Performance Analysis of EV for PV System Based on FZPO MPPT Technique

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Abstract

The fixed zone perturb and observe (FZPO) maximum power point tracking (MPPT) divides the photovoltaic (PV) curve with the boundary voltages into multiple zones at different irradiance levels. This MPPT demanding has low cost and simple controller as it is easy to implement without any additional sensors. FZPO improves the steady state efficiency of the system compared to conventional perturb and observe (P&O) technique. The zone boundaries are set based on linear equations that reduces the system's complexity and also provides efficient tracking at varying irradiance conditions. Governments all over the world have been devoting enormous resources to improving air quality in order to combat the alarming problem of air pollution. So, a focus towards electrical vehicle (EV) is increasing and it is necessary to integrate renewable sources like PV systems to it. In this paper the analysis of EV system is performer with the PV system and it is compared with FZPO to conventional P&O MPPT. The PV system based on FZPO MPPT is shown fast transient performance at varying temperature and irradiance conditions from 300 to 1000 W/m^2. The overall EV system performance is verified in the various aspects: - MATLAB/Simulink environment.

Keywords
Fixed zone perturb & observe (FZPO), maximum power point tracking (MPPT), electrical vehicle (EV), battery storage system (BSS) and DC-DC converter.

1. Introduction
Our earth has a lot of potential to give us energy for lifetime, the main problem for human being is how to utilize that energy. Human being has discovered many ways to extract the energy from different sources present on the earth like for sunlight we can use solar thermal and solar photovoltaic system, for wind we use wind turbines and for biomass we use different methods to convert biomass to energy. Sun has a lot of potential to give us energy. In this paper we will see the photovoltaic energy of the sun. To convert the solar energy, we use solar panels. The energy generated from the panels will stored into the batteries and some energy may be sent to the grid also. In solar panels semiconductor material junction are used to generate energy from excitation due to sunlight. Panels are designed to get maximum power from the sun. According to design the panels are divided mainly into categories, Monocrystalline and Polycrystalline. These materials are set in an arrangements by consideration the safety and efficiency issues.

When exposed to daylight, photons are absorbed by electrons in the semi-conducting substance, that causes to become extremely charged. These migrate between the semiconducting material's top and bottom surfaces. A current termed as a direct current is created by the movement of electrons (DC). After that, the power is supplied through an inverter, which converts it to alternating current (AC) for usage in your house. (Mertens & Hanser, 2018).

The commonly used energy sources (renewable) are solar, wind, hydro and energy storage systems. From the above sources solar is most commonly used now a days. The energy from sun reaches to the earth in the form of rays and the photovoltaic system is used to extract/convert that radiation into the usable form of energy. The panels produce the dc power from the sun radiation. The energy is further used in different forms to complete the work. This dc energy may be converted to alternating energy to fulfill the demand. The conversion equipments are used like inverter. Inverter converts the dc to ac and gives a better efficiency. This energy can further be stored or transmitted to grid according to needs.

The PV system has many advantages like it can easily available, environment friendly. With its advantages it also has certain disadvantages like it can't be available at night or cloudy time. Although the efficiency of it has not achieved at a much high rate. The many techniques are implementing to increase the efficiency of the panels and with these improved systems we are implementing in our daily life works like: battery charging stations for electrical vehicles (EVs), agriculture, houses etc. There are many MPPT techniques like P and O, Incremental conductance, reference cell method, sampling method, fuzzy logic method (Syafaruddin et al., 2009), hill climbing etc (Chitransh & Kumar, 2021, Jain & Agarwal, 2004). The conversion process from solar power to electrical power and supplied to load is shown in Figure 1.

