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A Soft Computing Intelligent Control Algorithm to Extract Maximum Energy from Solar Panel

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Abstract
Utilizing soft computing, a maximum power point tracking (maximum PPT) control algorithm is developed, and its performance is compared to that of more traditional Lead Acid battery charging methods such as incremental conductance technique-based maximum PPT. Since the power vs voltage graph of a photovoltaic (PV) cell is nonlinear, a suitable control method seeks to obtain the highest power under dynamic conditions. In order to construct a PV cell with the maximum PPT, a fuzzy logic control approach known as soft computing is used. The cell active energy is used to charge the lead acid battery. A fuzzy logic compares its performance with the incremental conductance technique under dynamic conditions. Moreover, dc to dc converter is required to maintain constant output voltage to charge the battery under low level voltage. A zeta converter is taken to maintain output voltage under various insolation. The significance of algorithm is demonstrated by MATLAB Simulation results and hardware results.

Keywords- Incremental conductance, Lead acid battery, Soft computing, Solar PV system, Zeta converter.

1. Introduction
World is under a global threat many trailers come as a big disaster, recently, in Pakistan's 2022 devastating rainfalls and landslides have affected millions of people. In the other hand galciers are being disappeared as temperature of the earth is continuously increasing due to greenhouse effect. Thus, a green energy is required to compensate the global threats whereas a substantially, reduces in the cost graph in a solar panel. It increases the trade value of solar items to compensate the global threat and enhance the green energy program. The solar photovoltaic system has nonlinear power versus voltage graph. Therefore, a good control algorithm is required to extract maximum power continuously (Guo et al., 2021) at maximum power point (MPP). There are many literatures available to design maximum power point tracking (Maximum PPT). In Chen et al. (2015), simplified conventional techniques are discussed which are based on fractional short circuit, open circuit voltage, perturb and observe (P & O) and Incremental Conductance (IC). These techniques are more popular in available market while some intelligent techniques like fuzzy logic and ANN based maximum PPT are in recent trends. Moreover, some techniques P & O and Hill Climbing (HC) can simply use in analog and digital forms (Ahmed et al., 2012; Zhu et al., 2018). However, integrated circuit techniques are more complex (Ez-Zghari et al., 2022; Ahmadi et al., 2021). Thus, digital circuit is used to limit the burden (Hasan et al., 2022a; Hasan et al., 2022b).

Numerous researchers explored how to generate the most electricity from solar PV systems under partial conditions (Eltamaly et al., 2020a; Eltamaly et al., 2020b; Millah et al., 2022). While optimizing and extracting maximum power under dynamic partial conditions and under complex partial conditions (Chalh et al., 2021; Zafar et al., 2021). To determine the maximum PPT of solar photovoltaic, more researchers are using intelligent algorithms in a variety of fields. The brushless dc motor based pump is developed to function on a fuzzy rule based Maximum PPT system in (Hasan et al., 2022c) and efficiency is notable under varied insolation conditions. Whereas, Merchaoui et al. (2020), a fast fuzzy logic particle swarm optimization based MPPT controller has modified the conventional PSO to overcome its long convergence time. Additional, intelligent technique artificial neural network (ANN) based Maximum PPT controller is examined to enhance the output of PV module (Chouay and Ouassaid, 2020). In this case, mean value of duty ratio is extracted by a perturb and observe techniques to train the Maximum PPT under various conditions of insolation. Thus, soft computing technique is more efficient for PV solar charger to charge the battery under dynamic condition without delay. Whereas, perturb and obserb techniques has some disadvantage during suddenly change in insolation and it keeps oscillating at maximum power point (Esram and Chapman, 2007; Kumar et al., 2018). on the other hand, an incremental conductance technique to charge the battery is good option but it has complex mathematical calculation causes sluggish in nature to reach peak point. However, a converter is necessary to obtain a consistent output voltage in partial darkness. The duty ratio of the converters is used to convert variable input DC to constant single and multiple DC output (Aranda et al., 2022). In this study, (Ray and Kumar, 2023) a multilevel buck converter-based method for quickly charging an electric car battery is suggested. It is suggested to use a three-stage charging infrastructure, with slow charging for states of charge greater than 100% and quick charging for states of charge between 20% and 80%. While, an excellent alternative for a PV system is a zeta converter since it has a wide range of adjustment for the duty ratio under different insolation conditions (Narula et al., 2016).

In this work, a soft computing technique is used to charge the lead acid battery via zeta converter using input solar photovoltaic (PV) system. A soft computing is a fuzzy logic which is based on skill data collection. It is free from crisp value only, it has range where data can calculate the fast and operate reliable. It bears zero alternation and zero lagging time under dynamic conditions of battery charging. The following significant works are given as,

- Soft computing is used to design a Maximum PPT.
- A hardware model is developed in the College of Applied Industrial Technology (workshop 401).
- A comparative performance of algorithms is assessed to appreciate the values.
- A MATLAB model is developed and evaluates the performance under various insolation.

