]AssistantProfessor,Department of EEE, Vels Institute of Science, Technology & Advanced Studies (VISTAS), Chennai, India. – 600117

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ABSTRACT

A novel battery charging regulator for hybrid solar-wind energy systems, utilizing Maximum Power Point Tracking (MPPT) alongside additional algorithms to enhance energy efficiency. The proposed framework incorporates MPPT to adaptively modify the power output from photovoltaic (PV) panels and wind turbines, thereby guaranteeing optimal energy extraction in response to fluctuating environmental conditions. Complementing MPPT, additional algorithms improve the system's functionality by mitigating energy variations, preventing battery overcharging, and maintaining system stability. The integration of these methodologies results in enhanced energy management and storage efficiency, thereby bolstering the reliability and sustainability of hybrid renewable energy systems. Both simulation and experimental findings substantiate the efficacy of the proposed framework in optimizing energy harvesting and prolonging battery life.

Keywords: Maximum Power Point Tracking (MPPT), hybrid energy systems, solar and wind energy integration, battery charging regulation mechanisms, energy optimization techniques, auxiliary algorithms

INTRODUCTION

The sun is the primary energy source utilized to generate solar energy. The earth receives around 1.6 x 1016 units of energy annually. Solar power generation technologies will contribute significantly to the future renewable energy supply. It is among the most ecologically benign forms of power generating when compared to conventional fossil fuel-based power generation. There are two distinct methods for producing solar energy: photovoltaic (PV) and concentrated solar power (CPV). The PV is a semiconductor device that generates electricity from solar radiation by utilizing the PV principle. The thin-film, multi-junction, single-crystalline, and multi-crystalline types of solar cells are the most widely used types. Optical concentrators, which are beng investigated for many uses, are employed in CPV technology to focus solar radiation onto solar cells. PV systems employ power electronics to directly transport electricity from sunshine to the associated load. The flexible system structure includes the PV module, which is the primary component and is arranged into arrays to increase the power-generating capacity. Solar power generation varies concerning sun light radiation level and temperature of solar cells. A solar PV panel will produce maximum voltage at a unique point called as maximum voltage point of the panel at specific operating conditions. MPPT is the method used to track the maximum power point of a solar PV panel at all times during its operating cycle. MPPT controller is a device to implements the tracking algorithm for deriving maximum power output.

LITERATURE REVIEW

[I] proposed implementing an optimal Maximum Power Point Tracking controller based on the Grey Wolf Optimisation technique using the MATLAB/Simulink software. Root Mean Square Error and global efficiency are used to assess the controller's performance. [II] Conducted investigation under actual climatic circumstances, solar panels behave nonlinearly, and their output power varies as a result of changes in solar irradiation and temperature. Consequently, a management technique is necessary to get the most power out of solar panels under all operating circumstances. [III] Provided a nonlinear robust controller for MPPT of a PV system based on a supertwisting sliding mode algorithm that not only reduces chattering but also increases the dynamic responsiveness of the system as a whole. [IV] Suggested MPPT-controlled DC-DC boost converter design and its application as a battery charger are described. [V] Improved solar photovoltaic (PV) energy conversion systems rely heavily on maximum power point tracking (MPPT) algorithms. In modern technology, several algorithms have been created and effectively used.

[VI] Presented an analysis of multiple maximum power point tracking (MPPT) methods for solar charge controller applications with varied converter topologies. The system is composed of a PV panel, a DC to DC converter, a charge controller, and a battery. [VII] Explained the various solar tracking systems and solar PV system kinds. In order to get the maximum power output (MPP) produced by a photovoltaic (PV) generator linked to the battery through a boost DC-DC convertor, [VIII] Created the direct backstepping super-twisting algorithm control (BSSTAC) MPPT. [IX] To determine the appropriate size of the photovoltaic (PV) array and energy storage unit (ESU) for a PV grid-connected charging system for electric vehicles (EV), [X] The particle swarm optimisation (PSO) approach has been devised. [XI] Distribution networks have seen a major increase in distributed rooftop PV generating installations.

