Implementation of an Intelligent Battery Charging Process for Solar Energy System Using dSPACE

Arpita Basu[1],*StudentMember, IEEE*,Madhu Singh[2], *Member, IEEE*

[1,2]Department of Electrical Engineering, National Institute of Technology, Jamshedpur, India

Abstract -The paper represents a comprehensive design and battery control strategy for a photovoltaic (PV) energy system.This paper introduces the application of Proportional Integral (PI) controller for battery charge control according to acceptable performance criteria. The performanceis modified by using Takagi-Sugeno Fuzzy (TS-Fuzzy) controller. The simulation results, using MATLAB/Simulink tools show the comparative analysis of battery management in terms of rise time, overshoot, undershoot, peak value, peak time. The real time dSPACE 1202 controller boardis implemented to validate the results.

Keywords: Solar energy system; BMS; bi-directional converter;PI controller; TS-Fuzzy controller

INTRODUCTION

The primary objective of the power system is to ensure that the minimum loss has been met while distributing electricity. A judicious planning of the utilization of different energy sources is essential. Amongst different energy sources played an important role to control global emissions. Renewable energy sources in simple language mean energy that comes from sunlight, wind, rain, biomass, small hydro etc. PV power play a significant role in power generation and become essential due to these storage and environmental impact. More than 45% of necessary energy will be produced by PV array **[1]**. Berrera et al. discussed that the PV generation system have two problems i.e., the energy conversion efficiency is low due the weather changes and the power generation of solar array is also changed **[2]**. Fanguri et al. proposed that PV array consists of non-linear characteristics, hence the I-V and P-V characteristics is always changing with weather conditions **[3]**. Xiao et al. stated that MPPT is essential as there is a probable mismatch between the load characteristics and the MPPs of PV power generation **[4].**Koutroulis et al. proposed P&O method for MPPT technique irrespective of different irradiation and temperature. It shows how the output of MPPT is improved by using buck converter **[5].**The existing models, maximum power point tracking (MPPT) methods of PV arrays are proposed by some authors **[6, 7]**. The method of MPPT i.e., incremental conductance method (INC) is proposed by Esram et al. **[8]**. The comparison of different types of technique in MPPT methods such as fuzzy control, neural network, current sweep etc. are discussed in literature **[9, 10].** Ali et al. proposes fuzzy logic based algorithm with INC MPPT method for PV **[11].** Due to simplicity, ease of application, periodic tuning is not required and used in both analogue and digital domains Perturb & Observation (P&O) is preferred for maximum power point tracking (MPPT) **[12].**

The DC/DC power converter is an important component in the optimization of a PV solar system since it serves as an interface between the PVG and the adapted load. The duty cycle signal produced by the MPPT technique regulates the DC/DC power converter's switch. Practically one of these three types of converter is used in the literature; Buck, Boost and Buck-Boost power converter which are considered as converters not isolated from the source **[13]**. The control strategy of bi-directional converter operates at Buck,Boost, and shut-down mode proposed by some authors**[14].**

The charging-discharging of the ESS depends on the power generated by the PV array **[15].** The classical control of BDC scheme is presented by some authors **[16].** Though classical controller have the advantage of non-zero steady-state error but also have the limitations associated with overshoot, high settling time etc. **[17].** An intelligent battery management system is proposed in the paper to manage the switching of bi-directional converter for the arbitrary level of solar irradiation and environmental temperature of the PV array **[18].**The mathematical model for SOC estimation for battery management system is presented by many authors **[19, 20].**

In this paper, a circuitry modeling and control strategy of a 2kW PV energy storage system is presented. The sunlight is converted into a DC signal by the PV array. The output of the PV array is given to a boost converter to implement MPPT by using Perturb & Observe (P&O) method. The Lithium-ion battery is used for energy storage system. Moreover, the simulation shows the performance of the battery in the presence of different controller's schemes.

PHOTOVOLTAIC ENERGY SYSTEM

The photovoltaic (PV) energy system is shown in fig.1. The system is composed of four essential parts; the photovoltaic generation (PVG) that is sensitive to the weather conditions, a DC/DC boost converter and the MPPT technique which play the role of impedance matching, bi-directional DC-DC converter, and energy storage system. The PV array is not only sufficient to fulfil the source of energy due to its power variation in different weather conditions; such as irradiance, temperature, geographical location. Hence, another stable energy storage device is needed. Some authors have proposed a classical controller scheme for control mechanism of bi-directional DC/DC converter. Though classical controller have the advantage of non-zero steady-state error but also have the limitations associated with overshoot, high settling time etc. Given the ongoing limitations, this paper proposes a sophisticated design of the Takagi-Sugeno Fuzzy controller scheme.