The part of this publication has five sections, according to the authors. Model description and control algorithm are provided in sections 2 and 3, respectively, while results and discussion are offered in part 4. This paper is concluded in Section 5.

2. Model Description

This section goes into great detail regarding the functions of the suggested model. The PV panel is connected to a voltage and current sensor in Figure 1, these sensors produce low level analog signals. The analog signals are sensed by Nano microcontroller and pulse to the zeta converter switch (Q3) of dc to dc zeta converter using actual duty ratio (D). Finally, zeta converter gives the control dc current to charge the lead acid battery. The explanation is given of each component in subsection.

2.1 Solar Panel

A photovoltaic effect is a sun energy harvesting method which converts sun insolation into dc current. When sun energy exchange with semiconductor layer, it causes dc current (Iph). This phenomenon is known as photovoltaic effect. The sun insolation and temperature are at standard test condition (STC) which are given as follows,

Tc=25ºC and Geff=1000 W/m2- (1)

Solar cell can be designed using various constraint those are current, voltage, resistance, ideality factor, light current, reverse saturation current and many more factors. While two more important factors are temperature and insolation for the solar cell. The open circuit voltage of solar cell can calculate using given equation. Sufics st is the standard temperature

$$V_{oc} \approx a_{st} \ln \left({I_{ph,st}}/{I_{rs,st}} + 1 \right) \tag{2}$$

where, a_{st} is equal to nkT/q and n is the diode ideality factor, k is the Boltzmann constant, T is the temperature and q is the charge of electron. Whereas $I_{rs,st}$ reverese saturated current at standard temperature and $I_{ph,st}$ is light current at standard temperature. Besides, the short circuit current can evaluated as,

$$I_{sc} = I_{ph,st} - I_{rs,st} \left[e^{\frac{I_{sc,st}.R_{s,st}}{a_{st}}} - 1 \right] - \frac{I_{sc,st}.R_{s,st}}{R_{sh,st}} \tag{3}$$

where, R_s is series and R_{sh} is shunt resistant respectively.

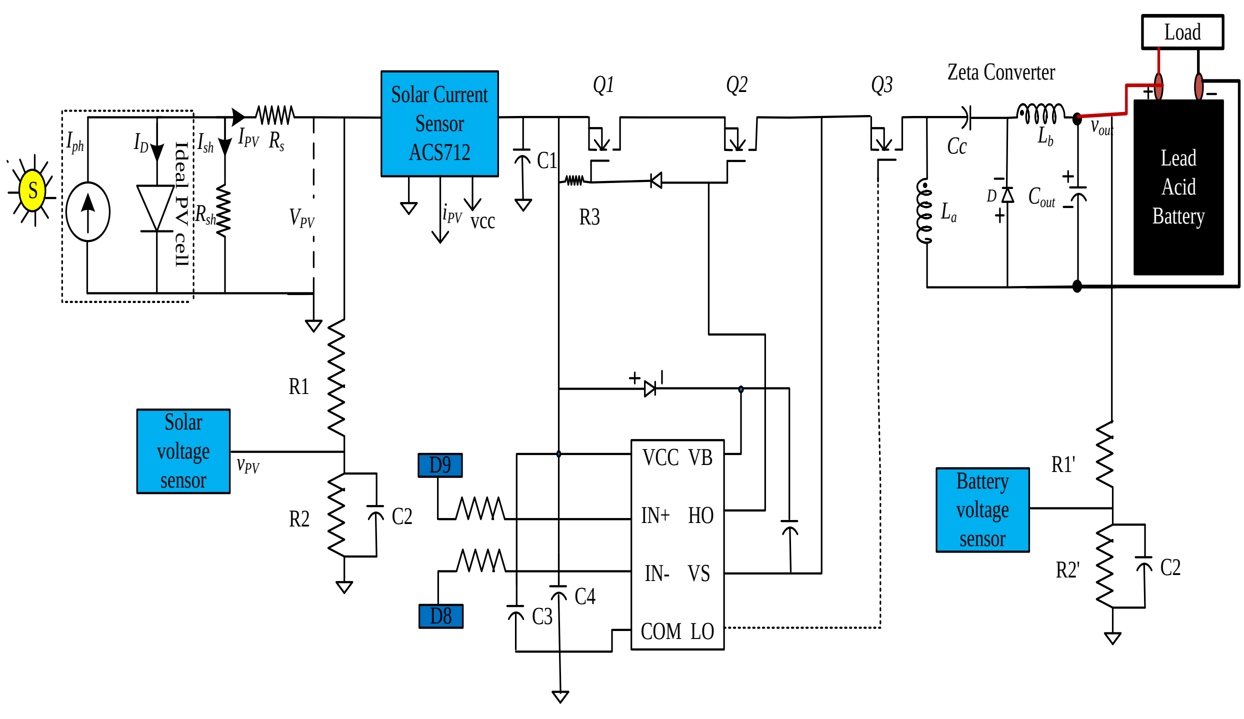


Figure 1. A hardware model of solar battey charger.