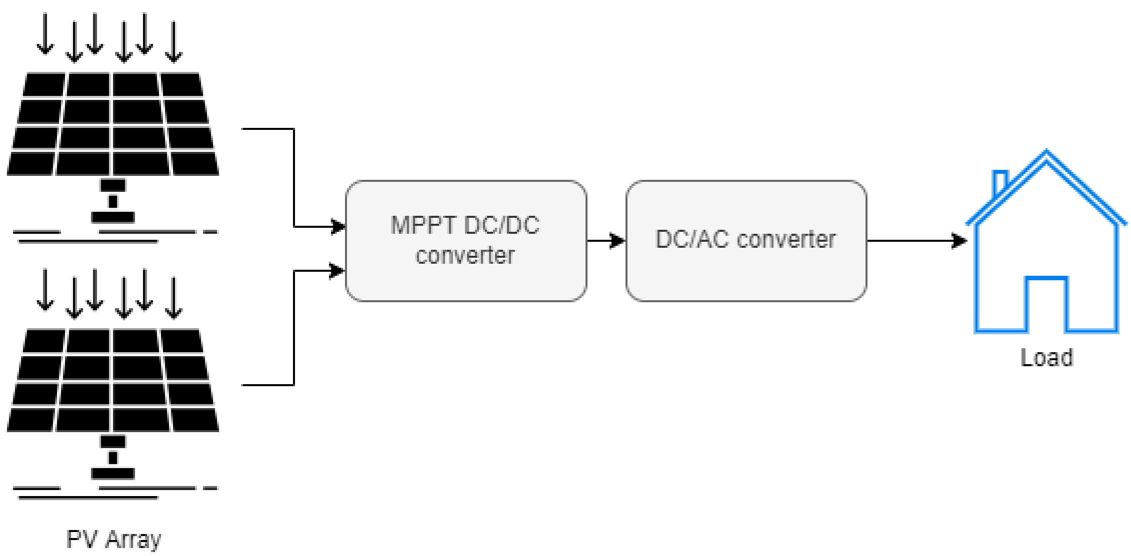

Figure 1. Conversion of solar power and supplied to load

Here we use FZPO MPPT tracking because is very simple and easy to appliance. By using this our model will work on higher efficiency. In our system the boost converter is connected with the FZPO MPPT and then the output of the system having load in parallel to the BSS used for EVs. In the conventional method the MPP is tracked depends on the panel voltage and power perturbation due to different irradiance and environment conditions. The control parameters of the system is converter's duty ratio (D) in direct P&O scheme. The convention scheme is based on the fixed step-size and frequency of perturbation. The step size describes how fast the MPP scheme; if the size of step is higher than the tracking response will be fast but this will causes a large steady state loss and vice versa. Therefore, a comparison between conventional P&O technique and incremental conductance technique is presented by (Saidi & Benachaiba, 2017) . In (Swaminathan et al., 2022) steady state efficiency and speed of tracking improves using adaptive step-size P&O techniques. The wave forms of PV array used in simulation are shown in Figure 2. First wave form is of voltage vs current at temperature from 0 degree to 50 degree and second is of voltage vs power. The power first reaches to the maximum point and after it starts reducing with a rate faster than it reached to the maximum point so, to track the maximum point in the power voltage curve we use the MPPT.

The proposed implantation in this paper and power converter devices are used to enhance our results. The main purpose of this MPPT is that it tracks the maximum power with reduced time and also improves the steady state efficiency of the system. The charge controller used in the system has the MPPT setup. As one of the portions of the panel gets shaded is unable to extract the power then this scheme helps to get the maximum power. It tracks the maximum power from the panel and gives the desired output. To perform this scheme, we use the MATLAB environment. MATLAB Simulink toolbox is used to perform the operation. The tracking is continuous. The efficiency of the whole photovoltaic system is implemented using the FZPO MPPT tracking and using the power converter devices.

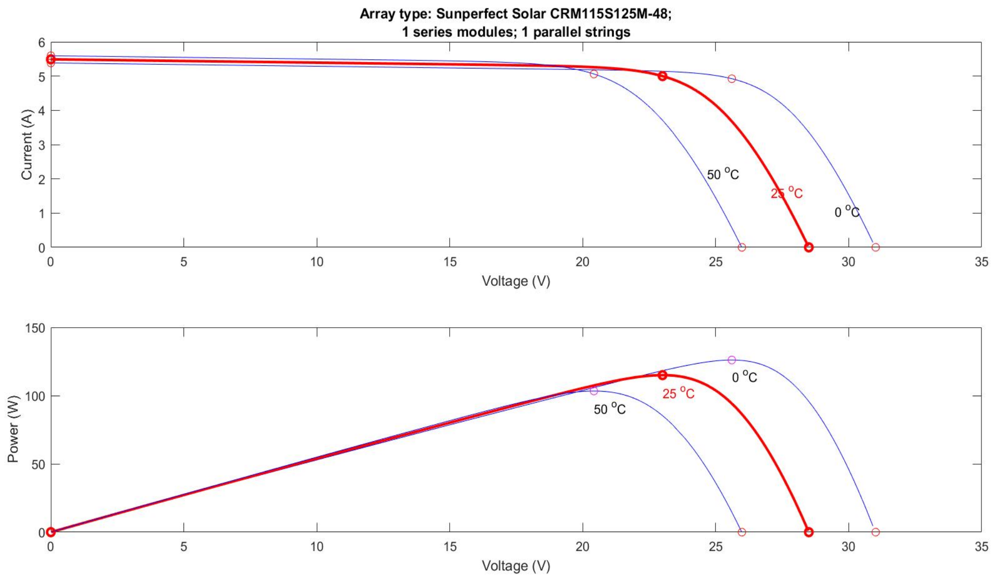

Figure 2. Waveforms of PV array

2. Literature Review

Energy from the sun can be collected as heat and converted into electricity with the help of photovoltaic cell and power converter topology. Solar technology has great future and this energy can be utilized into many applications like: lighting, industries, electrical vehicles, water heating etc. But with the advantages every technology has certain disadvantages; solar has disadvantage like: unavailability at night, high cost etc. The unavailability at night might be reduced with the help of battery storage. (Hayat et al., 2019) discuss the solar energy system and provides a review about the ways to convert electricity from sun's energy directly or indirectly. The performance of PVs are also discussed in it furthermore, their challenges are also studied with the future scope.