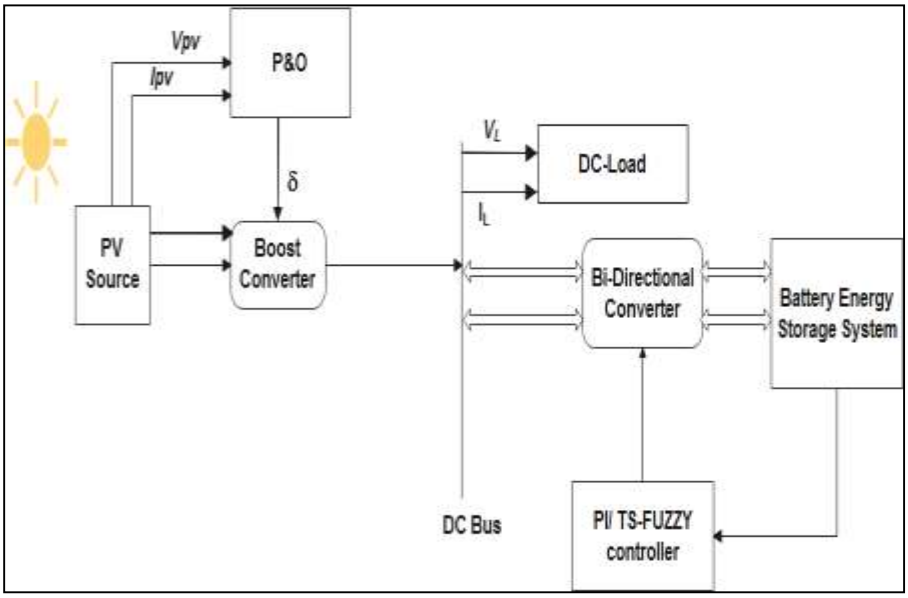


FIGURE 1

SCHEMATIC DIAGRAM OF PHOTOVOLTAIC ENERGY SYSTEM

SELECTION OF PHOTOVOLTAIC ARRAY

A2kW PV array is designed by using the model data sheet of 1Soltech 1STH-215-P solar panel in MATLAB.Characteristics of solar array at specified temperature at 25^0 C with 1000W/m^2 irradiance are shown in fig 2 with the help of data sheet.

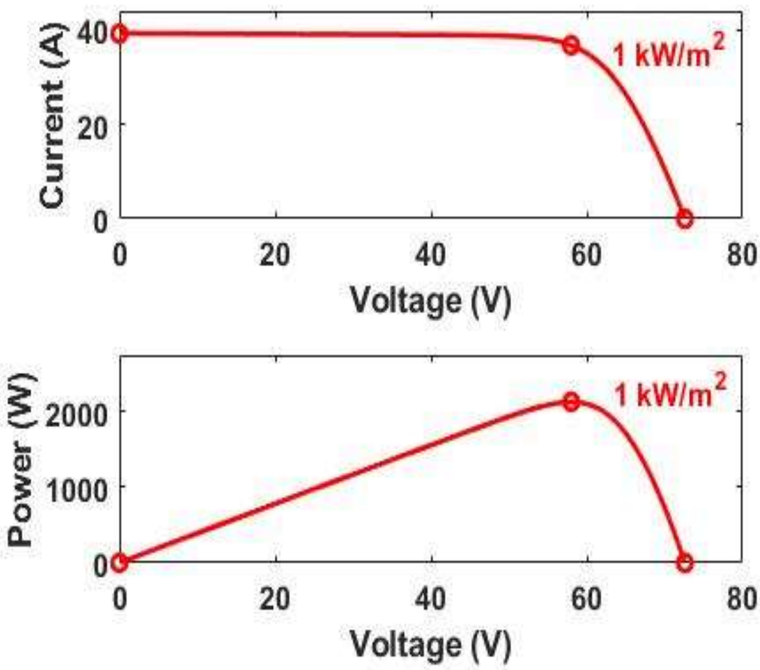


FIGURE 2

CHARACTERASTICS CURVE OF PV ARRAY

TABLE 1

SPECIFICATION OF SOLAR ARRAY

Parameters	Values
PV array	213Wp panels. 5panels per string 2 strings in parallel Total=2kWp
Voc	36.3 V
Vmp	29V
Isc	7.84A
Imp	7.35A

DESIGN OF BOOST CONVERTER

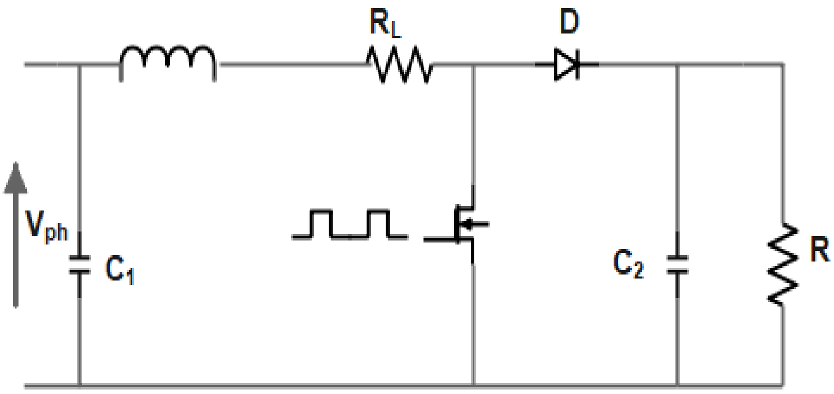


FIGURE 3

SCHEMATIC DIAGRAM OF BOOST CONVERTER

Fig 3 represents the circuit diagram of boost converter. The output voltage of the converter is greater than the input voltage, hence it is called boost converter. For high efficiency a series connected boost converter with PV array is proposed. The switching frequency (F_{sw}) is considered 5 kHz and the output voltage ripple (ΔV) and output current ripple (Δi_l) are considered as 5% and 10 % respectively.