2.2 Zeta Converter

The key function of dc to dc converter is to step up and down the voltage level. The zeta converter can work as step down and step up voltage. It has long range duty cycle with non-inverted output. In Figure 1 constructional design is given. To design a zeta converter, the two passive and two active switches are required. Just after switch (MOSFET Q3) a parallel connection of inductor (L_{b1}) is placed and in series a coupling capacitor (C_c) is needed to store the charge whereas a parallel connection of Diode (D) is connected to pass the current under reverse condition of circuit than again an inductor (L_{b2}) is connected in series with parallel connection of capacitor (C_o). The practical data to design a zeta converter is given in Table 1.

2.3 Duty Cycle

An ideal state of zeta converter under constant voltage mode the duty ratio (D_T) can find as,

$$D_T = \frac{V_o}{V_{max} + V_o} \tag{4}$$

where, V_o is output voltage of converter whereas V_{max} is the maximum voltage at maximum PPT of solar panel

$$V_o = \frac{D_T}{1-D_T}(V_{max}) \tag{5}$$

An equation (5) can work for both step up and step down voltage respectively, if D_T is more 0.5, it behaves as step up and if D_T is less than 0.5, it work as a step down respectively.

Table 1. Parameters of zeta converter.

Parameters	Calculated data	Practical data
Duty Ratio (D_T)	Using equation (4) = 0.38	0.38-0.5 (Range depends on insolation)
Input capacitor values (Cin)	$\frac{DT \times V_{pvo}}{\Delta V_{pp} \times Vsw_{pvmax}}$=0.38X12.5/0.1X20X20kHz=118.75μF	100 μF
Coupling Capacitor (Cc)	$\frac{DT \times I_{pvo}}{\Delta V_{pp} \times Vsw_{pvmax}}$=0.38X5/(0.1X20X20kHZ) =47.5 μF	50 μF
Inductor (L)	$\frac{DT \times V_{pvmax}}{2 \times \Delta V_{Lb(pp)} \times f_{sw}}$=0.38X20/(2X0.1X20kHZ)=1.9mH	2mH
Output Capacitor (Co)	$\frac{DT \times V_{pvmax}}{2 \times \Delta V_{Lb(pp)} \times f_{sw}}$ =0.38X12.5/(2X0.1X20kHZ)=118 μF	100μF

2.4 Lead Acid Battery

Lead Acid battery is a storage cell. Storage cell means it can work as voltaic cell when it gives electric charge and under recharge condition, it is known as electrolytic cell. Thus, it can work in both the mode. A lead acid battery is charging by the solar PV system via zeta converter under dynamic condition using soft computing technique and compared with INC methods. The electrochemistry of the l acid battery is given as follows,

***Discharging mode*:** Under such a mode of operation both the negative and positive plates are in same chemical formula lead sulfate $PbSO_4$ whereas electrolytes losses dissolve H_2SO_4 and work as primary water which is given in Figure 2(a).

Discharge mode of operation with two identical lead sulfate plate and dilute sulfuric acid condition		
$PbSO_4$ (+ Plate)	**Dilute H_2SO_4**	**$PbSO_4$ (- Plate)**

Figure 2(a). Under discharge condition.

***Recharging Mode*:** Under this condition the positive plate possesses lead oxide PbO_2 and negative plate possesses lead Pb while electrolyte solution concentration is highly sulfuric acid in nature which is given in Figure 2(b).

Recharge mode of operation with lead dioxide at positive plate and lead negative plate whereas fully concentrated sulfuric acid		
PbO_2(+ Plate)	**H_2SO_4(aq)**	**Pb(- Plate)**

Figure 2(b). Under recharge condition.

3.Control Algorithm

The soft computing technique is used to extract the voltage and current analog signals from solar panel using voltage sensor and current sensor ACS 712. In this work one of the soft computing techniques is the fuzzy logic. Fuzzy logic technique is a simple to design based on the human mind skill calculation without using mathematical calculations. The voltage and current sensor are used to calculate these signals at sampling time *t* and *t*-1 which gives an error signals e(t) and change in error signals Ce(t). These signals sense output and input signals to generate duty cycle (D_c) and pulse to the zeta converter to provide controlled output voltage. A control voltage charges the 12-voltage lead acid battery.