In (Abuzairi et al., 2019; Kivimäki et al., 2018; Mohamed & Abd El Sattar, 2019; S. HIWALE et al., 2014; Swaminathan et al., 2022) the maximum power point tracking for solar system is studied. Different types of topologies with their advantages and disadvantages are discussed. In (S. HIWALE et al., 2014) MPPT is used to charge the battery storage system at different irradiance and temperature conditions. So, to enhance the efficiency of the system MPPT is used. Here Perturb and Observe MPPT is used to enhance the system efficiency. With variable irradiance conditions and temperature, the MPPT tracks the peak of the power curve and provides better efficiency. PWM is used to provide the duty to buck converter. A low cost charge controller for solar system is designed in (Abuzairi et al., 2019). Arduino UNO is used to design the system, which control and provides the PWM signals to the converter. Different test related to validate the MPPT are performed are done and found that this charge controller is efficient up to 52%. As there are two main MPPT techniques are trends: P and O and Incremental and conductance. A comparison of the two is discussed in (Mohamed & Abd El Sattar, 2019). Here the main aim is to maximize the amount of power extracted from the PV array. A simulation study of both the algorithms are discussed in it to conserve the efficiency of the system. From the results it is found that incremental and conductance algorithm has faster MPP point and better than P and O due to drift free with rapid changing conditions. In P & O algorithm, a minor disturbance is introduced. The disturbance causes the solar array's power to fluctuate over time. If the disturbance raises the power, the disturbance continues in the same direction. When peak power is attained, the power at the following instant falls, and the perturbation repeats. When the algorithm reaches a stable state, it fluctuates around the peak point. To keep the power fluctuation to a minimum, the perturbation size is maintained minimal (Belkaid et al., 2017). The flow of algorithm is shown in Figure. 3. To optimize MPPT performance two parameters must be in priority: step size and frequency of perturbation. The perturbation step size must be high with limiting frequency to differentiate the response of system. (Kivimäki et al., 2018) aims to introduce the step size and perturbation frequency guidelines. The results here verify the validity of proposed guidelines. Under partial shading condition a simple perturb and observe technique fails to identify the global maxima. The global maxima tracking is determined in (Selvakumar et al., 2019) using high speed MPPT. This tracking is found to be better than other MPPT controllers and considerably high accuracy. The results are tested on 2.5 kW setup and this technique is based on particle swarm optimization. The MPPT for FZPO is discussed in (Swaminathan et al., 2022). The FZPO technique improves the steady state efficiency and provides drift free operation. The zones are divided first and then zone with maximum power is selected to implement. The panel's information is only required at initial stage that makes it low cost technique. A buck boost full bridge converter is used to supply the duty. This technique is found to be 20% more efficient than the simple perturb and observe technique. The power loss during MPPT is one sixth of the conventional MPPT. A complete study of buck boost full bridge converter is done in (Swaminathan et al., 2021).

(Hasaneen & Mohammed, 2008) provide the simulation and design of Boost converter. At switch mode working the converter has non-linear behavior. The input to the boost converter is supplied through PV panel at different irradiance and temperature conditions. The equations to analyze boost converter is discussed and simulation is performed on MatLab.

A charge controller that has MPPT for solar panel is developed in (Jana et al., 2014). The output voltage and charging current of battery is controlled by the proposed controller. This aims to provide a better efficient for solar panel that works on embedded system. A case study related to electrical vehicle charging station is discussed in (*Electric Vehicle Charging Station (Case Study on Infrastructure of EV Charging Station)*, n.d.). The potential needs of electrical vehicle charging stations for Indian scenario is studied. Selecting location and provide smart infrastructure is an important concern. Some problems like: range anxiety, battery degradation, auxiliary loads, integration to grids, infrastructure are discussed. The paper (Ul-Haq et al., 2017) discussed the modelling of smart charging stations for electrical vehicles that are suitable for quick charging with reduced losses. Vehicle to grid scheme is also implemented during peak load demands with bidirectional converter topology. And at final financial potential financial incentives are also discussed.

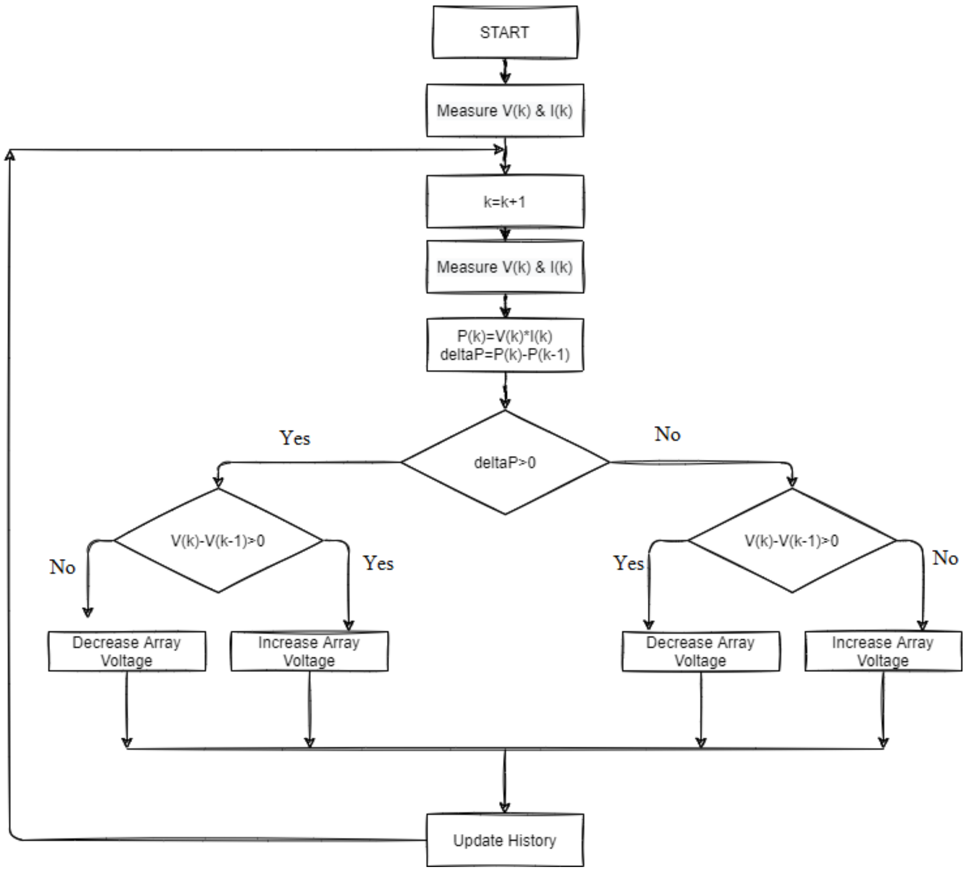

Figure 3. Perturb and observe flow chart

3. FZPO technique with ESS

3.1 FZPO overview

The PV curves are divided into multiple zones and a combination of fixed and adaptive step size is used to enhance the performance and steady state efficiency of the system. This technique provides the natural and drift free tracking at different irradiance conditions and doesn't have any sensor or measurement devices that makes this implementation simple. The power-voltage curve of PV arrays are divided into four zones as shown in Figure 4. Here zone1, zone2 and zone4 are non MPP zones while zone3 is MPP zone. The mathematical representation of these zones. The zone boundaries Z_{12}, Z_{23}, Z_{34} and Z_{45} are defined depends on the PV voltage curve. The frontier voltages are unique at dissimilar irradiance level for the PV array to improve the FZPO performance. MPP is not same for the various temperature and irradiance levels.

