ElectroSphere: Electrical Electronics Engineering Bulletin

PRIME OPEN ACCESS

Volume 1, Issue 1

Research Article

Date of Submission: 14 February, 2025
Date of Acceptance: 28 March, 2025
Date of Publication: 07 April, 2025

Design and Simulation of the PV Solar System and MPPT with PI Controller Based for Rural Electrification in Semera Using Matlab Simulink

Yigrem Eguale Anbes[1*] and Hunachew Moges Mitiku[2]

[1]Faculty of Technology, Debre Tabor Universit (DTU), Debre Tabor, Ethiopia

[2]School of Electrical and Computer Engineering, Woldia University, Woldia, Ethiopia

***Corresponding Author:**
Yigrem Eguale Anbes, Faculty of Technology, Debre Tabor Universit (DTU), Debre Tabor, Ethiopia.

Citation: Anbes, Y. E., Mitiku, H. M. (2025). Design and simulation of the PV solar system and MPPT with PI controller based for rural electrification in Semera using Matlab Simulink. *ElectroSphere Electr Electronic Eng Bull, 1*(1), 01-13.

Abstract
The use of renewable energy sources is increasing and will play an important role in the future power systems. The unpredictable and fluctuating nature of solar power leads to a need for energy storage as the prevalence increases. Photovoltaic (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductor that exhibit the photovoltaic effect. The method is used to implement and determine the characteristic of a particular photovoltaic cell panel and to study the influence of different values of solar radiation at different temperatures concerning performance of photovoltaic cells. This model it can be used for build a photovoltaic circuit model for any photovoltaic array. An MPPT (maximum power point tracking) algorithm using DC/DC converter (Boost converter) is applied to make PV arrays to work at maximum power point. Then, the system behaviour and performance are studied. The simulation results of MATLAB/SIMULINK address that the proposed PI controller has a good performance. This validated model contributes to a better sizing of PV panel and battery energy storage for the small and medium standalone PV system. Power smoothing efficiency is demonstrated with different battery module sizes. Changing the power smoothing algorithm parameters to suit the battery capacity is shown to be effective in providing as good smoothing as possible within battery constraints.

Keywords: Modeling, Solar Cell, Matlab-Simulink, Photovoltaic (PV), Maximum Power Point Tracking (MPPT), Boost Converter DC/DC, DC/AC and PI Controller

Introduction
Climate change is being caused by greenhouse gas emissions, specifically carbon dioxide. Since CO2 has a well-known greenhouse effect, it is obvious that reducing emissions is necessary to prevent unfavorable outcomes. Accelerating the development and application of renewable energy technologies is imperative to buck the trend. It is anticipated that solar energy will play a significant role in the future, particularly during this time when the majority of developing nations in the world are concentrating on this field. Therefore, using solar cells to generate electricity is a modern and effective method.

The local voltage control techniques used to regulate PV storage systems are described in [1]. To create the PV module, these solar cells are stacked in series or parallel to achieve the necessary voltage and current levels. Cloud movement and other factors can cause sudden changes in PV system output. Voltage and frequency control issues may occur in a power system if these systems are widely used [2]. One way to lessen these problems is to use energy storage on-site. Technology related to energy storage was the focus of the specialization project [3]. An array is a grouping of one or more modules connected together.

These days, solar energy technology adds even more emphasis to the benefits of sun- powered energy being flawless, plentiful, eco-friendly, and limitless. The PV system's output power is stochastic due to external factors and variations in solar irradiation [4, 5]. Because it is inexpensive and easy to use, it is widely used worldwide. An MPPT tracker and a battery charge controller are components of a solar PV MPPT charge controller. The battery charge controller receives the maximum power from the PV panel, which is tracked by the MPPT. Nevertheless, there is no performance analysis regarding charger efficiency, and the charge controllers that are being presented are not MPPT-charged. In local residential areas, a battery-powered energy storage unit can supply power to the load when the solar grid's power input declines.

Methodology

Figure. 1 shows a summary of the solar photovoltaic MPPT controlled array system with PI controller in the MATLAB/ Simulink environment. It is made up of an MPPT charge controller block, a solar PV array, a DC-DC converter, a battery, and an inverter (DC- AC). There is an MPPT algorithm called Perturb & Observe MPPT inside the MPPT charge controller block. A three-stage charger for lead-acid batteries and a P&O MPPT tracker are included in the MPPT charge controller block. The DC-DC converter's switching device is switched by a PWM control signal output by the MPPT charge controller block [6]. Many commercial solar PV MPPT battery charge controllers have this common design. Direct downloads of the battery and solar PV array models are made from the Simulink Sims cape Electrical block set library. A 680V battery can be charged by the model using a 54.15 kW photovoltaic array source. For performance analysis, this model is run through simulations and tests in the Simulink environment. This is a comprehensive model for a 54.15kW group that is connected to the 288KV via a boost DC-DC converter. DC voltage is increased by the boost converter from 680 V to 733 V. This circuit makes use of an MPPT framework, which automatically modifies the duty cycle to obtain the necessary voltage and maximizes power. The PI controller used in this paper in conjunction with a PV model provides a good idea of the appropriate control performance of any real system with change time during the day and can be used to analyze the PV generating system's performance [7]. Using the Simulink platform and Mat lab, the control is developed and tested. The fundamental neutralization of the theory of semiconductors, which defines the I-V relationship of the photovoltaic model mathematically.

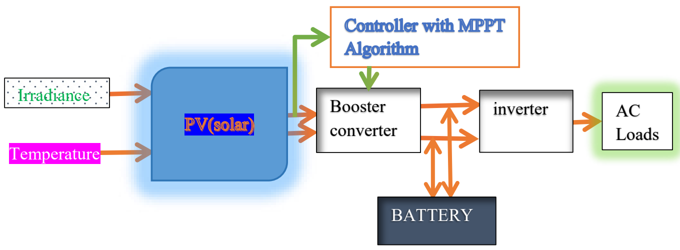


Figure 1: Block Diagram of the Overall System

The Red arrow lines indicate power flow and green line indicates signals.

Appliance	Hours	No of appliance	Watts	Total power(w)
Light	7	3	100	2100
fan	24	3	75	5400
fridge	24	1	800	19200
TV	6	1	200	1200
Washing machine	0.3	1	500	150
Grinder machine	0.4	1	500	200
Stove	5	1	300	1500
Air conditioner	24	1	1000	24000
Boiler	1	1	400	400

Table 1: Calculation of Power for Home Application

Table 1 calculates the appliance's total power consumption over a specified time period to be 54.15 kW/day. Finding the total power and energy consumption of all the loads that need to be supplied each day is the first step in designing a solar PV system.

An efficient and sustainable use of electricity in a household can be achieved through proper monitoring and management of energy consumption. The total energy needed for the PV panels is now equal to the daily total energy consumption times one [8]. Where the system's loss factor is 1.3.54150-watt hours per day x 1.3 is the total energy required from the PV modules to run the appliance. Daily energy required is 70,395 watt-hours [9].