A fuzzy logic control algorithm to extract maximum power point tracking under four steps

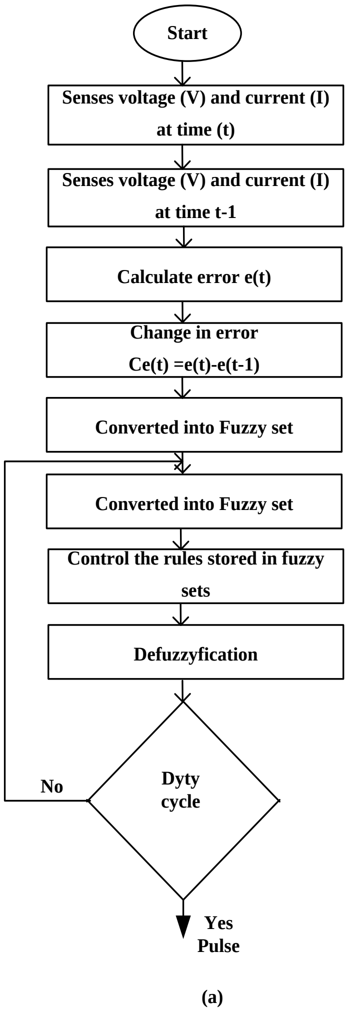
(i) ***Measurements*:** Sense input signals error and change in error at time *t* sampling time and *t*-1 sampling times.

(ii) ***Fuzzification*:** In this case input measurements are converted into fuzzy sets to express measurements uncertainty

(iii) ***Inference Engine*:** The uncertain measurements are used by the inference engine to evaluate the control rules stored in fuzzy rule based. The fuzzy rule matrix have the following range such as very high (VH), Low (L) , Neutral (N) , High (H) and Very Low (VL). These range is used to develop rule matrix to control the duty cycle of the zeta converter.

(iv) ***Defuzzification*:** In this case fuzzy set turn into single crisp value. It is a final step of the fuzzy control algorithm.

In the Figure 3(a), Fuzzy logic algorithm to generate duty cycle whereas in Figure 3(b) a coman incremental algorithm is used to generate duty cycle. A fuzzy logic controller is simple in design whereas incremental is a more complicated a tedious to design.



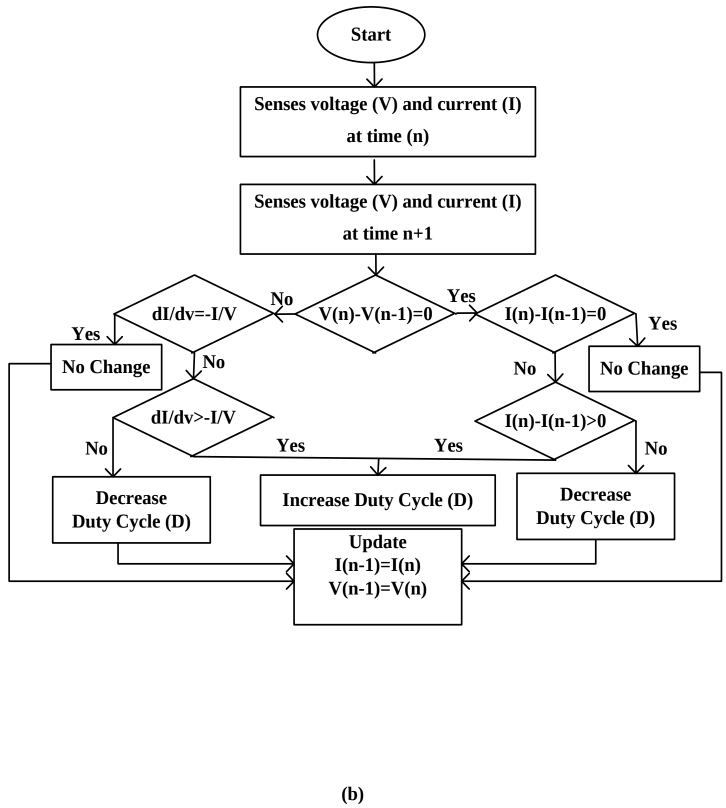


Figure 3. (a)-(b) Soft computing intelligent algorithm for generation pulse at MPPT and an incremental conductance algorithm to generate pulse at MPPT.

4. Results and Discussion

In Figure 4, a hardware model to extract maximum power using soft computing technique to design fast battery charger. While, the performance evaluation of soft computing technique and incremental conductance (INC) techniques are compared using MTLAB SIMULINK. In Table 2, a hardware data is given. It is used to extract maximum power versus voltage graph under all condition of solar irradiance. And pulse at maximum power point to the zeta converter to charge a lead acid battery. The performance of soft computing intelligent control algorithm and INC control algorithm are presented using MATLAB SIMULINK to understand the values of soft computing intelligent control algorithm.