[XII] Utilising photovoltaic (PV) modules, solar energy is transformed into electrical energy. The amount of solar radiation and PV module temperature has an impact on the output power. Partial shade created by some things, such as trees, buildings, clouds, and so on, may be an issue. [XIII] Suggested hybrid system offers a practical method of incorporating PV into a hybrid system. This addresses the development of controllers for grid-connected hybrid systems that use distributed renewable generators (Wind and PV) as their major source, BESS as their secondary source, and FC with Electrolyzer as their tertiary source. [XIV] A MATLAB programme is used to track the temperature of the lead acid battery as well as the charging and discharging current. [XV] Examined the operation of such systems would be difficult in this regard since it would be difficult to reach the maximum power point (MPP) when there are issues with partial shading (PS) and mismatched modules.

DESIGN AND EXPERIMENTAL INVESTIGATIONS

Modeling of Solar PV Panel

The solar array in use is a Sun Power SPR 305 solar array with five series models and 66 parallel strings. The maximum output of this model is 100 kW at 1000 W/m² solar irradiation. The solar array's highest voltage is 274 V, with a 400 kW capacity. Figure1 displays the Simulink model of the solar PV cell.

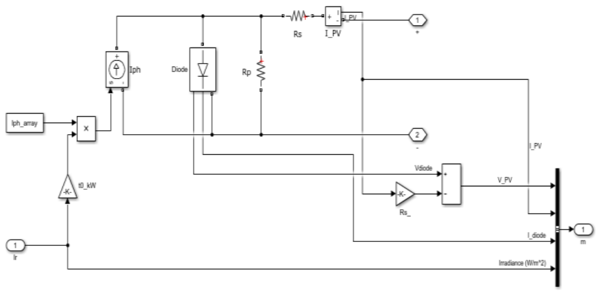


Figure1Simulinkmodelofthe solarcell

Regarding solar radiation, the highest power point varies. Individual PV cells can produce a maximum power of 48 W at 250 W/m2, and a PV panel can provide a maximum power of 48 kW. Individual PV cells can produce a maximum power of 300 W at 1000 W/m², whereas a panel can provide a maximum power of 100 kW.

Implementation Model

Figure 2 displays the Simulink model for the incremental conductance method. The duty cycle value is generated between 0 to 1 by caseswitches in the model based on slope of the power curve.The delta D isgenerated fromthe D valuebasedon theswitch turn on andoffcondition.

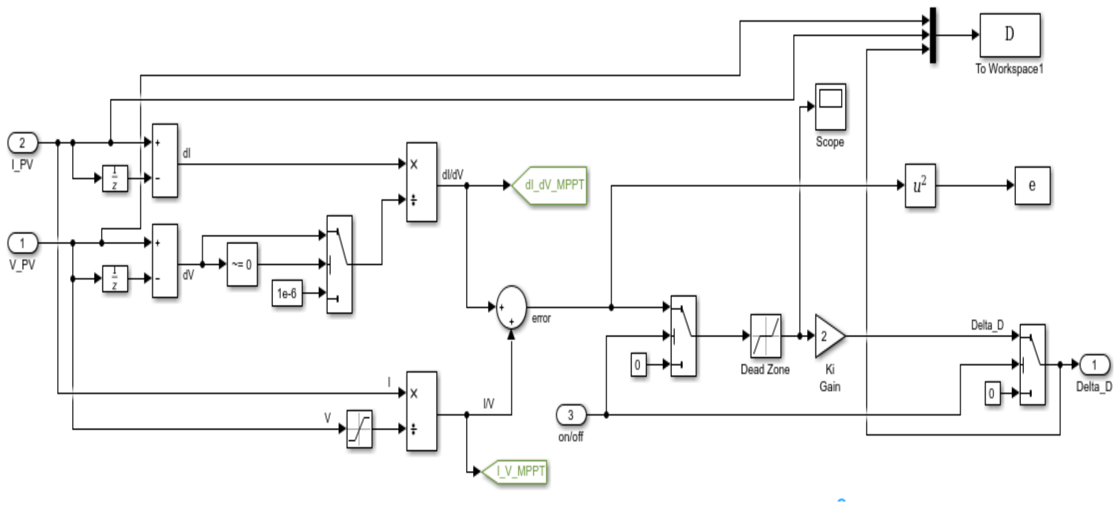


Figure2 SimulinkmodelofincrementalconductanceMPPTcontroller

CHARGING METHODS

Constant Voltage Charging

Because it shortens the overall charging time and boosts capacity by up to 20%, this approach is the usual way for charging lead-acid batteries which is shown in figure 3 (a). However, this approach roughly lowers efficiency by 10%. The charging voltage is maintained constant using this approach the whole time the battery is being charged.