Solar Panel Sizing Model

For simulation of Photovoltaic Solar PV Module is sized based on the load consumption requirements.

$$\text{Nm} = 1\text{module} \times \frac{\text{watt}-\text{peak rate}}{\text{rated output of pv availabe}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1\ [10]$$

Where Nm number of pv modules

$$\text{total watt} - \text{peak rate} = \frac{\text{total energy required}}{\text{module generation factor}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2\ \ [11]$$

$$\text{total watt} - \text{peak rating} = \frac{70393}{4.32} = 16370\text{wh/day} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

The PV module available=335wp[12] from solar panel so the total number of panel modules for system=16370/335=36.9 panel=37 panel

$$\mathrm{Nms} = \frac{\mathrm{Vsytem}}{\mathrm{Vmodule}} = 1\mathrm{module} \times 680 \div 37 = 19\mathrm{pv\ modules} \ldots\ldots 4 \quad [12]$$

$$\mathrm{Nmt} = \mathrm{Nms} \times \mathrm{Nmp} \ldots\ldots 5 \quad [13],[14]$$

$$\mathrm{Nmp} = \mathrm{Nmt} \div \mathrm{Nms} = \mathrm{Imodule} \times 39/\mathrm{Nms} = 37/19 = 2\mathrm{pv\ module} \ldots\ldots 6 \quad [15],[16]$$

$$\mathrm{Parray} = \mathrm{Nms} \times \mathrm{Nmp} \times \mathrm{Pmodule} = \mathrm{Nms} \times \mathrm{Nmp} \times 335 \ldots\ldots 7 \quad [17],[18]$$

Where: Nmt=number of total PV modules, Nmp=number of PV modules in parallel, Nms=number of PV modules in series.

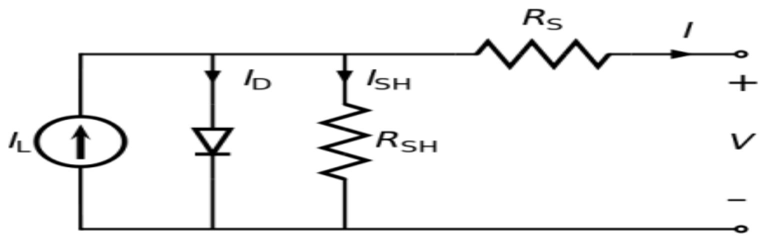


Figure 2: Circuit Diagram of PV Cell

The current-voltage characteristics equation of solar cell referred to in Figure.2. is given as-

$$\mathrm{I} = \mathrm{n_p} * \mathrm{I_{ph}} - \mathrm{n_p} * \mathrm{I_{sc}} \left[e^{\left(\left(\frac{q}{AKT}\right)\left(\frac{V}{n_s + I*R_s}\right)\right)-1} \right] \ldots\ldots 8 \quad [19]$$

The photo current depends on the solar insulation and cell's working temperature,is given as-

$$\mathrm{I_{ph}} = \left[(\mathrm{I_{sc}} + \mathrm{K_t}(T - \mathrm{T_r})) * \frac{S}{1000} \right] \ldots\ldots 9 \quad [20]$$

The cell's saturation current changes with the cell temperature and is given as-

$$\mathrm{I_{sc}} = \mathrm{I_{rsc}} (\frac{\mathrm{T}}{\mathrm{T_r}})^3 * e^{\left(\frac{qEgap}{AK}\right)\left(\frac{1}{T_r} - \frac{1}{T}\right)} \ldots\ldots 10 \quad [21]$$

Symbol	Description	Value
$\mathrm{I_{ph}}$	Photo current	
Isc	Module reverse saturation current	
q	Electron charge	$1.602e^{-19}$C
A	Ideal factor	1.60
k	Boltzmann constant	$1.38e^{-19}$J/k
R_s	Small series resistance	
I_{sc}	Short circuit current	3.27A
K_i	Temperature coefficient	$1.7e^{-7}$A
T_r	Reference temperature of solar cell	300K
I_{rs}	Revers saturation current	$2.06e^{-6}$A
E_{gap}	Silicon Band-gap energy	1.1ev
n_p	Number of cells connected in parallel	40
I	Output current	
V	Voltage of PV array	
n_s	Number of cells connected in series	11
S	Solar irradiation level	$0 - 100\mathrm{w/m^2}$
T	Pv module surface temperature	400k

Table 2: Shows the Different Parameters of PV Cell Along with Their Symbols and Values

A blocking diode permits current to flow from a solar panel to a battery, but it stops or restricts current from the battery to the solar panel, keeping the battery from draining. In PV modules, bypass diodes are used to stop high reverse voltage from being applied across the cells in the case of shading [10-21]. The bypass and blocking diodes in the solar plant block increase maximum power and prevent overheating of the solar panel.

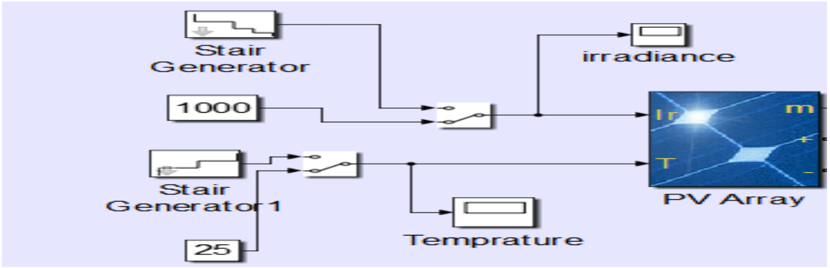


Figure 3: Solar Panel System Design Model

DC-DC Converter

The DC-DC converter changes the DC output voltage to a higher or lower value based on the DC input voltage source. For solar PV charge controller applications, a buck topology is typically selected because the PV array voltage is higher than the battery voltage [22]. In order to reduce the input voltage from the PV array while preserving power delivery for battery charging, the buck converter functions as a regulator. Stepping down the input voltage and raising the output current that is supplied to the battery allows for this. As illustrated in Figure. 4, the buck converter circuit consists of a MOSFET switching device, an input and output capacitor, and a high-power inductor or Schottky diode. During the night, the reverse blocking diode D1 is used to stop current from flowing backward from the battery to the PV array. A pulse generator with a switching frequency of 1000 Hz is used to switch the MOSFET. The ratio of the buck converter's input voltage, Vin, to its output voltage, Vout, can be used to calculate the output voltage (11), where D is the PWM signal's duty cycle.

$$D = \frac{V_{out}}{Vin} \quad \ldots\ldots 11$$

Boost converter specification design:

Output current $Io = \frac{p}{vo} = 200A$, Current ripple $\Delta I = 0.05 * IO * \frac{Vo}{Vin} = 20A$ Voltage ripple $\Delta v = 0.01 * Vo = 5v$, Inductance $L = \left(\frac{Vin(Vo-Vin)}{\Delta I * fs * Vo}\right) = 1.25mH$, Capacitance $C = \frac{Io(Vo-Vin)}{fs*\Delta Vo*Vo} = 4000\mu f$, for D1 Ron $= 0.002\ \Omega$, Vf = 0.5 V, Rs = 500 Ω,Cs = 250 e −9 F , C1 = C2 = 1000 e −6 F ,L = 10e −3 H , for MOSFET Ron = 0.02 Ω, Rd = 0.01 Ω, Rs = 1e 5 Ω, Cs = ∞ , for D2 Ron = 0.002 Ω, Vf = 0.8 V, Rs = 500 Ω,Cs = 250 e −9 F