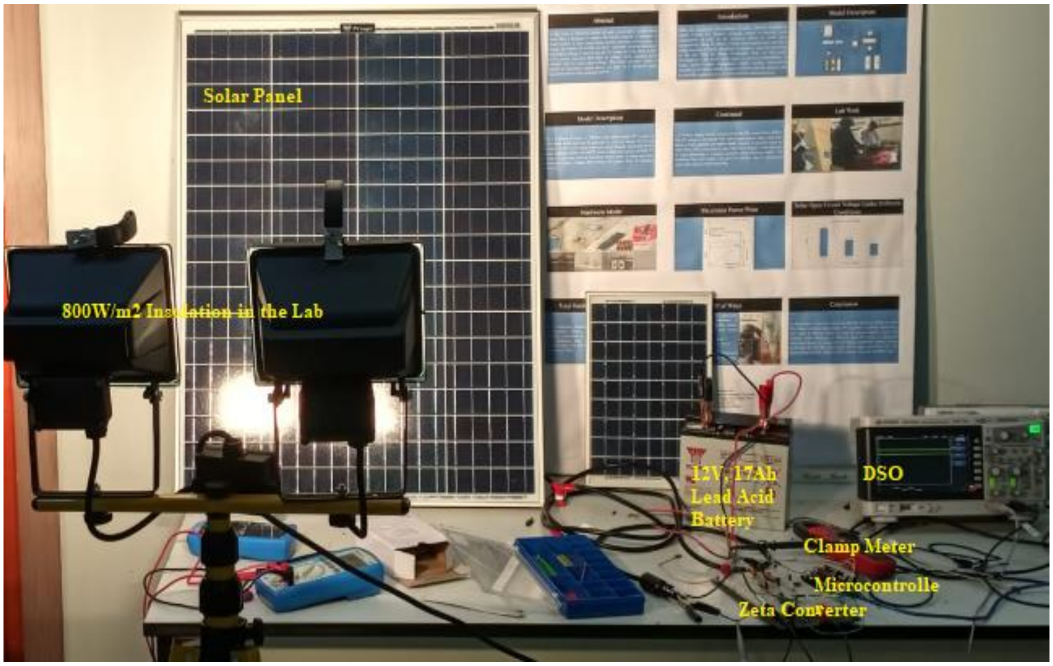


Figure 4. A hardware model for solar battery charger using soft computing techniques.

Table 2. Control solar panel parameters under standard test condition.

Nominal Peak Power (Wp)	80W
Nominal voltage (Vmp)	17.6V
Nominal current (Imp)	4.91A
Open circuit voltage (Voc)	21.9V
Short circuit current (Isc)	4.55A
Operating temperature	-40^0 to $+85^0$
Maximum system voltage	1000V DC
Dimensions	835*670*35mm
Weight	6.3Kg
Insolation in lab	400-800w/m2
Insolation at STC	1000W/m2
Designed by	Solar technology international

4.1 MATLAB SIMULINK Results

In Figure 5(a)-(b), the graphs of current versus voltage and power versus voltage are evaluated under 1000w/m2 and 500w/m2 of solar insolation. These results indicate SIMULINK model of solar PV model is working satisfactory and performed well.

In Figure 6, A INC algorithm performance is seen where solar current (Ipv), solar voltage (Vpv), solar power (Ppv) and duty cycle (D_T) are shown under full sun and partially sun light. It takes more delay time to charge the battery. Whereas, Simulink results for soft computing intelligent control algorithm is shown in Figure 7, where delay to charge the battery is zero while there is no overshot and undershoot in current voltage and power. Thus, its performance against the INC control algorithm is superior. It is good to opt as fast controller to get maximum energy from solar panel.