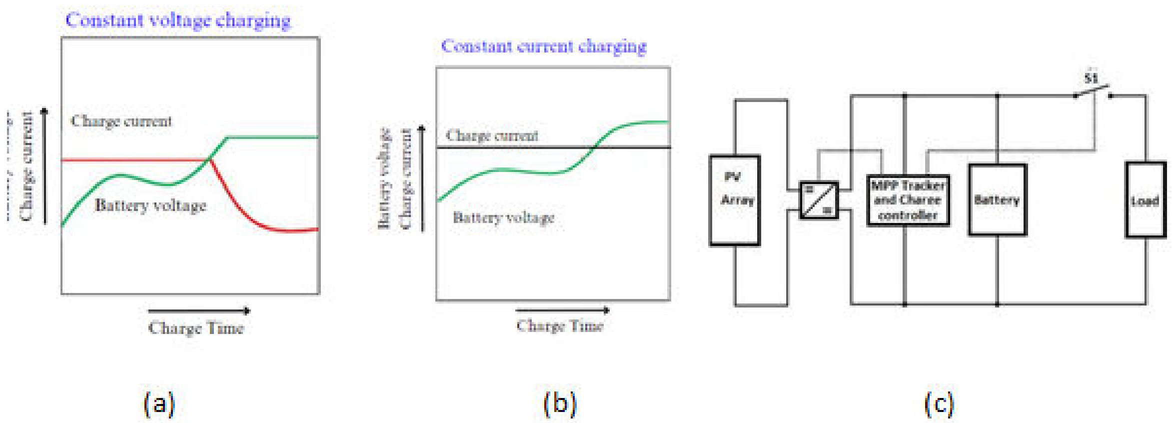


Figure 3 (a) Constant voltage method (b) Constant current method (c) TheMPPTchargecontroller.

Constant Current Charging

The charging can be done in two parts, with an initial charge that is roughly greater current and a finishing charge that is lower current, to prevent excessive gassing or overheating. About one-eighth of the ampere ratings of this method's charging current are available. The supply circuit's additional voltage is absorbed by the series resistance which is shown in figure 3 (b). To lessen the energy consumption of the series resistance, the battery groups that require charging should be connected. To prevent the opposition from overheating and burning out, the series resistance's current carrying capability must be more than or equal to the needed charging current.

MPPTchargecontroller

An MPPT charge controller's block diagram is seen in Fig. 3 It includes a DC-to- DC converter so that the PV array can run at its peak efficiency under the current solar irradiation.In olden days wind power was utilized for the movement of ships.USA was the first country utilized wind power to generate electricity in 1890.Since it is a clean form of energy many companies are started using windgenerators to generate electricity. Initially small capacity wind generators aredeveloped and explained in figure 3(c),currentlyitisenhancedtofewMegawatts.Becauseofthetechnology development size of the wind turbine reduced and capacity of thewind turbineincreased.The costofwind power generationhascome downfrom 35 percent to 5 percent per kW/hr in 1997 and wind power becomes theleastcosteffectivepowersource.