The design parameters of the boost converter are shown below:

Duty Cycle(D)=1-(V_{in}/V_{out}) (1)

V_{in}= input of boost converter=output of PV array.

The inductor value is given as,

$L=V_{pv}D/(2\Delta i_l F_{sw})$ (2)

The output capacitor is given by,

$C=I_O D/(\Delta V F_{SW})$ (3)

TABLE 2

PARAMETER VALUES of BOOST CONVERTER

Parameters	Values
Input voltage	50-52 Volt
output voltage	60 Volt
Duty Cycle	0.15-0.75
inductance	1.7e-3 H
Output capacitance	1.786e-3 F

MPPT OF PV ARRAY

The MPPT with PWM control method measure the current and voltage of PV array and generate the duty cycle for the converter.

PERTURB AND OBSERVE (P&O) METHOD

The name MPPT refers to the perturbation of a PV system that is caused by the increasing or decreasing of a reference voltage.The basis control actions for various operation points in the P & O method are shown in the table 3.

TABLE 3

VARIOUS CONTROL OPERATION OF P & O ALGORITHM

Case	ΔV	ΔP	Voltage Control Action	Duty Cycle
1	+	+	Increase V by ΔV	Decrease
2	-	-	Increase V by ΔV	Decrease
3	-	+	Decrease V by ΔV	Increase
4	+	-	Decrease V by ΔV	Increase

BI-DIRECTIONAL DC-DC CONVERTER

A bidirectional DC-DC converter allows the transfer of power from one source to another.

The converter has two mode of operation.

Mode1: (buck mode: Charging mode) -The input voltage is high compared with the output voltage. Switch S1 is triggered but switch S2 is turned off as shown in fig 4. As Switch S1 is on mode hence, the increased input current flows the path S1-L. When S1 has turned off the current of the inductor falls until the next cycle has occurred. The stored energy in the inductor is supplied to the battery for charging purposes.

BDC operates with the components as an inductor (L+) and capacitor (c+). The values of the converter are calculated as given by,

$$L_+ = \frac{(V_{dc}-V_{bat})D_+}{\Delta I_L f_{sw}} \quad (4)$$

$$C_+ = \frac{(1-D_+)V_{bat}}{8L+\Delta V_{bat} f^2} \quad (5)$$

Where, ΔI_L and f_{sw} are the ripple current and switching frequency of the buck converter respectively.

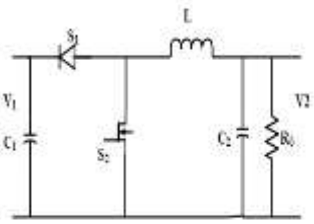
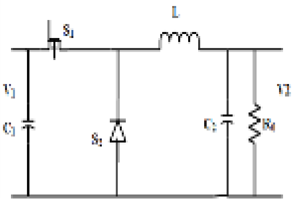
 

FIGURE 4FIGURE 5

CIRCUIT IN BUCK MODECIRCUIT IN BOOST MODE

Mode II: (Boost mode: Discharging mode) -The output voltage is higher than the input voltage. Switch S2 is triggered but switch S1 is turned off as shown in fig 5. As Switch S2 is on mode hence, the increased input current flows the path S2-L. When S2 has turned off the current of the inductor falls until the next cycle. The stored energy is supplied to the load. The components as an inductor (L_-) and capacitor (c_-). The values of the converter are calculated as follows,

$L_- = \frac{V_{bat\,D-}}{\Delta I_L f_{sw}}$ (6)

$C_- = \frac{V_{dc} D_-}{R_O \Delta V_{dc}\, f_{sw}}$(7)

ΔV_{dc}, *Ro* are the ripple voltage and output voltage of the boost converter respectively.

The values of L and C are considered as follows:

$L=max(L_+,L_-)$ (8)

$C=max(C_+,C_-)$ (9)

TABLE 4

PARAMETER VALUES OF BUCK-BOOST CONVERTER

Parameters	**Values**
C	0.5e-3H
L	1000e-6H
f_{sw}	5kHz

The operation of buck-boost converter (BDC) depends on the duty ratio which is obtained during the charging and discharging modes of operation. There are various control strategies for BDC**[21].**But due to simplicity and ease to applythis paper proposes the PI control scheme for the first set of simulations **[22].**

In order to reduce the complexity of the scheme the dynamic modeling equation of BDC has been proposed.

For buck mode:

$\dot{x}_1 = -(\frac{1}{L} - \frac{1}{LR})V_c + \frac{V_{in}}{L}$ (10) $\dot{x}_2 = \frac{i_L}{C} - \frac{V_c}{RC}$ (11)

For Boost mode:

$\dot{x}_1 = -(\frac{1}{L} - \frac{1}{LR})V_c$ (12)

$\dot{x}_2 = \frac{i_L}{C} - \frac{V_c}{RC}$(13)

Using equation 16,17,18,19 the complete dynamic equations are expressed as:

$$\begin{bmatrix} \frac{di_L}{dt} \\ \frac{dV_c}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \frac{1}{LR} - \frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} i_L \\ V_c \end{bmatrix} + \begin{bmatrix} \frac{V_{in}}{L} \\ 0 \\ 0 \end{bmatrix} d + \begin{bmatrix} 0 \\ 0 \\ r \end{bmatrix} \qquad (14)$$