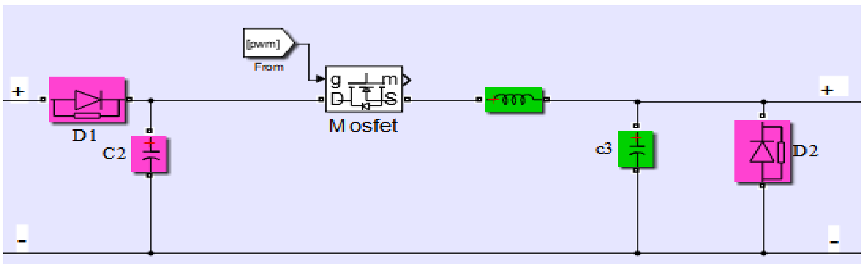


Figure 4: DC-DC Converter Implementation in Simulink

The solar PV power is managed by a boost DC-DC converter, which can function in voltage control and MPPT modes. Only in situations where the load power is less than the solar PV plant's maximum power as determined by incident irradiance and panel temperature does the voltage control mode come into play.

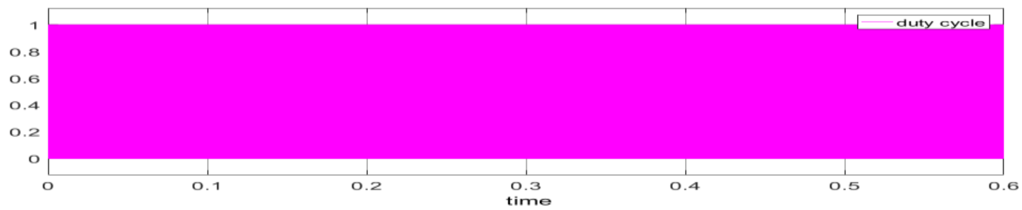


Figure 5: Duty Cycle

Maximum Power Point Tracking Algorithm

The purpose of a charge controller is to control the amount of energy that your solar panel array puts into your battery bank, prevent overcharging, and reverse current flow at night. The PV module specification in our case states that the short circuit current is 8.96A.

$$Irated = (Nbp \times Isc) \times 1.3 \ldots\ldots 12$$
$$= 4 \times 8.96 \times 1.3 = 47A$$

Where Nbp is the number of parallel batteries, Isc is the short circuit current, and Irated is the solar charge controller rating [23]. The safety factor is 1.3. Therefore, our system's reference solar charge controller is 60A. Because of the nonlinear relationship between current and voltage in PV arrays and the singular point at which maximum power is produced, MPPT algorithms are necessary. Furthermore, because cloudy terms and other changing atmospheric terms cause irradiation to change quickly. To ensure that the greatest power is always available, the MPP must be precisely followed in all reasonable circumstances. the problem by concurrently simulating the controller and monitoring the output for the critical response parameters while experimenting with different combinations of I and P. These three crucial responses are: a low-rise time; a low settling time; and a maximum overshoot that should be low. The best output response is provided by the pairings of P and I. The four parameters that indicate how to adjust the controller's parameters are increased time, steady state error, settling time, and overshoot. There is a transfer function in PI controller.

$$C(s) = K_P + \frac{K_I}{s} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 13 \quad [24]$$

The tuning issue will be more challenging if the system is nonlinear since the values of the PI parameters will need to be adjusted based on the operating conditions of the system [24]. Typically, only 30–40% of the total solar radiation that strikes a panel can be converted into electrical energy. A photovoltaic panel's maximum power is determined by variables like cell temperature, ambient temperature, and sun irradiation. In Figure 6, the P&O MPPT algorithm flowchart is displayed. The algorithm detects variations in power and modifies the operating voltage of the PV panel by altering the duty cycle of the converter switching device, thereby modifying the buck converter's effective input resistance [25]. If it reaches its maximum power, it observes once more, and the cycle continues endlessly.

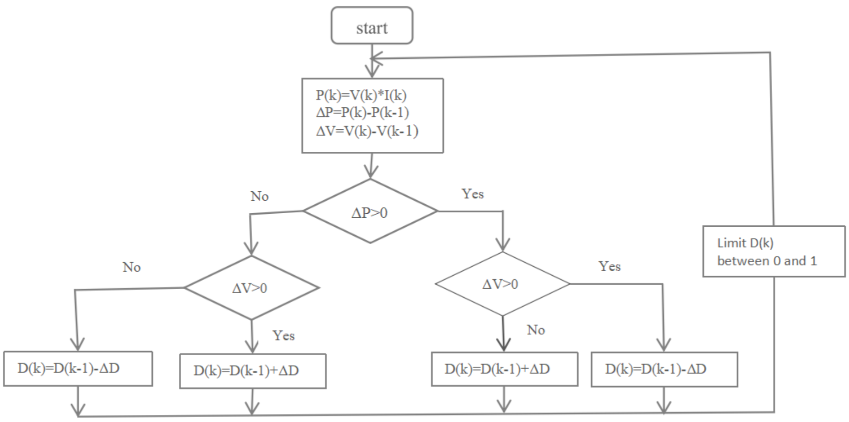


Figure 6: Perturb & Observe MPPT Algorithm Flowchart

The implementation of the P&O MPPT algorithm takes in voltage and current reading from the PV array, the previous sample (K-1) function is carried out by the unit delay block. The three if-else conditions of the P&O algorithm are carryout by the condition switch block, the ΔD block allows the user to set the perturbation step size of the duty cycle, the duty cycle increment and decrement function are carried out by an adder with a memory block D(K-1) feedback loop. The D(K) limit block limits the duty cycle exceeding the range between 0 to 1. The output of the duty cycle is connected to the battery charge controller section. The PV power output is also connected to the battery charge controller for conversion efficiency computation.

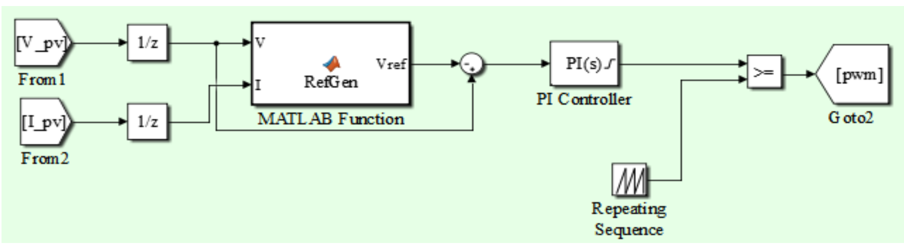


Figure 7: Implement the MPPT Algorithm in Simulation and Observe its Behavior

Battery Modeling

Figure.8. represents dialog box of a 680V, 477.8Ah Lead-Acid battery and also illustrates block parameters of this battery. Block sets consist some parameters are briefly discussed below [26].