Genetic neural network-based optimisation of the novel MPPT technique

The system settings are changed after the maximum power value has been reached. Real measurements are supposed to replace the training data generated by the PV model when the PV module is put into use. The recommended ANN is displayed in Fig. 4 (a). The three layers that make up this system are the input layer, the hidden layer, and the output layer. The temperature T (°C), solar irradiation G (Wm^2), temperature coefficient I_{sc}(i), and temperature coefficient V_{oc}(v) are the four neurons that make up the input layer. I_{opti}(A), the predicted ideal current, is present in the output layer. The buried layer has the CPU for the evolutionary algorithm. In order to use the MATLAB/SIMULINK GA tool, cognitive function is used. The following model equations are used to generate it:

$$I_{SC}=I_{SC_S}(/G_s)+\alpha_i(T-T_S) \quad (1)$$

$$V_{OC}=V_{OC_S}+ (T-T_S)- (I_{SC}-) \quad (2)$$

Where

V_o:Open-circuitvoltageatthereferencetemperature(V)

α_i :ThetemperaturecoefficientofI_{sc}

α_v :ThetemperaturecoefficientofV_{OC}

Finding the ideal voltage and ideal current is required to obtain the best power out of the PV system.

$$I_{optimum}=K_i*I_{SC} \quad (3)$$

$$V_{optimum}=K_v*V_{OC} \quad (4)$$

The normal values of the proportional components K_v and K_i fall between (0.75-0.85) and (0.9-0.92), respectively. Figure 4b shows how the MPPT controller is updated using the best value the GA controller was able to provide. It also shows the interaction between the MPPT and the genetic neural network.

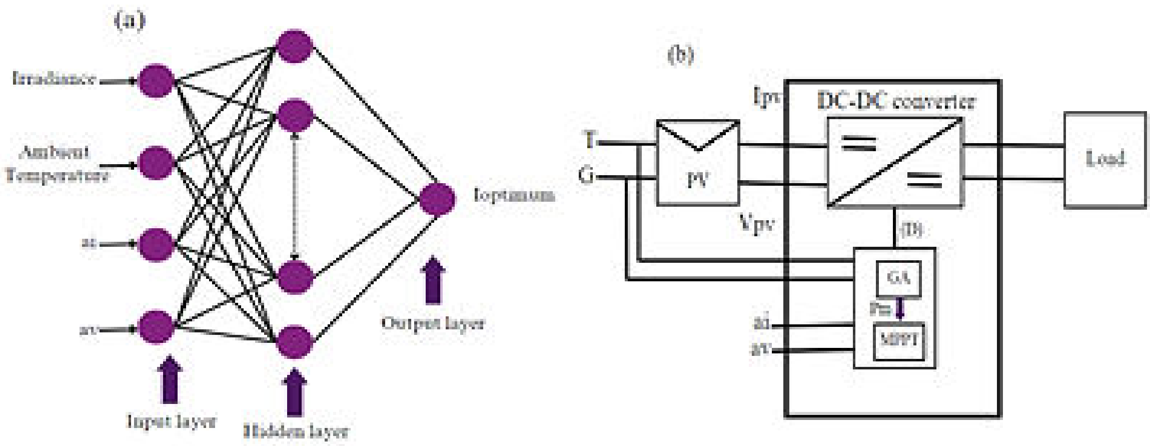


Figure.4 (a)ANN (b)GAinterfaceswithMPPT.

ModifiedP&OMPPTAlgorithm

Normally the testvalues are obtained from power versus rotor speed and electromagnetic torqueversus rotor speed relationships. MPPTtechniqueis Perturb andObserve. This P&Omethodis also called hill-climbing method. By regulating the converter sidevoltageand current the wind turbine speed can be controlled. Regulating the convertervoltageorcurrentisachievedbycomparingthesuccessivepowermeasurementsofthewindgeneratoroutput. The enhanced P&O for wind energy conversion system maximum power point tracking is shown in a flow diagram in Figure 5. This Modified P&O approach uses the 6.5 m/sec, 7.5 m/sec, and 9.5 m/sec wind speed variations. The software programme MATLAB is used to carry out the proposed strategy. To lessen the variety in wind speed, a wind speed simulator is employed. The diode bridge rectifier is connected to the generator's output. The load is connected to the diode bridge converter by a boost converter. It is possible to modify the converter voltage or current to reach the Maximum Power Point (MPP).