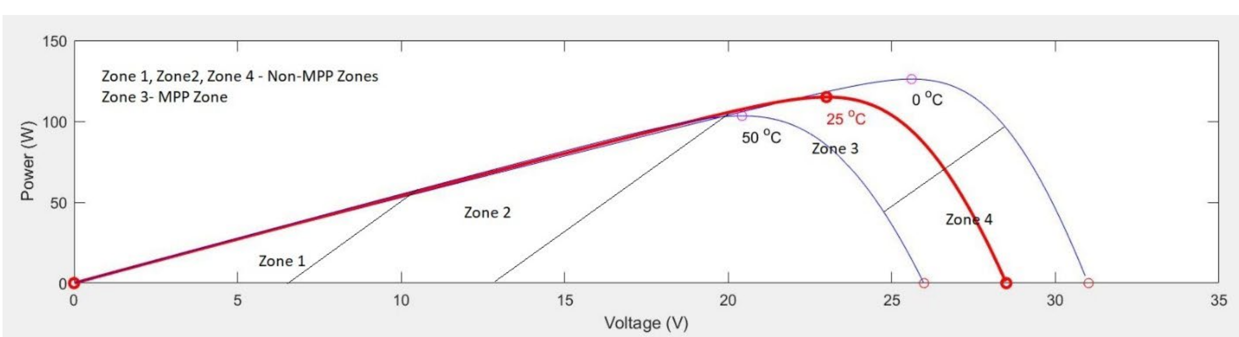

Figure 4. Zones defined at P-V characteristic curve

The boundaries of zones are defined based on the slope of the PV curve at temperature 25℃ and irradiance level for 300-1000 W/m^2. As the temperature of the panel increases then the efficiency of the panel reduces. At temperature 55℃ and irradiance 1000 W/m^2; the panel will have more losses as compared to the previous defined temperature. The equations that defines the dependence of panel on temperature is shown below in equation (1).

$$I = I_{PV} - I_o\left(e^{\frac{V+IR_s}{nV_T}} - 1\right) - \left(\frac{V+IR_{sh}}{R_{sh}}\right) \quad (1)$$

where, I is panel's output current to the load, I_{PV} is panel's current, I_o is reverse saturation current, R_{sh} and R_s are shunt and series resistances of the panel, V is terminal voltage and $V_T = \frac{kT}{q}$ that depends on temperature T. The relationship between isolation and PV current is given in (2). These are directly proportional to each other.

$$I_{SC} \propto I_{PV} \propto Isolation \quad (2)$$

Small variations in the parameters of PV array doesn't affect the performance of the FZPO technique because the operating PV current and voltage affects the perturbation step size not the panel parameters. Therefore, it is not mandatory to use the exact PV curve, as the FZPO controlled can be implemented by using the theoretically PV curve obtained from the datasheet. The four boundary equations for designing the zones conditions are (3-6):

$$Z_{B12} = Z_{B23} + A_1 \quad (3)$$
$$Z_{B23} = m_{23}I_n + D_{23} \quad (4)$$
$$Z_{B34} = m_{34}I_n + D_{34} \quad (5)$$
$$Z_{B45} = Z_{B34} + A_2 \quad (6)$$

A_1 and A_2 are voltage among parallel boundaries Z_{12} & Z_{23} and Z_{34} & Z_{45} (V). D_{23} and D_{34} are x-axis intercepts of Z_{34} and Z_{23} (V). From the equation (3) to (6) the boundary voltages can be found out; let Z_{B12} = 19.921 V, Z_{B23}= 23.821 V, Z_{B34}= 27.279 and, Z_{B45}= 28.529 V are the boundary voltages at a particular condition and the operating voltage of PV 24.5 V that is in the Zone 3 according to FZPO technique.

3.2 Step- Size

With linear equation, find mixed step size.

$$\Delta step = (mV_n(g) - V_b(g)) + C \quad (7)$$

where, m is slope of linear curve fitting and C is y-axis intercept. The step-size according to the equation (7) is directly related to difference of operating voltage and boundary voltage ($V_n(g)$ & $V_b(g)$). This also shows that step size equation doesn't depends on the PV parameters.

3.3 Controller operation of FZPO

The solar PV system will boost converter and battery storage is shown in Figure 2. The operation of the FZPO method is shown in the Figure 3; the step by step operation of this method is shown here. In start the operating panel voltage and current are fetched, the zones boundaries are calculated from the equation (3) to (6). At stage 3 the operating Zone is selected and the condition for this is applied with the step size from equation (7). If the working point is within the Zone 3 then the step will be fixed and if the working point is not in the Zone 3 then the step changes. With the resultant parameters as duty Cp will be added or subtracted from the step change and the operating point will shift into the Zone 3. At end the FZPO update the Cp into the controller and wait for the next perturbation to quantity input parameters and repeat the procedure.