• Battery Type

A set of preset charge behaviors for four different battery types—Lead-Acid, Lithium- Ion, Nickel Cadmium, and Nickel-Metal-Hydride—are given in this section. Lead-acid batteries are selected over the others due to their numerous advantages, including their lower self-discharge rate, higher energy density, and ability to operate at higher voltages.

• Rated Capacity (Ah)

The battery's minimum effective capacity is indicated by its rated capacity, expressed in ampere-hour. Generally speaking,

the maximum theoretical capacity is equivalent to
105% of the rated capacity when the voltage crosses 0 volts. This battery has a rated capacity of 477.8 Ampere-hour (Ah).

• Initial State-of-Charge (SOC)

The discharge curve is unaffected by this parameter, which is only used as the simulation's starting condition. A battery at 100% is said to be fully charged, and one at 0% is said to be empty. At 65% of its total charge, the battery will begin to charge

• Full Charge Voltage

The voltage factor (% of the nominal voltage) corresponding to the fully charged voltage, for a given nominal discharge current.

• Internal Resistance (Ohms)

The resistance is supposed to be constant during the charge and the discharge cycles and does not vary with the amplitude of the current.

• Capacity @ Nominal Voltage

The percentage (%) of the rated capacity extracted from the battery until the voltage drops under the nominal voltage. This value should be between 0% and 100%.

• Exponential Zone

The voltage zone that should lies between nominal voltage and full charged voltage. cycle to zero.

The battery bank system voltage can be 12v,48v,96v, depends on the amounts of voltage your solar system produces. If you buy battery for solar system that is 12v and 380AH the energy this battery will store 670*380=254600Wh, this means you can power 254600Wh/70395/24h= 3.46hr on full charged battery. The battery capacity should be large to store enough energy to operate the appliance at night and cloud condition.

$$\text{Size of battery} = \frac{\text{c+n}}{0.85*0.6*\text{Vsystem}} \ldots\ldots\ldots\ldots\ldots\ldots 14 \quad [27]$$

Where:
0.85=battery loss,0.6=depth of discharge,Vsystem=12v,c=battery bank capacity or energy required per day in Wh,n=autonomy days when there is no power produce by PV panel

$$\text{Battery size with autonomy 3 days} = \frac{70395/\text{day}*3\text{days}}{0.85*0.6*12\text{v}} = 34507.4\text{Ah} \ldots\ldots 15 \quad [28]$$

Our reference battery capacity =477.7Ah

$$\text{number of battery required} = \frac{1\text{ battery}*34507.4\text{Ah}}{477.7\text{Ah}} = 72\text{ battery} \ldots\ldots\ldots\ldots 16 \quad [29]$$

$$\text{Nbs} = \frac{\text{Vsystem}}{\text{Vbattery}} = 1\text{battery} * \frac{680}{12} = 56\text{ battery} \ldots\ldots\ldots\ldots 17 \quad [30]$$

$$\text{Nbp} = 1\text{battery} * \frac{\text{Nbt}}{\text{Nbs}} \ldots\ldots\ldots\ldots 18 \quad [31]$$

$$\text{Nbp} = 1\text{battery} * \frac{72}{56} = 2\text{battery}$$

$$\text{Nbt} = \text{Nbp} * \text{Nbs} \ldots\ldots\ldots\ldots 19 \quad [32]$$

Where
Nbt=number of total battery,Nbs=number of series battery,Nbp=number of parallel battery

$$\text{Battery size} = \text{Energy use (kWh)} \times \text{ NO of days of autonomy} / (1 - \text{SOC}.20 \quad [33]$$

$$\text{Battery bank size} = 54.15 \text{ x } 3 / (1 - 0.5) = 324.8\text{kwh}$$

$$\text{Ah} = 1000 \times \text{Energy storage/Battery voltage} = 324.8\text{k}/680 = 477.9\text{Ah} \ldots 21 \quad [34]$$

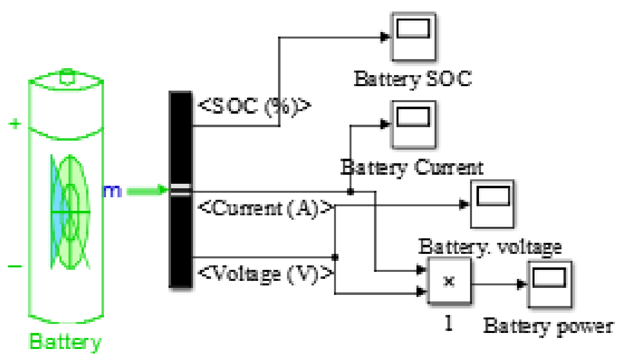


Figure 8: Lead Acid Battery Implementation in Simulink

The battery will power the load in the event that the voltage source is turned off [27-34]. The battery will be powered by the voltage source when it is activated.