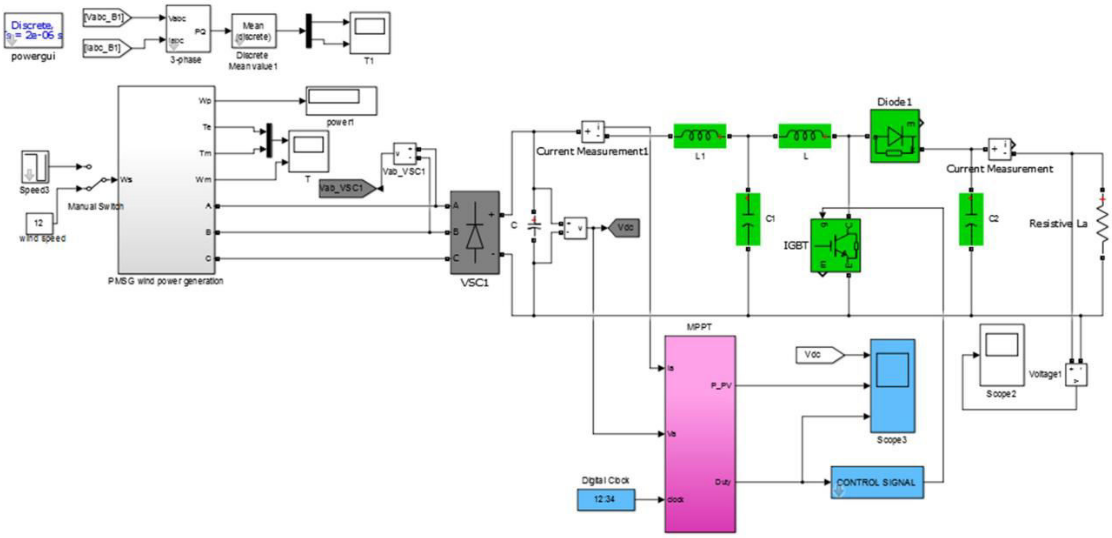


Figure5SimulationmodelofModifiedP&OMPPTforWindEnergyConversionsystem

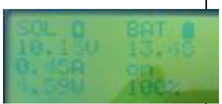
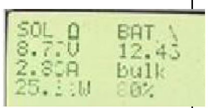
RESULTSANDDISCUSSION

The solar irradiation and temperature are kept constant for IC and P&O methods. With IC, the energy output was correlated with changes in irradiation; for P&O, the response was slow and correlated with variations in insolation; for P&O, the power supplied to the network was correlated with changes in insolation; for IC, the duty cycle variation was consistent, but the disruptions were extremely high, especially where insolation or temperature fluctuations are more noticeable.

Regulatorforcharging:

The solar charge controller's experimental findings are shown in Tab. 1. It has 4 states float,OFF,aON, andbulk,which are detailed in the tab. below.

Table.1Results of regulatorforcharging

State	**ON**	**OFF**	**FLOAT**	**BULK**
Needestate	Sol_power>Low_sol_power&sol_power<Min_sol_power	Solarwatts<Low_SOL_WATTS	Bat_volts>BATT_FLOAT	Solar_watts>MIN_SOL_WATTS& bat_volts<BATT_FLOAT
Output	BatteryCharging&Load OnON	BatteryCharging& Load OnOFF	BatteryCharging &Load OnFLOAT	BatteryCharging&Load OnBULK
Observation				

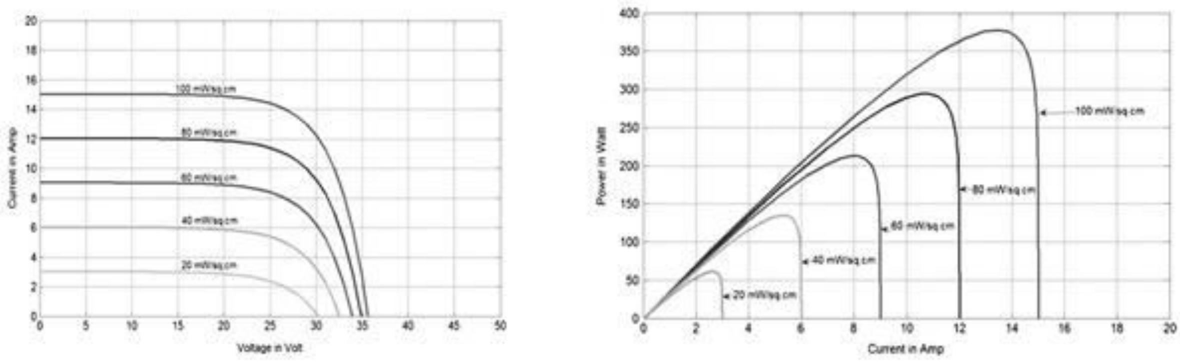


Figure 6a) V-ICha.Variation of MPPwithSolarIlluminationforSolarPanel. B) P-ICha.