3.4 Energy storage system for EV

In this paper we use boost converter connected to load and a battery storage system in parallel to it shown in Figure 5. The Li-ion battery with state of charge (SoC) 50% is used for power supply when more power is needed. SoC of battery is the ratio of its remaining capacity to the fully charged capacity. So, a fully charged battery will have SoC 100%. In today's portable applications, Li-ion is the most widely utilized battery chemistry. For the user's convenience and to extend the battery life, accurate state-of-charge (SOC) and lasting run-time information for movable devices is critical. The SOC is the percentage of the battery's highest allowable charge that is currently present. The SoC of battery will continue to decrease till the minimum limit is reached. In these states, the battery voltage and dc-link voltage remain constant throughout the control operation of boost converter. The performance of the batter with FZPO technique is investigated at different irradiance conditions.

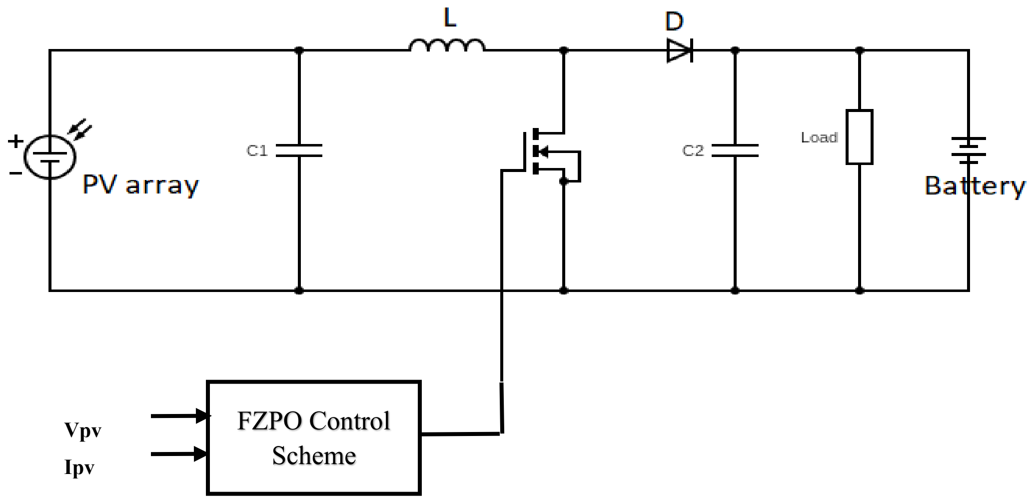

Figure 5. Circuit Model of FZPO technique with BSS

You can charge the battery using the solar panels installed on the premises of the charging station, so you can charge the electric vehicle without increasing the load on the grid. During peak demand, the energy stored in the battery helps relieve pressure on the electrical system. Electric vehicle batteries can be used to charge campuses and homes with bidirectional charging, reducing the grid's non-renewable energy requirements. When consumers power their homes by combining renewable energy with two-way electric vehicle charging, they don't have to pay prepaid electricity (with solar panels on the roof) and buy so much from the utility. It may not be necessary to use.

Ferreira et al. (2011) proposes the design of an intelligent process-based system for generating and managing the charging process of an electric vehicle (EV). Due to network limitations and the lack of smart metering devices, charging of electric vehicles should be carried out in a balanced manner, considering past experience, data extraction-based weather information, and simulation methodologies. So, in smart grid it is planned to implement in vehicle to grid (V2G) and connect it EV with renewable sources.