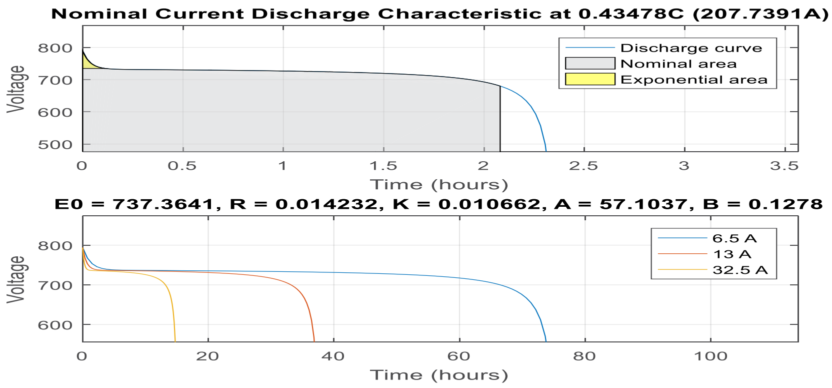


Figure 9: Nominal Discharge Battery Characteristics

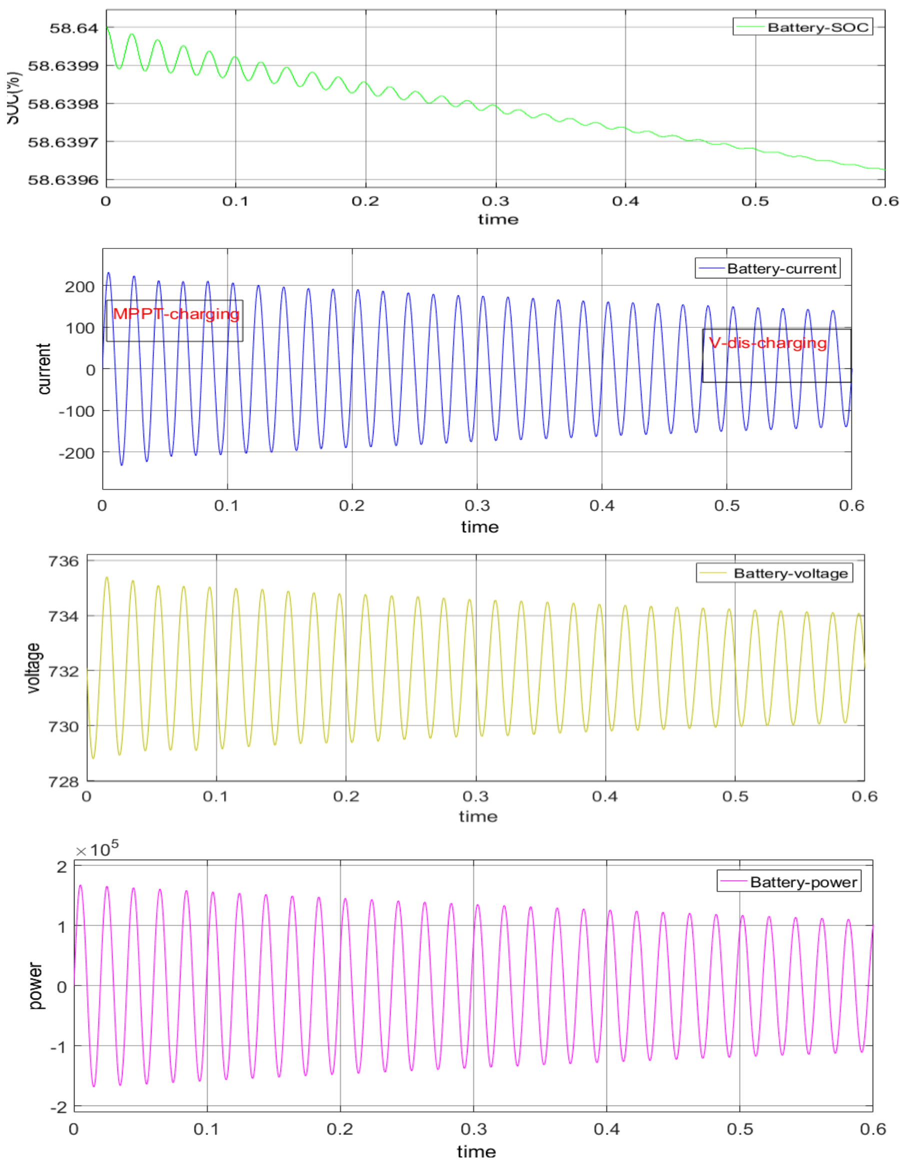


Figure 10: The Simulation Response for Battery SOC (%), Battery Current (A), Voltage (V), and for Battery Power (W) Respectively

An initial state of charge of 50% and a battery response time of 60 seconds are set for a lead-acid battery with a rated capacity of 477.8 Ah and nominal voltage of 680V. The load is powered by this battery, which is discharged due to linear oscillation in the SOC percentage. The enhanced performance and longer lifespan of the battery used in the suggested charge regulators are shown by the waveform above. MOSFET1 is a switching element in this suggested topology. Thus, by cutting the number of switches in half, the switching losses are minimized. Compared to the conventional, the overall system efficiency is higher [35]. As can be observed, the battery is first charged by the charge controller at the MPPT bulk charging stage when the voltage and SOC of the battery are less than 732V and 56.8%, respectively. When the battery voltage reaches 732V at 0.6 seconds, the charger switches to a constant voltage absorption charging stage.

To maintain the constant voltage of 732V during this stage, the duty cycle is switched between MPPT and zero, as seen by the duty cycle time of 0se to 1sec.The charge controller switches to the float stage, where the duty cycle is zero and the battery voltage drops to the floating voltage of 732V, when the SOC reaches 56.8% at 0.6 seconds.

DC-AC Converter

Never should the inverter's input rating be less than the appliance's total wattage. Your battery and the inverter need to have the same nominal voltage. The inverter's input rating ought to be 25–30% greater than the power consumption of your device. Our appliances have a combined wattage of 54150w.

$$\text{inverter size} = \frac{\text{total watt}*130}{100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 20 \quad [36]$$

$$\text{inverter} = 54150/130\% = 70395\text{w}$$

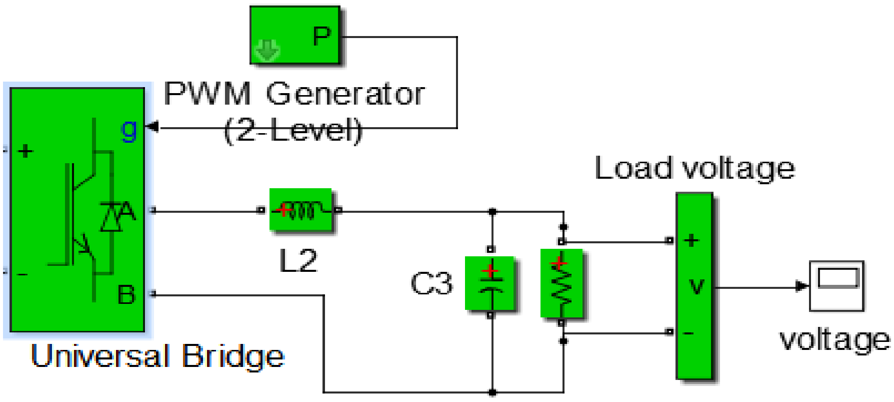


Figure 11: DC to AC Converter Design in Simulink Model

Overall Charge Controller Efficiency Performance

The MPPT battery charge controller model achieves its overall efficiency performance by charging the battery under a range of solar irradiance conditions, from 400 W/m2 to 1000 W/m2 [36]. MPPT controllers are appropriate for larger solar systems because they have higher efficiency, quicker charging times, and greater energy harvesting.

The ratio of the PV array's input power to the battery's output charging power can be used to calculate the efficiency. This is done to mitigate the oscillation in efficiency brought on by the MPPT algorithm. This is done to mitigate the oscillation in efficiency that the MPPT algorithm causes. With no MPPT, the power produced at 1000 watts per square meter is 120.9 watts, and when MPPT is used, the power produced is 599.3 watts, indicating an efficiency of roughly 97.9%.