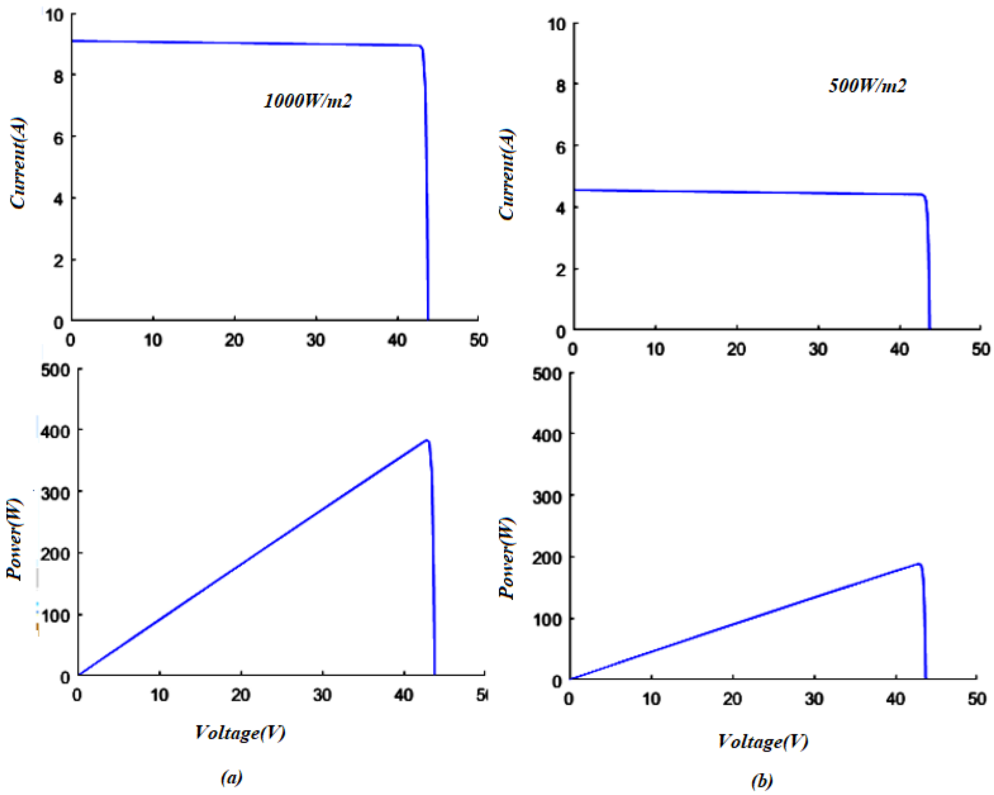


Figure 5 (a)-(b). Characteristics of PV cell under full and partially insolation.

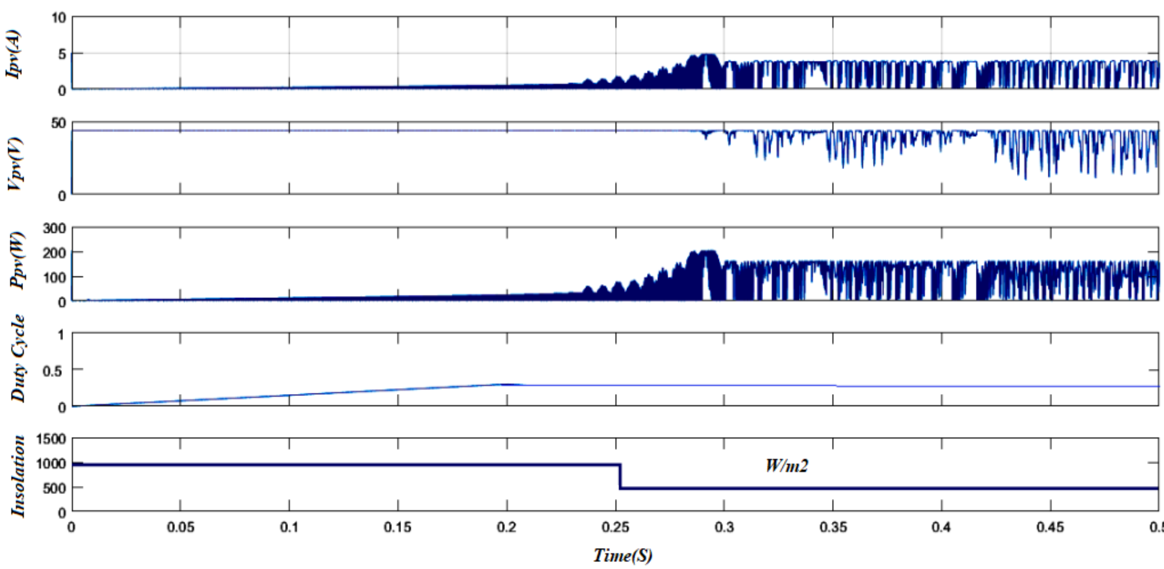


Figure 6. An incremental conductance based algorithm performance under 1000w/m2 and 500w/m2 of insolation.