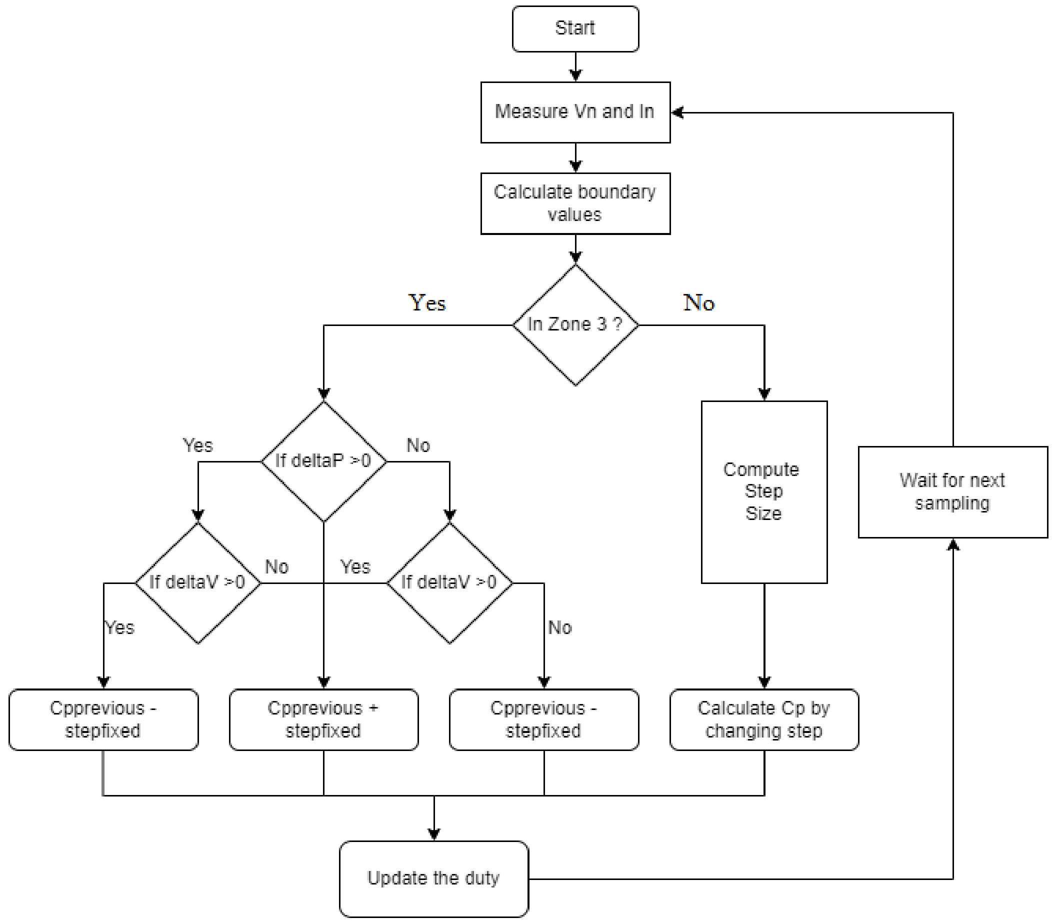

Figure 6. Flow chart of FZPO MPPT technique

4. Simulation Results and Discussion

The simulation for the designed technique is used for charging the battery in EV charging stations. The simulation circuit is shown in Figure 8 and their results are described in the below section. The simulation is performed in MatLab R2021 b (9.11.0.1769968). The solar panel used in the simulation is "Sunperfect Solar CRM115S12M-48". The parameters of solar panel and BSS are given in Table 1. In this technique the boost converter uses a decoupled control scheme comprise with FZPO MPPT technique with reference voltage perturbation shown in Figure 7 (Killi & Samanta, 2015; Kivimäki et al., 2018).

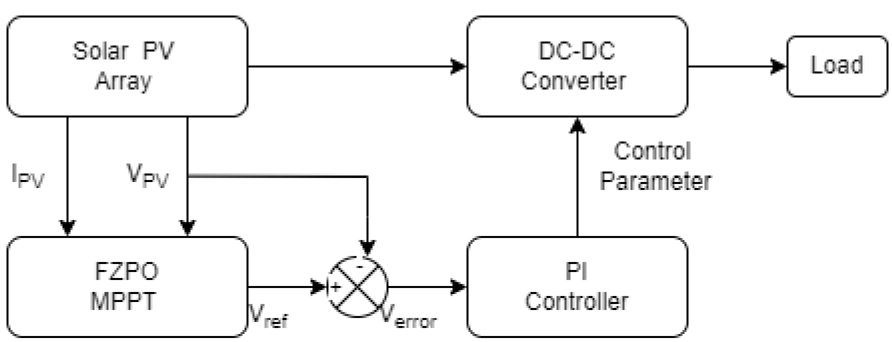

Figure 7. PV system with FZPO MPPT

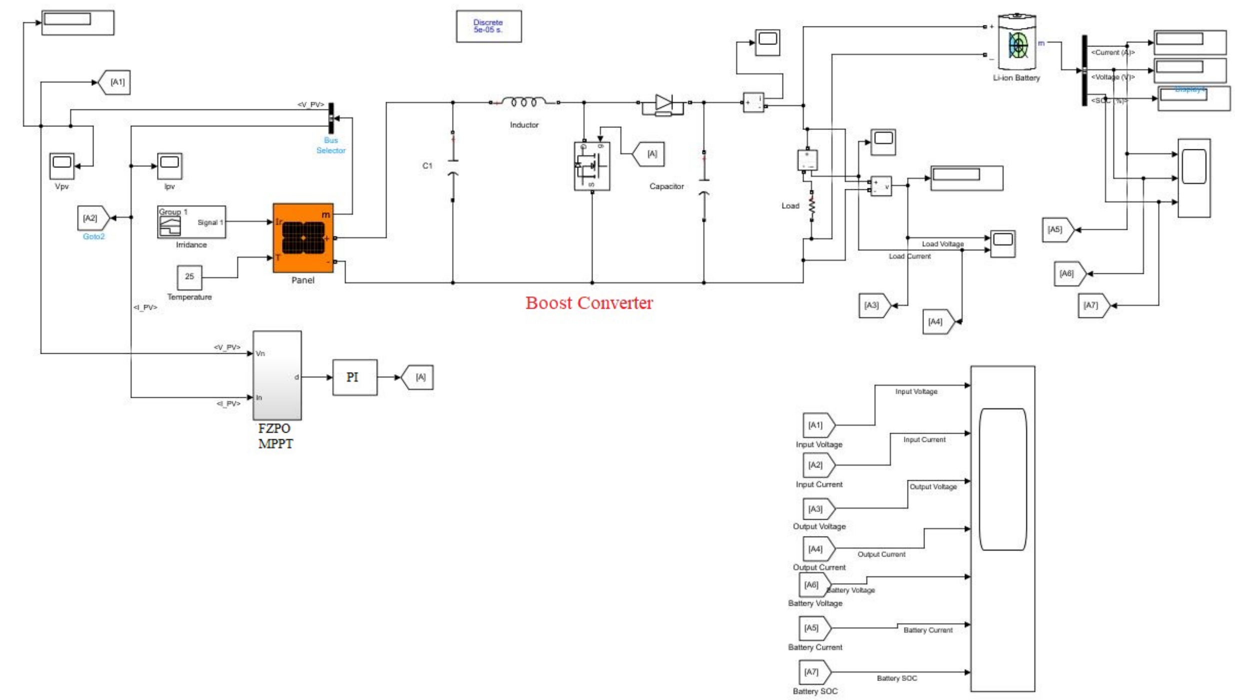

Figure 8. Simulation block diagram of the system

Table 1. Solar Array and Battery parameters

S. No.	Solar Array		S. No.	Solar Array		Battery (Li-ion)		
1.	Maximum Power	115 W	6.	I_{MPP}	5 A	**S. No.**	**Parameters**	
2.	Cells per module	48	7.	Diode saturated current	1.47 e-10 A	1.	Nominal Voltage	45 V
3.	Open circuit voltage	28.5 V	8.	Shunt resistance	102.76 Ω	2.	Rated Capacity	40 Ah
4.	Short circuit current	5.49 A	9.	Series resistance	0.40 Ω	3.	Initial state of charge	50 %
5.	V_{MPP}	23 V	10.	Light generated current	5.511 A	4.	Battery response time	30 s

The FZPO MPPT Technique is tested in dissimilar irradiance conditions and the results are discussed in this section. For constant irradiance e.g. 300W/m^2 and 1000W/m^2 the output of the PV array terminals are shown in Figure 9. The output power oscillations at 300W/m^2 are higher than 1000W/m^2 due to constant step size used in zone 3. The waveforms for battery parameters for FZPO and P&O technique are also shown in Figure 10.