All Over System Simulation Model Using Matlab Simulink

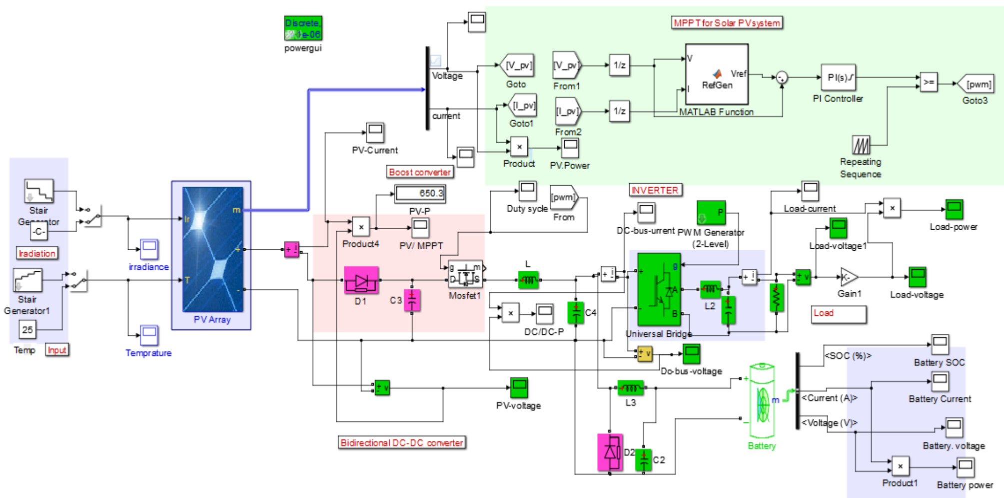


Figure 13: Overview of Solar PV MPPT Charge Controller Model

The simulation's reaction to input parameters, such as sun radiance intensity and cell the y-axis selects the sun's irradiance shape to be between 400 500 600 800 and 1000 w/m2. T=0.6 seconds is selected as the time. T=0.6 seconds is the time, and the temperature's arbitrary shape of 25 C.deg.

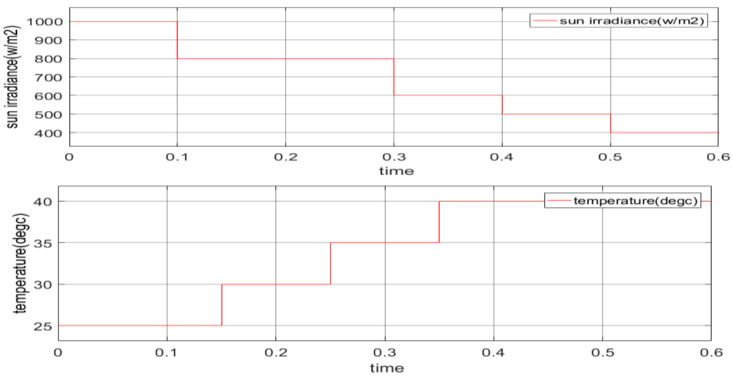


Figure 15: The Response of the Simulink Model to the Voltage (V), Current (A), And Power (W) of the PV-Array

Figure 15. displays the obtained response from the PV array for power (W), voltage (V), and current (A). As the sun's radiance increases, we can observe that the voltage increases gradually and that the current nearly exactly matches the input sun radiance intensity values.

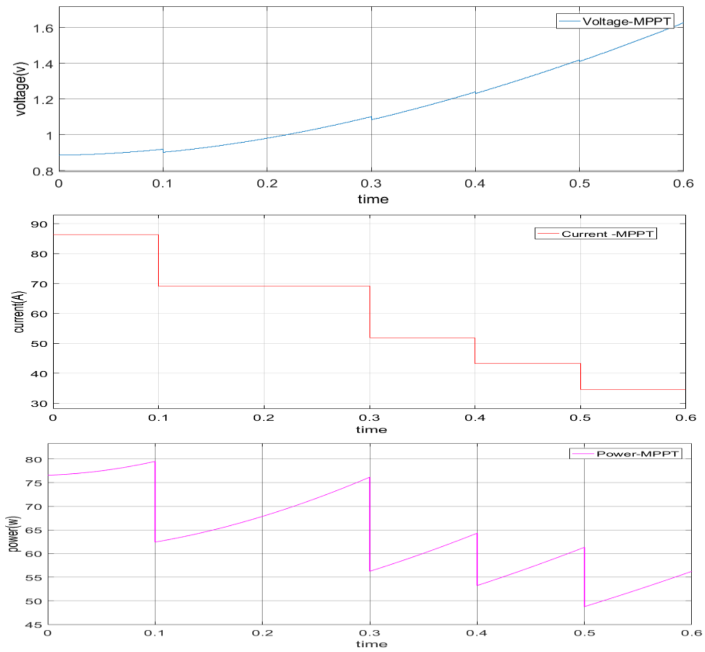
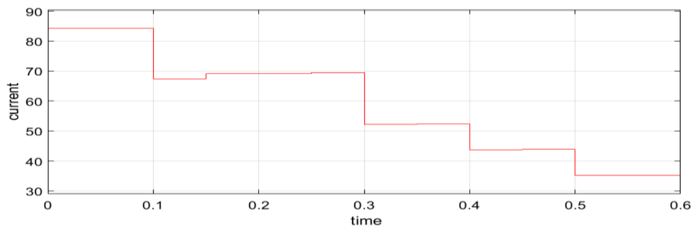


Figure 16: The Simulink Model Response Current (A) from the PV-Array for Variable Temperature and Irradiance



. The Simulink model response current (A) from the PV-Array for variable temperature and

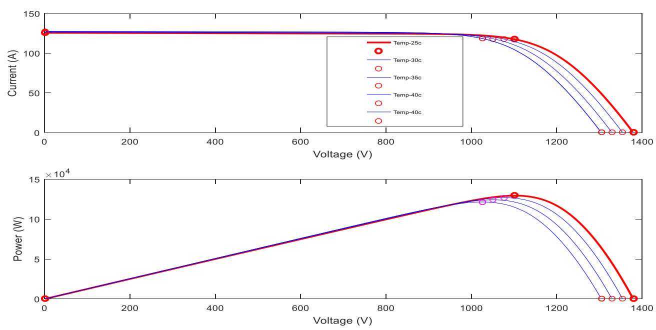


Figure 17: The V-P Characteristics of PV Panel for Level of Irradiation of 1000W/M2 for Different Temperature

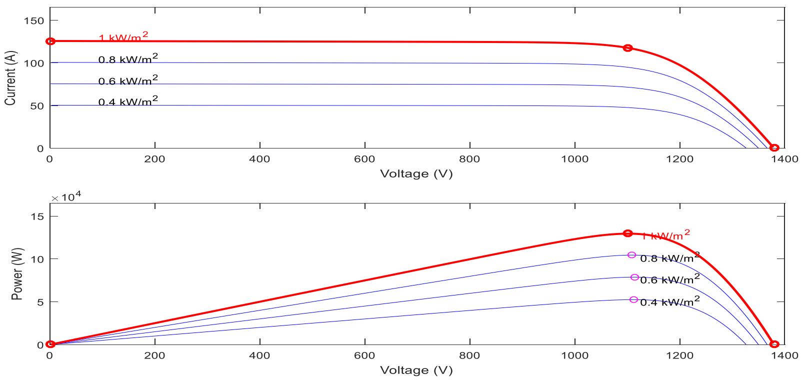


Figure 18: V-P Characteristics of PV Panel for Level of Temperature At 25°C for Different Irradiation the MPPT Simulation Shows at Varies Solar Irradiance Traces the Point So MPPT Work Exactly OK. At 1kw/M^2 Radiation the Maximum Power Is 48.9kw