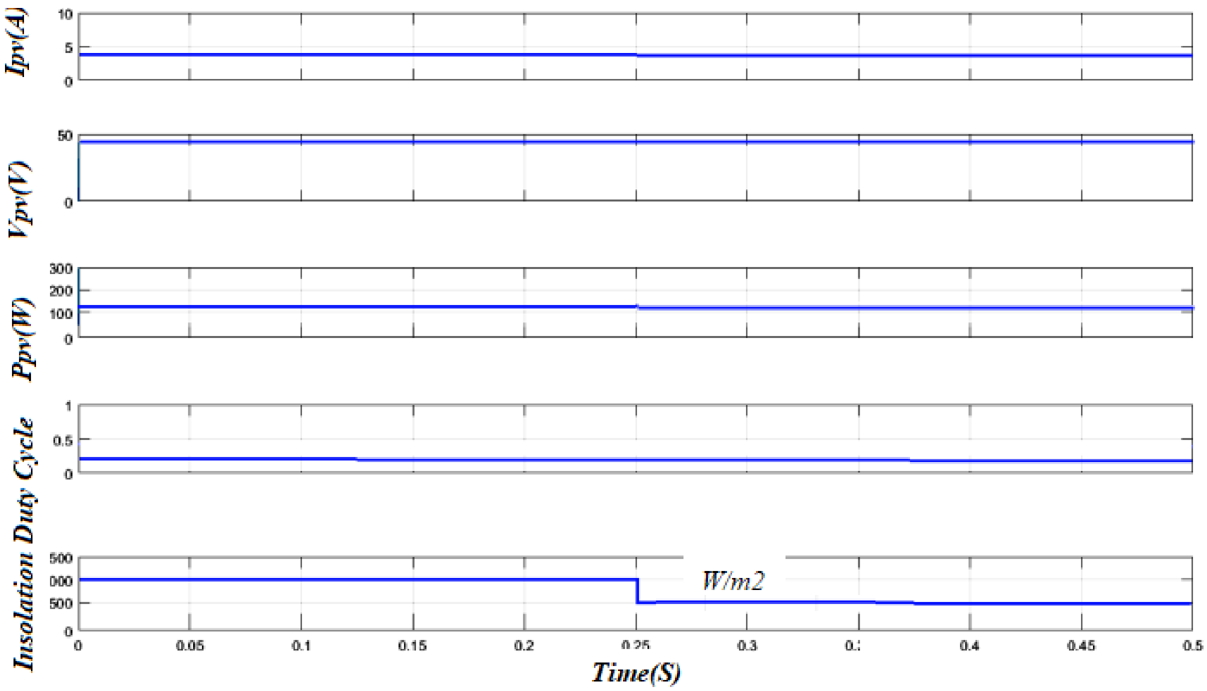


Figure 7. Soft computing based intelligent algorithm performance under 1000w/m2 and 500w/m2 insolation.

4.2 Hardware Results

Figure 8 shows how a hardware system performs in a lab setting with varying solar insolation. Although there is a noticeable difference below 200 W/m2, the nominal voltage difference between 800 W/m2 and 400 W/m2 insolation is 0.7 volts. As a result, the zeta converter employs a soft computing intelligent control technique to function well in this situation.

Under 800W/m2, 400W/m2, and 200W/m2 solar insolation, the dynamic charging of a lead acid battery to increase battery voltage is shown in Figures 9 through (11).

In Figure 9, the charging current is 40mA whereas, the solar voltage and charging voltage are 15.2V and 12.6V under 800W/m2 solar insolation in the lab. The zeta converter and pulse approaches both operate well and satisfactorily. And in Figure 10, as the solar insolation is decreased to half, or 400W/m2, the charging current and solar panel voltage respectively drop to 24mA and 14.4V, while zeta converter output charging voltage is remained constant under partially condition hence performance of pulse and charger works satisfactory. Moreover, in Figure 11, as the solar insolation is decreased to 200W/m2 the charging current and solar panel voltage respectively drop to 11mA and 13.2V while output charging voltage remain same. Thus, under all condition of solar insolation the proposed control algorithm to extract maximum power to pulse zeta converter is satisfactory.

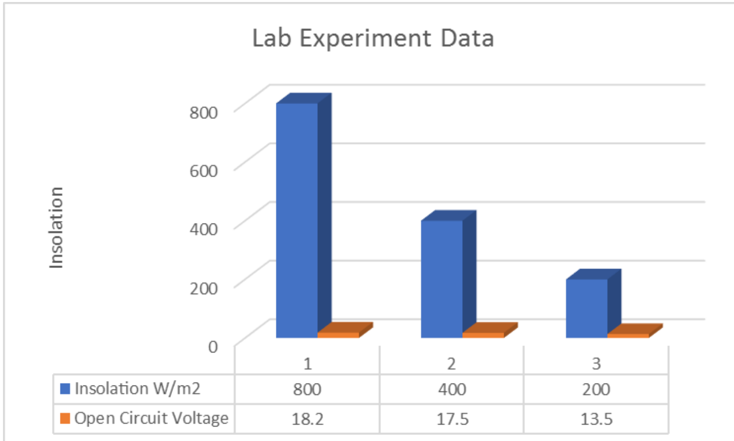


Figure 8. Solar panel open circuit voltage under various conditions of insolation.