The FZPO MPPT technique at varying irradiance conditions from 300W/m^2 to 1000W/m^2 is shown in Figure 9. The response time of FZPO technique to reach the steady state is lesser than conventional P&O MPPT Technique. The drift present for FZPO technique is also less compared to P&O technique and shown in Figure 11 and Figure 12. The tracking speed is also faster than the simple P&O technique. The all three results are shown in Figure 11 and Figure 12. The output battery waveforms are shown in Figure 13 for both the techniques.

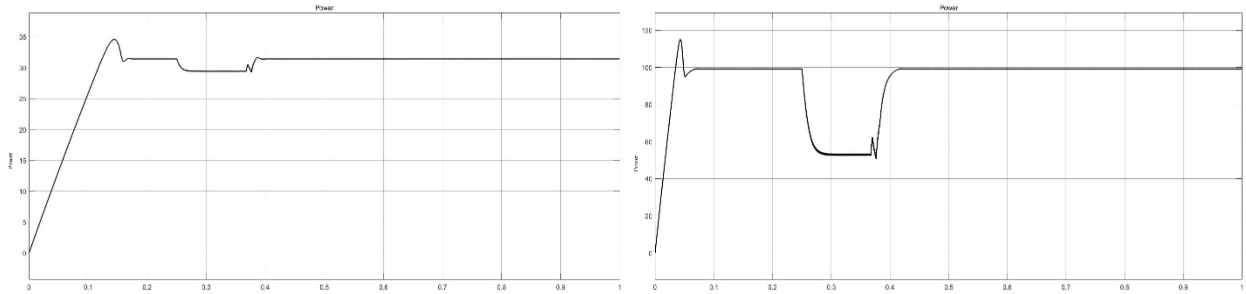

Figure 9. The output power of the PV system for 300 W/m^2 & 1000 W/m^2 irradiance based on FZPO MPPT

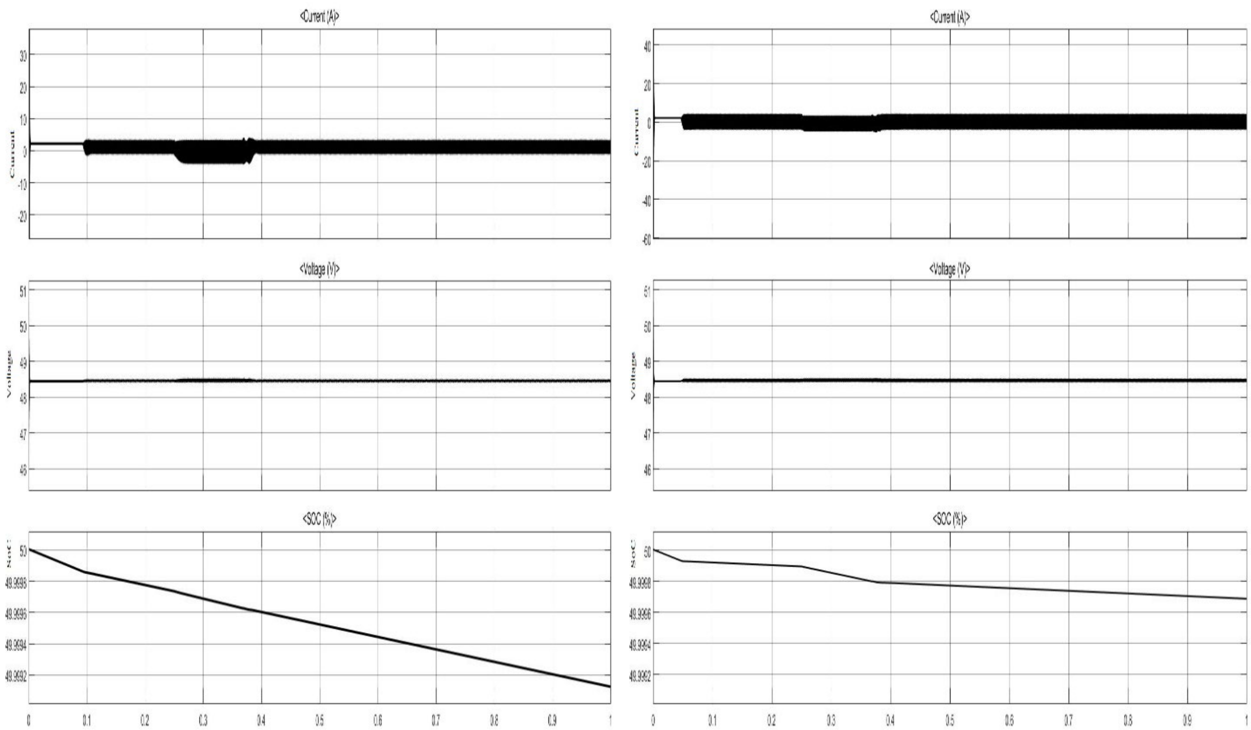

Figure 10. The output current, voltage and SOC of the battery for 300 W/m^2 & 1000 W/m^2 irradiance based on FZPO MPPT