To reduce the steady state error to zero, define a new state variable X_{err}

$x_{err} = \int (r - y(t))dt$ (15)

Where, r: target voltage; y (t) : output voltage

Add the new state variable:

$$\begin{bmatrix} \frac{di_L}{dt} \\ \frac{dV_c}{dt} \\ \frac{d_{xerr}}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \frac{1}{LR} & -\frac{1}{L} \\ \frac{1}{C} & \frac{1}{R} & \\ 0 & 0 & \end{bmatrix} \begin{bmatrix} i_L \\ V_c \\ x_{err} \end{bmatrix} + \begin{bmatrix} \frac{V_{in}}{L} \\ 0 \\ r \end{bmatrix} d + \begin{bmatrix} 0 \\ 0 \\ r \end{bmatrix} \quad (16)$$

The system described by the following nonlinear equations:

$$\dot{x}(t) = A\iota x(t)^{\cdot} + B\iota u(t) + \rho \ (17)$$

$y(t) = Cix(t) + Diu(t)(18)$

Where, $u = \begin{cases} 1, & switch\ closed \\ 0, & switch\ open \end{cases}$

$x\ and\ \dot{x}$= vectors of variables $(i_{L\,,}V_C)$.

BATTERY MANAGEMENT SYSTEM

The battery bank of a PV array is connected to the system's energy storage device (ESS). The bank is required to be charged to avoid overcharging.If the total power of the battery exceeds the desired limit, the bank will charge or vice versa. The initial state of charge (SOC %) of the battery is considered 80%. Here, PI and TS-fuzzy logic controller are used for BMS. The better performance of the controller is shown after the MATLAB simulation.

The dynamic model of Lithium-ion battery is shown in fig 6 where v(t) is used for switched in charging and discharging mode of operation. The battery voltage is given by:

$V_{bat} = E_O - K.\frac{S}{S-it}.i *.K.\frac{S}{S-it}.i^* - R.i + A\exp(B - it)(19)$

Where, V_{bat}=battery voltage (V), E_0 = constant voltage (V), K =polarization constant, (V/Ah), S=maximum battery capacity (Ah), A= exponential voltage (V), B =exponential capacity (Ah^{-1}), R= internal resistance (ohm), i*= filtered current. The system is capable of charging a 48 Volt, 200Ah Lithium-ion battery which is used for the storage system.

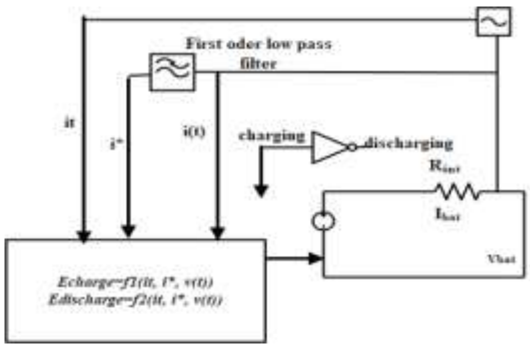


FIGURE 6

LITHIUM –ION BATTERY MODEL

BMS USING PI CONTROLLER

The battery management system of the system is used for charging and discharging as shown in fig 7. If the PV power (P_{pv}) is more than the load power (P_l) then the battery is charging otherwise discharging. According to the charging rate the reference current of the battery is set if the battery current and the error of the current are passed through the discrete PI controller. The output is considered as a class C chopper which is compared with a 5 kHz PWM generator. Switch S1, S2 is a compliment to each other as shown in fig 7. The PI compensator parameters are calculated as Kp = 0.01 Ki= 20

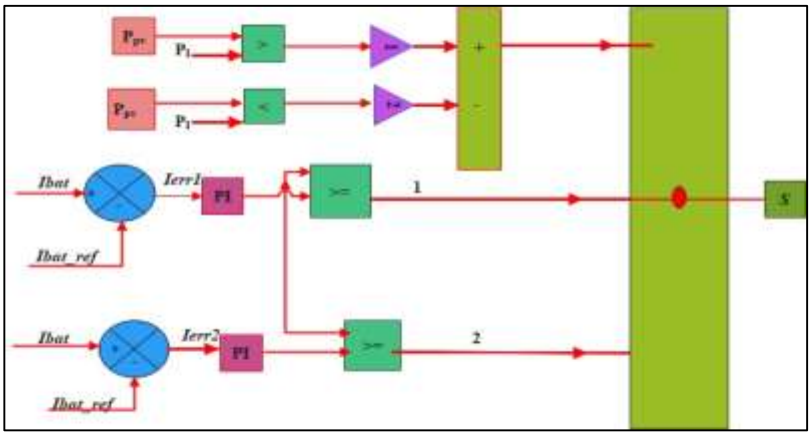
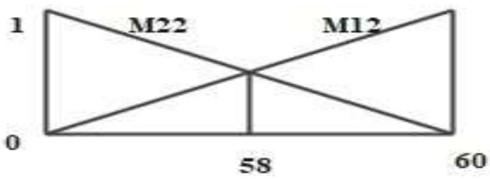