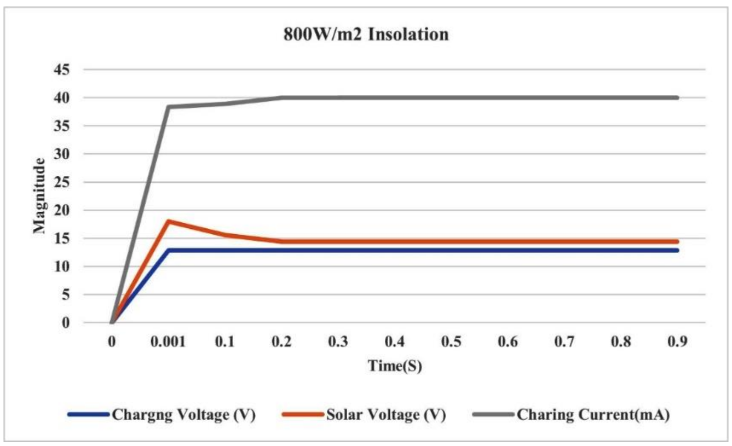


Figure 9. Lab performance of solar charger using soft computing technique under 800W/m2 insolation.

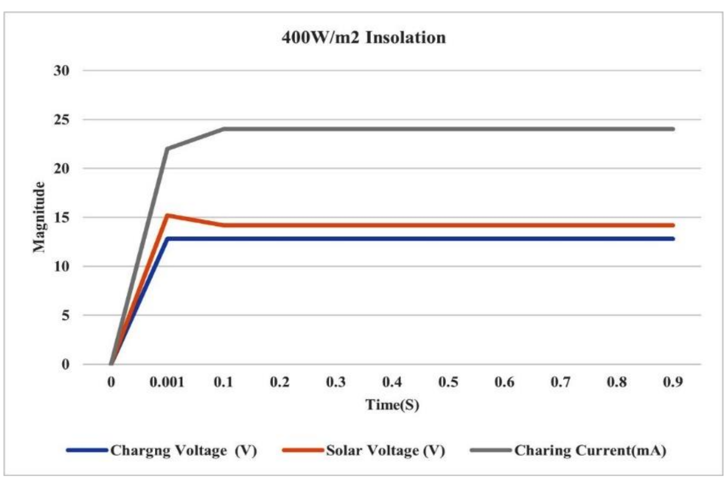


Figure 10. Lab performance of solar charger using soft computing technique under 400W/m2 insolation.

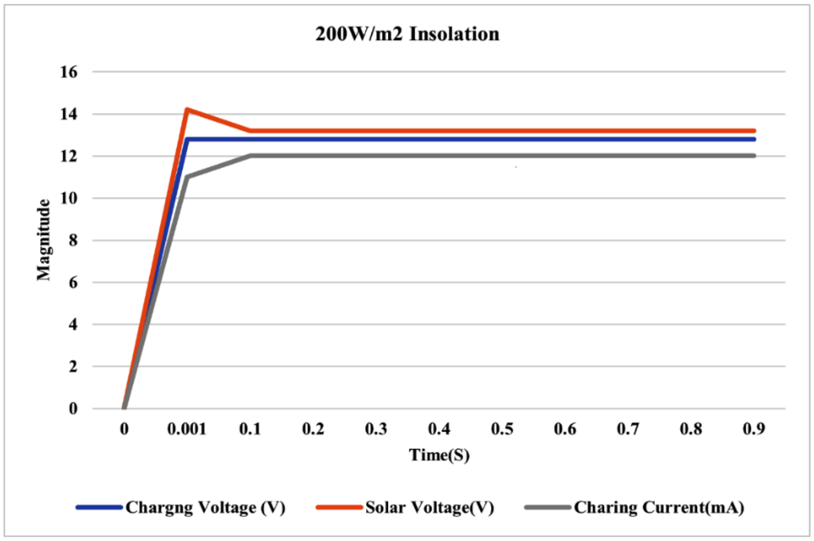


Figure 11. Lab performance of solar charger using soft computing technique under 200W/m2 insolation.

5. Conclusion

The performance of a soft computing technique based MPPT and INC based MPPT are compared and seen its qualities of response under different 1000W/m2 and 500W/m2 solar insolation. The MATLAB results shows the performance of soft computing intelligent controller and INC controller. The power versus voltage and current versus voltage curves at different insolation are compared and found that soft computing intelligent controller is the good option to choose as MPPT controller. Moreover, soft computing controller has zero delay to charge the lead acid battery while INC controller has a delay. These days, customer demands the reliable fast charger, thus, as per the market demand soft computing techniques are more needed to fulfill the market demand. Whereas a hardware result gives under 800W/m2, 400W/m2, and 200W/m2 solar insolation in the lab to perform its charging abilities. It is seen that the proposed model works satisfactorily under various solar illuminations. and dynamic condition. A combined effect of the zeta converter and solar MPPT is satisfactory for charging the battery under various conditions of solar insolation in the lab. Moreover, the future work is to design solar battery charging under optimize charging current to enhance the life of batteries.

Conflict of Interest

The authors confirm that there is no conflict of interest to declare for this publication.

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