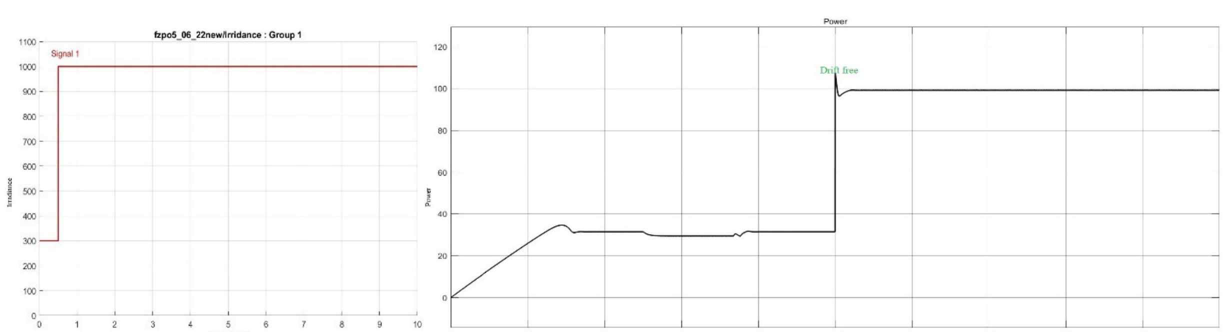

Figure 11. FZPO technique input step irradiance and output waveform with faster steady state response

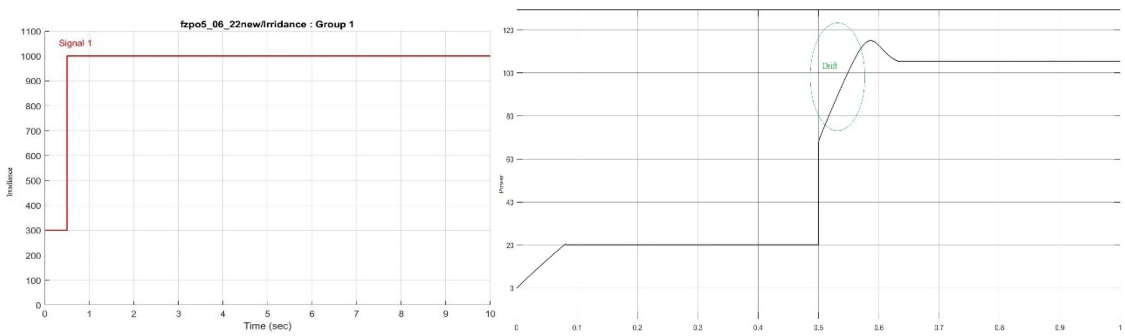

Figure 12. P&O technique input step irradiance and output waveform with slower steady state response

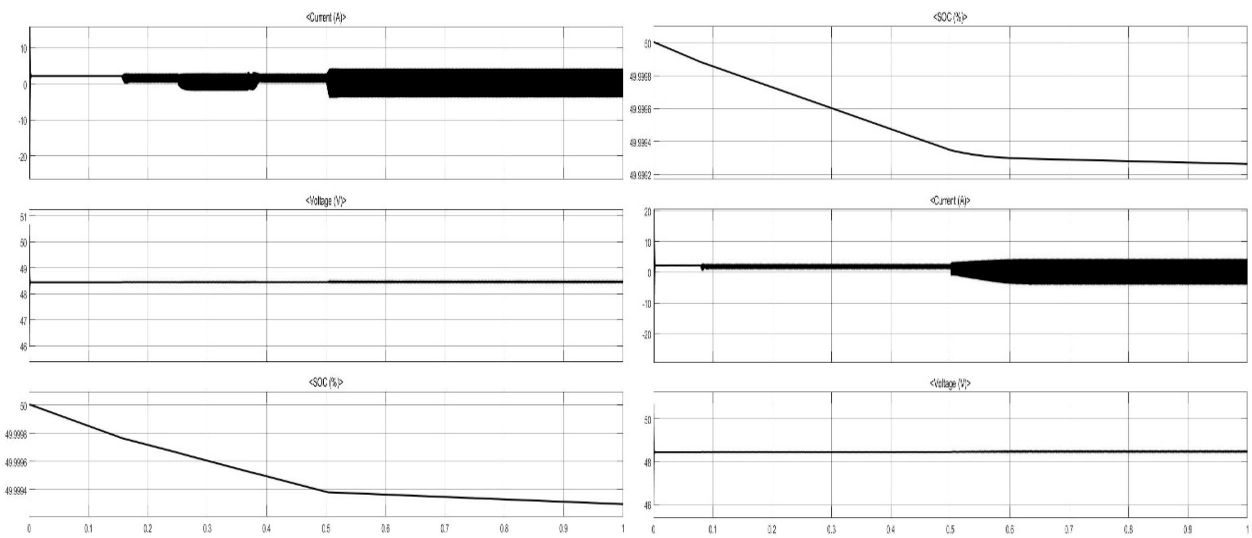

Figure 13. The output current, voltage and SOC of the battery for FZPO and P&O technique at varying irradiance conditions

6. Conclusion

In this paper, a FZPO MPPT technique is used to overcome the limitation like: drift in tracking, response time and high steady state loss etc. at varying irradiance condition without any irradiance and temperature sensors. At different boundary voltages the PV curve used in FZPO technique are divided into multiple zones. The adaptive and fixed step size using simple linear equations are used to make the calculation more efficient. In compare to P&O technique the FZPO technique attains a drift free tracking. The controller parameter for FZPO technique are used only for design stage and it does not need any complex calculation during real time tracking. Hence the FZPO technique is performed better than the conventional P&O MPPT for standalone PV system.

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