FIGURE 7

BATTERY MANAGEMENT SYSTEM USING PI CONTROLLER

BMS USING TS-FUZZY LOGIC CONTROLLER

A system is proposed to manage the switching of a bi-directional converter for a given level of solar radiation and the environment's temperature **[23].** The intelligent system is achieved by using the Takagi-Sugeno Fuzzy controller. In general, there are two approaches for designing the TS-fuzzy model. 1. Identify the input-output data for the system, 2. Derivation from the given non-linear system.In this system, the load voltage and a reference load voltage is taken as input values, whereas the output pulses is treated as charging-discharging of the battery. Here we choose a nonlinear term: $\boldsymbol{i_L}$



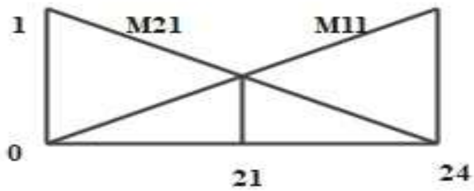


FIGURE 8

FIGURE 9

THE FUZZY SET OF $\boldsymbol{i_L}$THE FUZZY SET OF $\boldsymbol{V_c}$

Because the average current is about 21 A. So, we define the range: 0-24

$$\begin{cases} M_{11}\big(i_L(t)\big) = \frac{1}{24} i_L(t) \\ M_{11}\big(i_L(t)\big) = 1 - \frac{1}{24} i_L(t) \end{cases} \quad (20)$$

The model rule i (Buck Mode):If $q_1\ (t)\ is\ Mi_1$Then,

$\dot{x}(t) = A_i x(t) + B_i u(t) + E_i v(t),\ i = 1{,}2$(21)

Where, $q_1(t)$: $The\ non\ linear\ term;\ Mi_1 : The\ ith\ Membership$
 $function$

Control Rule i (Buck Mode): If $q_1(t)\ is\ Mi_1$Then, $u(t) = F_I x(t), i = 1{,}2$; Where, $F_I = Control\ gain$

The closed loop TS-Fuzzy control signal (Buck Mode):

$\dot{x}(t) = \sum_{i=1}^{2} \sum_{j=1}^{2} h_i(\dot{q}(t)) h_j(q(t))(A_i - B_i F_j)\, x(t) + E_i v(t)$(22)

Another nonlinear term:V_c

Because the average DC bus voltage is about 58 V

So we define the range: 0-60

$$\begin{cases} M_{11}(V_c(t)) = \frac{1}{60}V_c(t) \\ M_{22}(V_c(t)) = 1 - \frac{1}{60}V_c(t) \end{cases} \quad (23)$$

(

Model Rule i (Boost Mode);

If, $q_1\ (t)\ is\ M_{P1}\ , q_2(t)\ is\ M_{P2}$

Then,$\dot{x(t)} = A_\iota x(t) + B_i u(t) + E_i v(t), i = 1,2,4$(24)

Where, $q_1(t), q_2(t)$: $The\ non\ linear\ term$; $M_{P1}\ ,\ M_{P2}$: $The\ ith\ Membership\ function$

Control Rule i (Boost Mode):

If, $q_1\ (t) is\ M_{P1}, q_2(t) is\ M_{p2}$,

Then, $u(t) = -\ F_I x(t), i = 1,2..4$, Where, $F_I = Control\ gain$

The closed loop TS-Fuzzy control signal (Boost Mode):

$\dot{x}(t) = \sum_{\iota=1}^{4} \sum_{j=1}^{4} h_\iota(\dot{q}(t)) h_j(q(t))(A_\iota - B_\iota F_j)\ x(t) + E_i v(t)$(25)

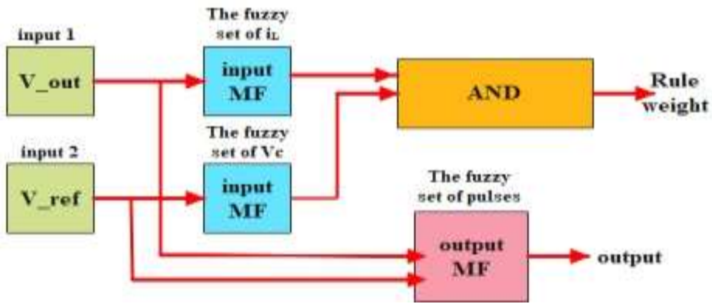


FIGURE 10

BATTERY MANAGEMENT SYSTEM USING TS-FUZZY

RESULT AND DISCUSSION

The test is carried out at various irradiations to ensure some of the aspects like output voltage, output current of PV array which is shown in fig. 11. Simulated results showed that the battery bank is charging from 0s to 1.5s when the irradiation is 1000Ww/m^2. After 1.5s it is discharging when the irradiation is 0W/m^2.The output power of Photovoltaic array is 2 kW.