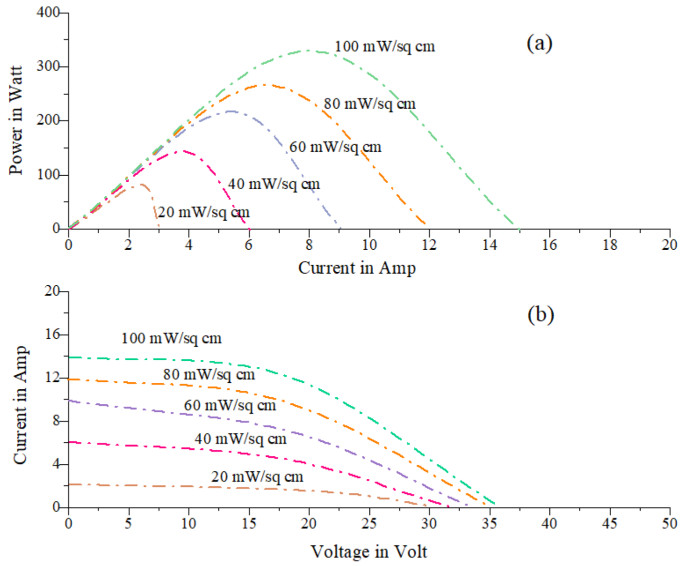


Figure 7 a) For a solar panel and its fluctuation with sun irradiation, P-V Graph B) V-IGraphfor Solar Array and MPPT Temperature Variation

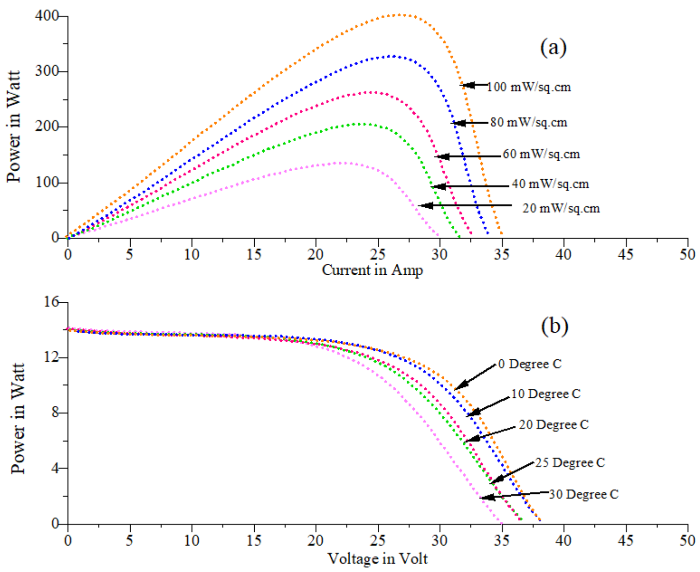


Figure8 a) Properties of the P-I. (f or Solar Array and MPP Variation as aFunctionof Temperature.(B)P-V Graph(forsolararraysandchangesinMPPasafunctionoftemperature)

The efficiency of solar panel models depends on MPPT parameters, i.e., wattage of solar panels(300 Watt), panel open loop voltage (59.2 Volt), MPP voltage for module(59.5 Volt), panel low voltage (4.49A), MPP current panel (4.49A), panels in parallel(70), network voltage(60kVA, 499 V/25kV), inductance of the power converter(6mH), inductance of the filter(245 µH), inverter(4 LevelVSC), load on the gird(20 km. (pi section)), and the length of network(19MW, 3 MVar). The system's total power increase the voltage output of the converter at MPP was 299 * 70*6 =110.98 kW 499 Volt. The results of the solar illumination, arrays and changes using MPP and MPPT are described clearly in figure 6, 7, and 8.