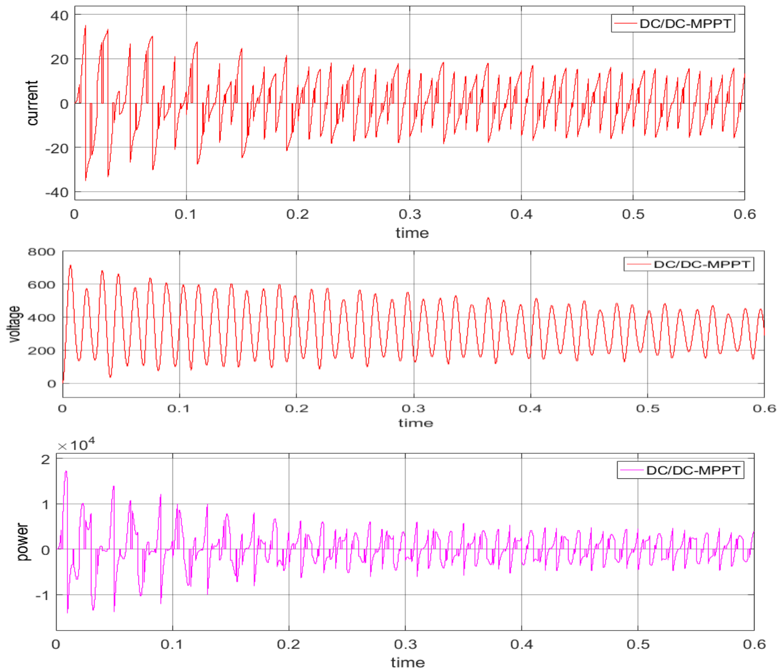


Figure 19: Output of Current(A), Voltage(V), and Power for Boost Converter Model Respectively

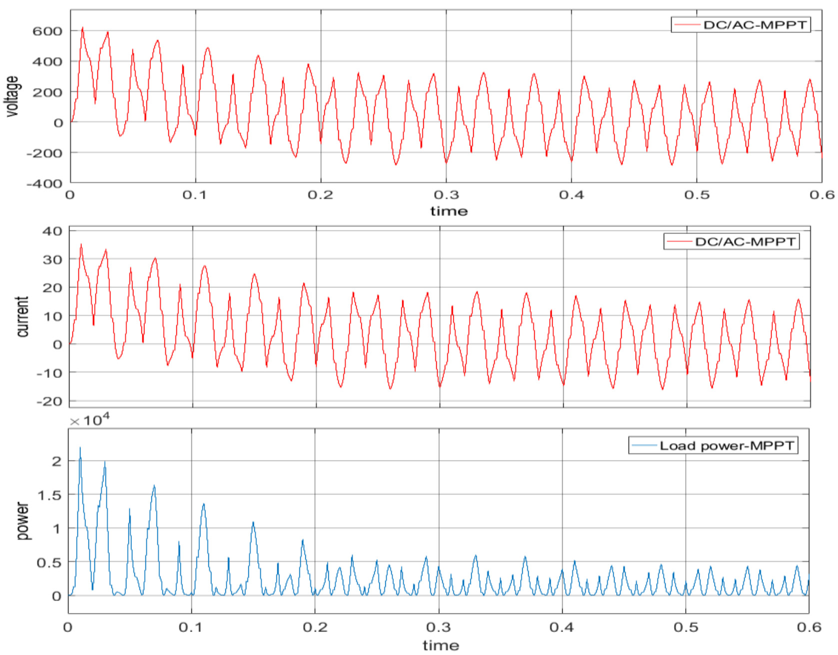


Figure 20: Inverter Model Output of Current(A), Voltage(V), And Power for Boost Converter Model for Load System Respectively

Results and Discussion

Scenario for simulation the estimated PV array characteristics are as follows using the developed model.

• Figure. 18 shows the I–V and P–V characteristics at constant temperature and varying irradiation. Here, temperature remains constant at 25 °C but solar irradiation varies with values of 400, 600, 800, and 1000 W/m2. In summary, an increase in irradiation leads to an increase in output voltage and current. In this operating condition, this leads to an increase in power output.

• Figure. 17 displays the I–V and P–V characteristics at constant irradiation and temperature. In conclusion, a rise in operating temperature results in a slight increase in current output but a sharp decrease in voltage output.

The MPPT tracking performance, battery charging performance, overall efficiency performance, and validation with a commercial MPPT charge controller are the four areas that outline the model's performance analysis.

Conclusion

A solar PV MPPT battery charge controller model's detailed circuitry modeling in Simulink is shown. The buck converter circuit, DC/AC, and MPPT P&O tracking algorithm are all fully reproducible and have clear explanations. A 48 V lead-acid battery can be charged by the MPPT battery charge controller by monitoring the 54.15 KW PV array power source's maximum power. In terms of environmental and physical parameters like solar radiation and cell temperature, it met many high-end commercial solar PV MPPT charge controller product specifications with an average overall efficiency of 97.9%.

The provided Simulink model is adaptable to any commercial MPPT charge controller with a comparable topology. The simulation model's performance was also confirmed using an actual commercial solar PV MPPT charge controller experimental setup. With small and medium standalone PV systems, this verified model helps with better sizing of PV panels and battery energy storage. The maximum power point tracking (MPPT) system, which is based on the boost DC/DC converter connected to the PV system and the controller system, ensures the maximum power in the event of weather fluctuations. A DC/AC inverter then integrates this power into the AC utility grid.

References

1. Rashmi N and Hemavathi R. Matlab/Simulink Model of Solar PV Array with Fuzzy Logic Based MPPT for Maximizing PV Array Efficiency. *International Journal for Modern Trends in Science and Technology 2021*, 7 pp. 258-263.
2. SOLAR CHARGE CONTROLLER FOR DOMESTIC APPLICATIONInternational Journal of Engineering Applied Sciences and Technology, 2021 Vol. 6, Issue 1, ISSN No. 2455-2143, Pages 325-330.
3. Vika, H. B. (2014). Modelling of photovoltaic modules with battery energy storage in Simulink/Matlab: With in-situ measurement comparisons (Master's thesis, Institutt for elkraftteknikk).
4. Ya-qin, G. U. O., Zheng-qun, W. A. N. G., & Yan, Q. I. N. (2013). Application of Proteus in Design and Production of Electronic Products. *Research & Exploration in Laboratory, 32*(12).
5. Zamani, M. A., Yazdani, A., & Sidhu, T. S. (2012). A control strategy for enhanced operation of inverter-based microgrids under transient disturbances and network faults. *IEEE Transactions on Power Delivery, 27*(4), 1737-1747.
6. Masenge, I. H., & Mwasilu, F. (2020). Modeling and control of solar PV with battery energy storage for rural electrification. *Tanzania Journal of Engineering and Technology, 39*(1), 47-58.
7. Haghbin, S., Khan, K., Lundmark, S., Alaküla, M., Carlson, O., Leksell, M., & Wallmark, O. (2010, September). Integrated chargers for EV's and PHEV's: examples and new solutions. *In The XIX International Conference on Electrical Machines-ICEM 2010* (pp. 1-6). IEEE.
8. Harrington, S., & Dunlop, J. (1992). Battery charge controller characteristics in photovoltaic systems. *IEEE aerospace and electronic systems magazine, 7*(8), 15-21.
9. Pham Van DuySimulation of on-grid solar power system by Simulink Module in MATLAB software The International Journal of Engineering and Science (IJES) Volume 8, Issue, 9 Series I, ISSN (e): 2319 – 1813 ISSN (p): 23-19 – 1805 Pages PP 21-26,2019.
10. Gusmedi, H., & Komalasari, E. (2014, December). Feasibility and optimal design of micro-hydro and photovoltaic hybrid system in support to energy independent village. *In The 2nd IEEE Conference on Power Engineering and Renewable Energy* (ICPERE) 2014 (pp. 136-139). IEEE.
11. Almukhtar, Z., & Merabet, A. (2016). Fuzzy MPPT Control and Power Regulation for Standalone Photovoltaic Energy Conversion System. *International Journal of Advanced Engineering Research and Applications (IJA-ERA), 2*(7), 371-381.
12. Chetan Singh Solanki chetanss@jitb.ac.in Solar Photovoltaic plant watch? SPV M L17 Solar PV Modules and PV Module Design.
13. Chy, D. K., Khaliluzzaman, M., & Karim, R. (2017, February). Analysing efficiency of DC-DC converters joined to PV system run by intelligent controller. *In 2017 International Conference on Electrical, Computer and Communication Engineering* (ECCE) (pp. 457-462). IEEE.
14. Kumar, A. P., Parimi, A. M., & Rao, K. U. (2014, May). Performance Analysis of a Two-Diode model of PV cell for PV based generation in MATLAB. *In 2014 IEEE International Conference on Advanced Communications, Control and Computing Technologies* (pp. 68-72). IEEE.