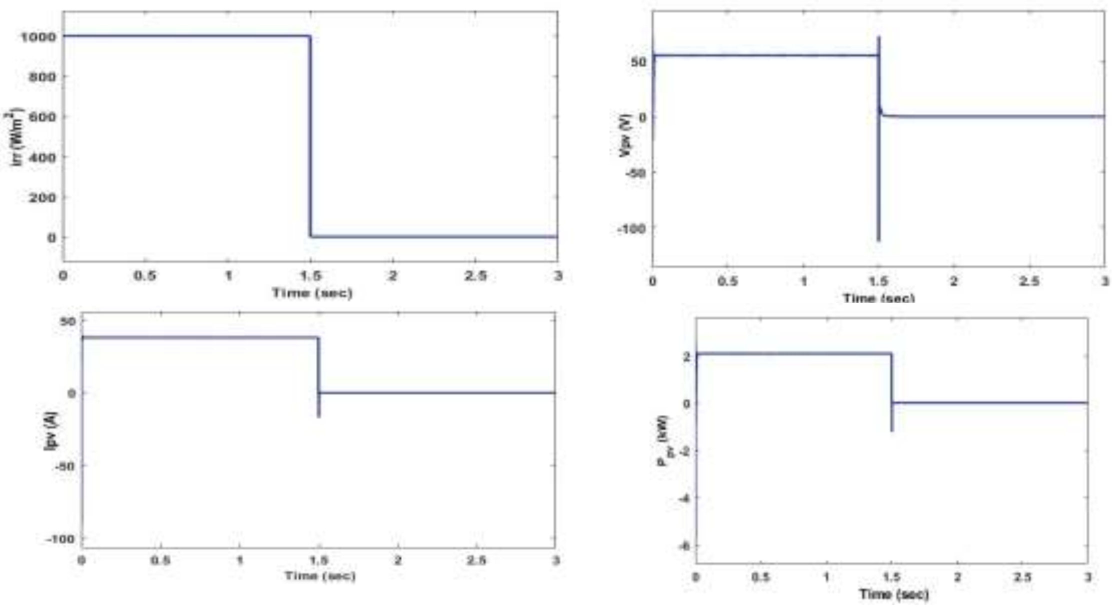


FIGURE 11

PV ARRAY VARIABLES

ESTABLISHMENT OF REAL TIME SIMULATION PLATFORM

The implementation of the battery control is done by using dSPACE 1202 real time controller board.The controller box is supported by a comprehensive dSPACEsoftware package (p.5), and the experiment software Control Desk. Fig 12 shows the control desk model of dSPACE1202 while Fig 13 shows the hardware setup of the system. Data acquisition and the battery charging and discharging system is implemented by using dSPACE 1202 software and digital signal processor card on PC. Simulation step size of dSPACE is 20e-6s.

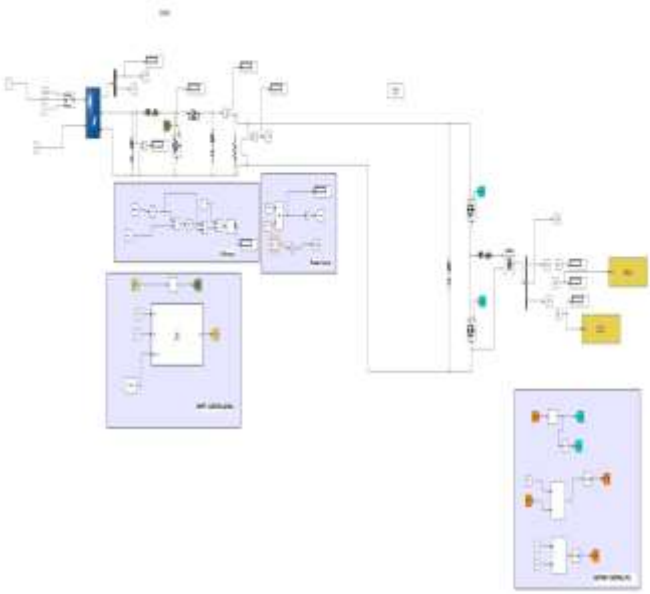


FIGURE 12

CONTROL DESK MODEL OF DSPACE 1202

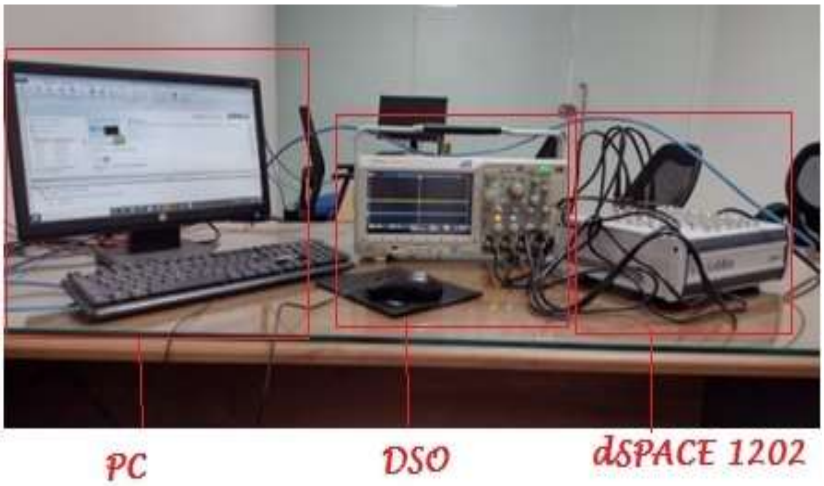


FIGURE 13

HARDWARE SETUP OF THE SYSTEM

The first set of simulations shows the schemes with closed-loop PI controller. The battery state of charging (SOC %) is increased from 0s to 1.5s. The battery current is maintained at 40A towards with the voltage of 52Volt. The SOC of battery is reduced from 1.5s, the battery current i.e. *Ibat* is reversed in direction and the battery voltage V*bat* is given a step change from 52 volt to 51 volts as shown in fig 14.Therefore, the BMS starts.