Simulationof a powergridsolar systemwitha capacityof 100 kW

Thesestrategiesaremodeledfora99kWconnectedtothegridsolarpoweraftermodelingthe solar array and comprehending the fundamental features of the 2 most prevalentMPPTmethods, namely(i) P&Oand(ii)ICmethod.Figure9depicts amodeling circuit schematicdiagram.

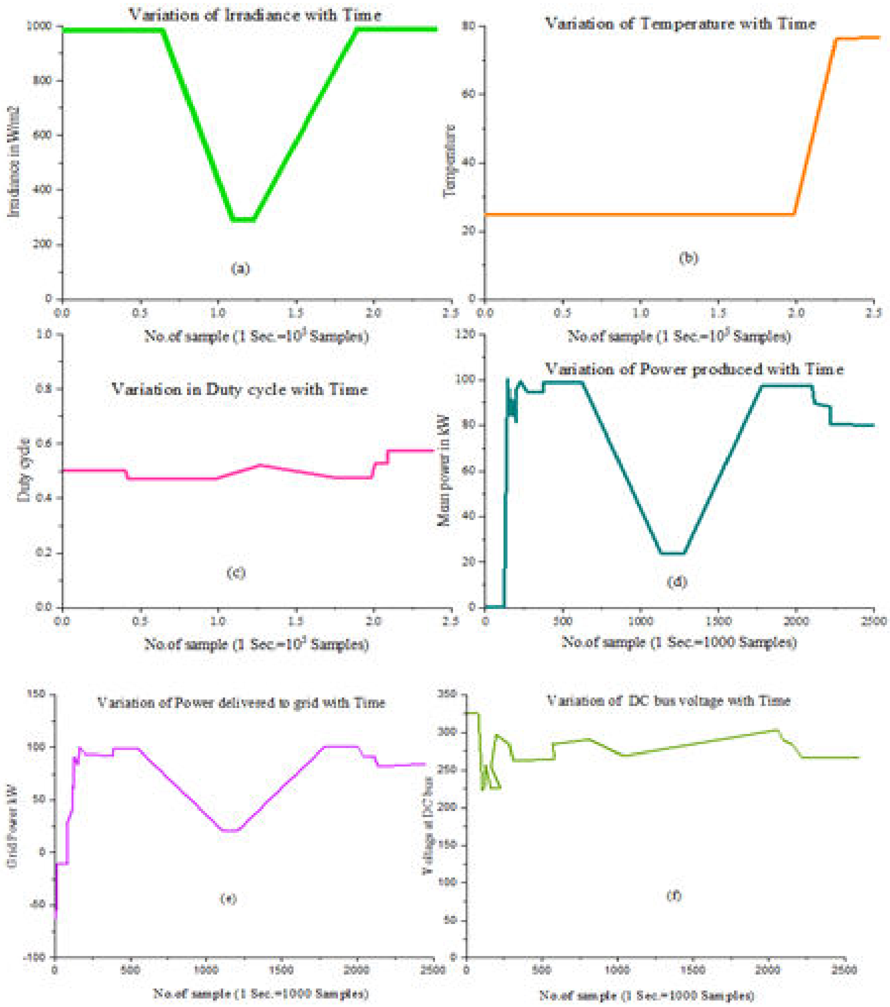
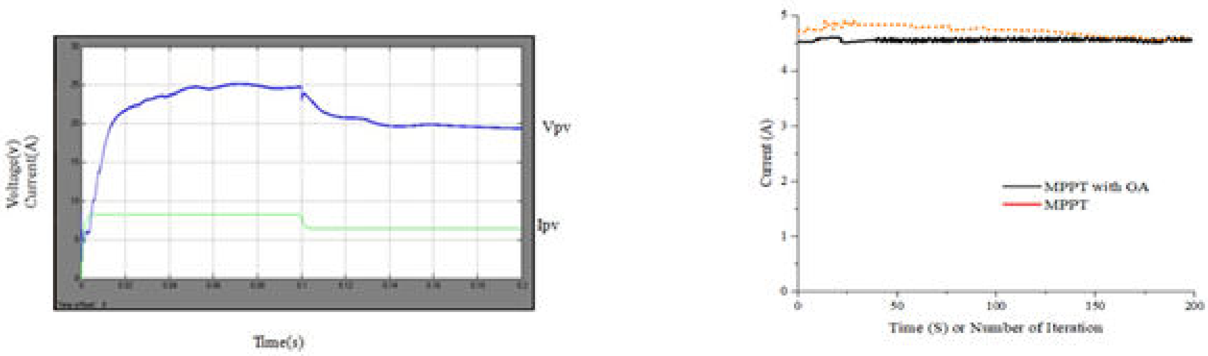