15. Jain, S., & Agarwal, V. (2007). Comparison of the performance of maximum power point tracking schemes applied to single-stage grid-connected photovoltaic systems. *IET Electric Power Applications, 1*(5), 753-762.
16. Pukhrem, S. (2013). A photovoltaic panel model in matlab/simulink. *Dublin Institute of Technology, Faculty of Electrical Engineering.*
17. Faranda, R., & Leva, S. (2008). Energy comparison of MPPT techniques for PV Systems. *WSEAS transactions on power systems, 3*(6), 446-455.
18. Tripathi, A., & Sahay, K. B. (2016, July). Modeling & simulation of proposed grid connected 10 MW solar PV array power plant at Lucknow. *In 2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)* (pp. 1-5). IEEE.
19. Mohapatra, B. N., Dash, A., & Jarika, B. P. (2017). Power saving solar street lights. *International Journal of Emerging Technologies in Engineering Research, 5*, 105-109.
20. Matlab and Simulink, the Math works, Inc. as of December 2013.
21. http://www.faulhaber.com/servlet/com.
22. http://solarwork.com/greatsolar_solarpvelectric.html
23. Roni Sarkar, et. al. Mathematical Modeling of Solar Photovoltaic Cell using MATLAB/Simulink and Study under Different Climatic Condition ISSN: 2248- 9622, Vol. 13, Issue 6, June 2023, pp.51-57
24. Al-Adwan, I., Mo'ath Al-Hayek, A. A., Issa, M. A. S., & Jaber, Q. (2019). Using Matlab for simulating real-world photovoltaic system. *Financed by Scientific Research Support Fund, 13*(1), 21.
25. Paraskevadaki, E. V., & Papathanassiou, S. A. (2011). Evaluation of MPP voltage and power of mc-Si PV modules in partial shading conditions. *IEEE Transactions on Energy Conversion, 26*(3), 923-932.
26. Ndagijimana, P., Tech, M., & Kunjithapathan, B. (2019). Design and implementation PV energy system for electrification rural areas. *Int. J. Eng. and Adv. Tech, 8*(5), 2340-2352.
27. Anish Yadav*, Abhishek Dhaigude**, Naval Kedar***, Nitin Deshmukh****Mathematical Modeling of Solar Cell Using MATLAB/Simulink, ISSN: 2248-9622 Vol. 9, Issue 6 (Series -II) June 2019, pp 74-76
28. International Journal of Electrical Engineering and Technology (IJEET) Volume 13, Issue 9, September 2022, pp. 15-22, ArticleID: IJEET_13_09_002.
29. Modeling And Simulation of Solar Photovoltaic System Using MATLAB, September 2020.
30. Simulink Based Modelling and Simulation of Solar Power Generation with Grid Interconnection System Using Matlab for Home Appliances, February 2024
31. Ibbini, M., Mansi, S., Masadeh, M., & Hajri, E. (2014). Simscape solar cells model analysis and design. Computer Applications in Environmental Sciences and Renewable Energy. *Kuala Lumpur,* 97-103.
32. Sheshraj BurandeModeling and Simulation of Solar System with MPPT Based Inverter and Grid Synchronization Volume: 10 Issue: 05 | May 2023.
33. M. A. Tariq, N. Abbas, and N. Naseer. "Grid integration of a solar photovoltaic system with maximum power point tracking and reactive power control." Journal of Solar Energy Engineering, vol. 142, no. 3, pp. 031013, 2020.
34. R. Kaur, J. Singh, and A. Gupta. "Design and simulation of a grid-tied solar PV system with a fuzzy logic controlled MPPT algorithm." Journal of Renewable and Sustainable Energy, vol. 10, no. 2, pp. 023703, 2018.
35. P. Kumar, P. Srivastava, and S. Kumar. "Design and implementation of a fuzzy logic controller based MPPT algorithm for grid connected solar PV system." Sustainable Energy Technologies and Assessments, vol. 41, pp. 31-41, 2020.
36. Babu, B. C., Cermak, T., Gurjar, S., Leonowicz, Z. M., & Piegari, L. (2015, June). Analysis of mathematical modeling of PV module with MPPT algorithm. In 2015 IEEE 15th International Conference on Environment and Electrical Engineering (EEEIC) (pp. 1625-1630). IEEE.

Appendices

MPPT code algorithm

```
function Vref = RefGen(V,I)
% I used MPPT alogorithm in the matlab examples
% I only modify somethings
Vrefmax=400;
Vrefmin=0;
Vrefinit=380;
deltaVref=1;
persistent Vold Pold Vrefold;
% Persistent variable type can be store the data
% we need the old data by obtain difference
% between old and new value
dataType='double';

if isempty(Vold)
    Vold=0;
    Pold=0;
    Vrefold=Vrefinit;
end

P=V*I;% power
dV=V-Vold;% difference between old and new voltage
dP=P-Pold;% difference between old and new power
% the algorithm in below search the dP/dV
% the algorithm will works
 if dP~=0
    if dP<0
        if dV<0
            Vref=Vrefold+deltaVref;
        else
            Vref=Vrefold-deltaVref;
        end
  else
        if dV<0
            Vref=Vrefold-deltaVref;
        else
            Vref=Vrefold+deltaVref;
        end
    end
else Vref=Vrefold;
end

if Vref >=Vrefmax | Vref<=Vrefmin
    Vref=Vrefold;
end
stored data
Vrefold=Vref;Vold=V;Pold=P;
```