Figure 9 (a)IC approach's irradiance fluctuation over time. (b)IC technique'stemperaturefluctuationovertime.(c)ICmetho dutycyclefluctuationovertime. (d) thepowergenerated bythePVpanelfluctuates overtime fortheIC approach. (e) IC method's power supplied to the grid fluctuates over time, (f) the IC approach'sDCvoltagevaries overtime.

SimulationResults ofAnnbasedMPPTController

The system is assessed under a constant solar irradiation of 1000 W/m² and temperature of25°C in order to evaluate the performance of the ANN controller. Figure 10 (a) shows the PVmodule output voltage and current and shows the steady state of the PV outputpower and its oscillation.The results verify the high speed of this method in tracking the MPP,andlowoscillationaroundMPPinsteady-state.Theconvergingtimeofthepower trackerfortheoptimal ANN MPPT method is the lowest when compared to the FLC-MPPT and conventionalP&O-MPPTmethods,beingabout0.07s, 0.08,0.11sand0.13s,respectively".



(a) (b)

Figure10 (a) PVModuleOutputVoltageandCurrentresponsebyANNcontroller (b) ThePVcurrentofMPPTversusthecurrentofMPPToptimizedbyGA.

In this test, both the temperature and the irradiance are set at 25 °C and 1000 W/m². To be compared are two test scenarios. The current curves of the PV with respect to time are shown in Fig. 10 (b). They demonstrate that the response sharply increases to the maximum power point in the case of typical MPPT. The duty cycle varies by 1.0% for each stage. Reaching the MPP takes roughly 200 seconds. When using MPPT with GA, it just takes a few seconds to do the same task. Finding the optimal value, which is the location closest to the MPP, requires 3 seconds of exploring the learning database.

CONCLUSION

ANNbasedMPPTtechniqueisthesecondproposedcontrollingtechniqueforthesolarenergyconversionsystem.TheANN systemtakespower and voltage are the two input variable and change in duty cycle as theoutputvariable. Thispaperintroducesthefundamentalnotionofsolarpeakpowerpointdetectionusingpower electronics-based methods. In the twoproposed MPPT techniques forthesolar power system,the hybrid MPPT is considered the best since it controls the boost converter toget maximum power for any value of solar irradiation compared to ANN basedMPPTtechnique. In the proposed improved P&O MPPT algorithm, the boost converter's duty cycle is altered to achieve maximum power after calculating the change in voltage and power for two consecutive intervals. Voltage, current, and power numbers are updated for the subsequent MPPT moment. MATLAB simulates the updated P&O MPPT algorithm. Three distinct wind speed circumstances, including 6.5 m/s, 7.5 m/s, and 9.5 m/s, are tested with the proposed improved P&O MPPT algorithm.

Conflict of Interest:

There was no relevant conflict of interest regarding this paper.

Abbreviation

CPV - Concentrating solar power

MPPT - Maximum power point tracking

PV - Photovoltaic

BSSTAC - Backstepping super-twisting algorithm control

ESU - Energy storage unit

PSO - particle swarm optimisation

T - Temperature

G - Irradiation

I_{sc}, V_{oc} - Temperature coefficient

I_{opti} - Predicted ideal current

V_o _Open-circuitvoltageatthereferencetemperature(V)

α_i -ThetemperaturecoefficientofI_{sc}

α_v -ThetemperaturecoefficientofV_{OC}

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