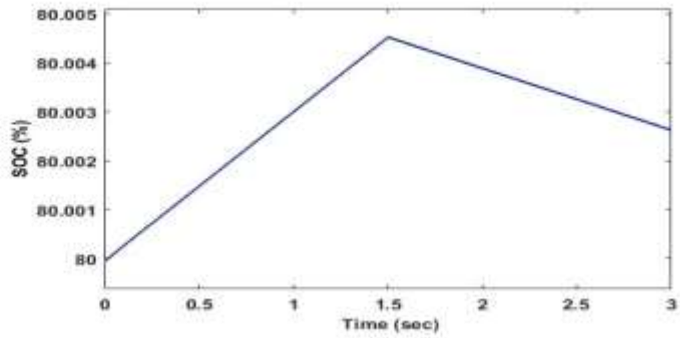


FIGURE 14

CHARGING-DISCHARGING OF BATTERY

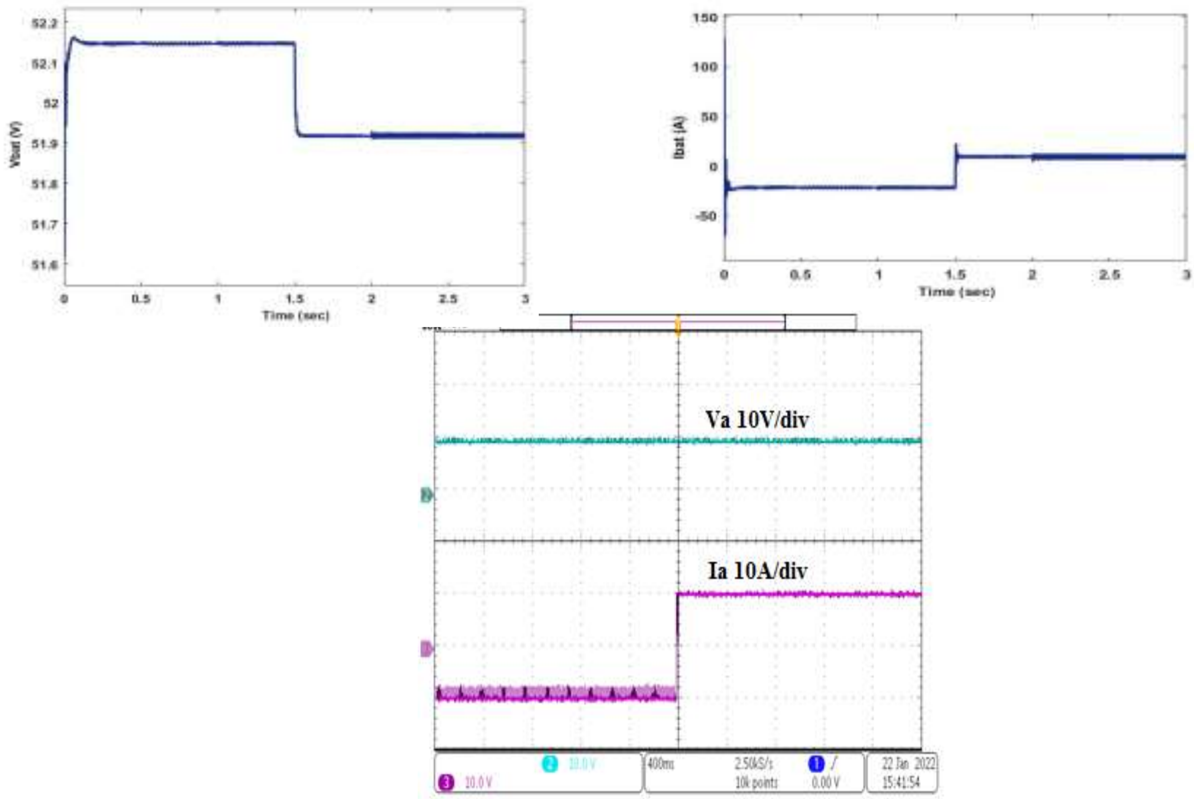


FIGURE 15

THE CHARGING AND DISCHARGE CYCLE OF THE BATTERY ARE HANDLED BY THE PI CONTROLLER USING DSPACE 1202 AND MATLAB SIMULINK

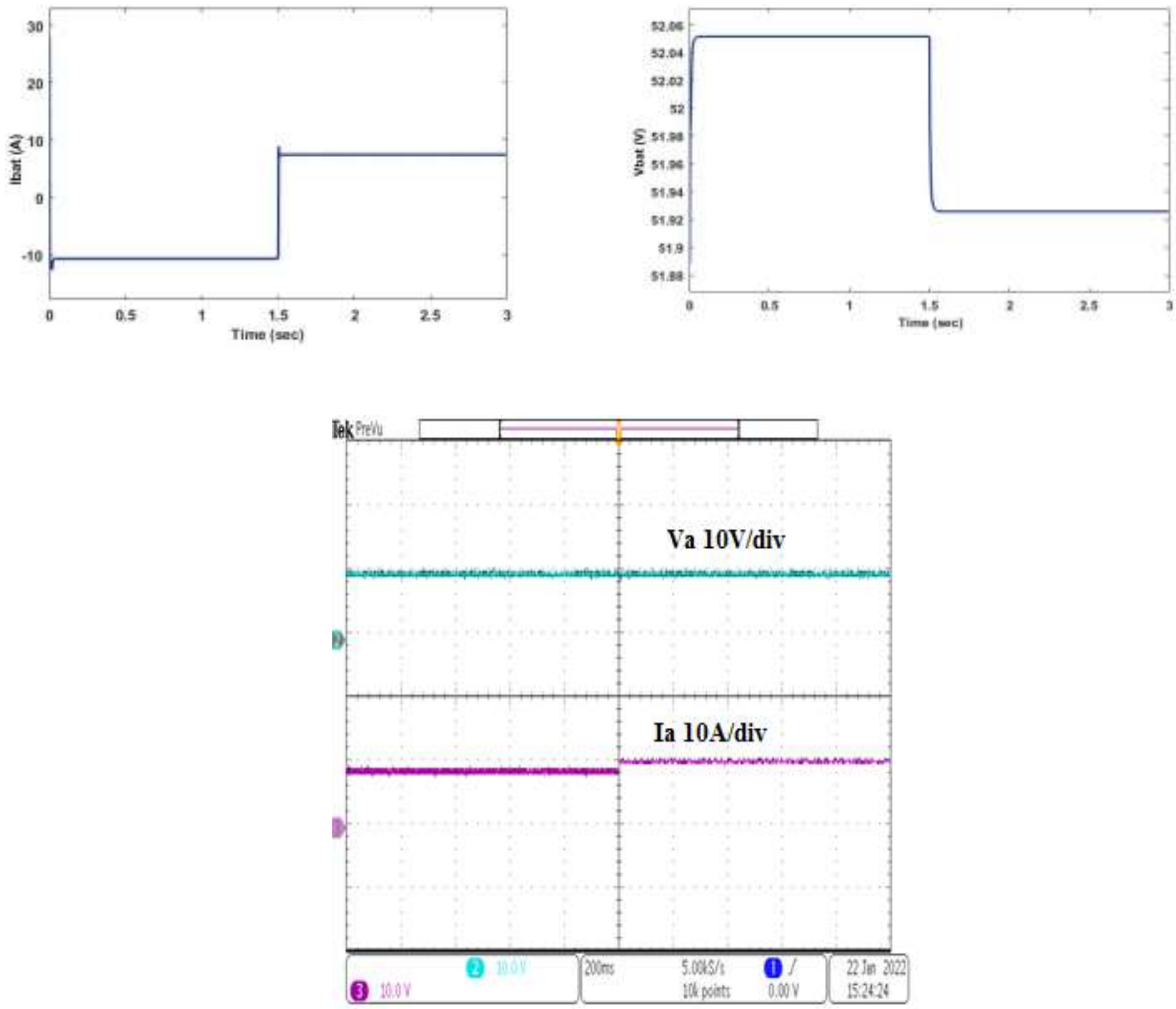


FIGURE. 16
THE CHARGING AND DISCHARGE CYCLE OF THE BATTERY ARE HANDLED BY THE TS- FUZZY CONTROLLER USING DSPACE 1202 AND MATLAB SIMULINK

The second set of simulations in fig 16 shows the scheme with closed-loop TS-fuzzy logic controller. The fuzzy logic controller has a fast dynamic response, small peak time, less overshoot.

The comparison table of PI Controller and TS-Fuzzy controller is shown in table 5.

TABLE 5

COMPARISON OF PI & TS-FUZZY CONTROLLER

Parameters	**PI Control**		**TS-Fuzzy**	
	V_{bat}	I_{bat}	V_{bat}	I_{bat}
Rise time	23.09ms	2.426ms	17.650ms	1.012ms
Overshoot	3.06%	3.115%	0.490%	1.994%
Undershoot	4.769%	45.200%	1.998%	0.503%
Peak value	5.12e+01	1.089e+02	5.17e+01	1.903e+01
Peak time	0.053	0.002	0.002	0.001

CONCLUSIONS

In this paper the study of PV battery management system was introduced with different weather conditions. The technique proposed method that show a 2kW PV system is equipped with two types of DC/DC converter, load and a 48 volt Lithium-ion battery for the storage system. The DC/DC boost converter is used to regulate the MPPT of PV array. The bi-directional DC/DC converter is used two schemes with two different controllers. Initially a Current control strategy with PI controller. Due to the advantage of less overshoot, rise time, fast dynamic response the TS-Fuzzy controller is preferred over the PI controller. The results show that by changing the value of irradiation the charging and discharging occurs in battery with respect to the voltage and current. The result shows the effectiveness of the system by using real time controller board 1202.

REFERENCES

[1] R. Faranda, S. Leva, and V. Maugeri, *"MPPT techniques for PV systems: Energetic and cost comparison",* IEEE Power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century (pp. 1-6). IEEE, July 2008.

[2] M.Berrera, A. Dolara, R. Faranda, S.Leva, *"Experimental test of seven widely-adopted MPPT algorithms," IEEE Bucharest PowerTech* ,(pp. 1-8), June 2009.

[3] F.Liu, S. Duan, F. Liu, B. Liu, and Y.Kang, 2008, *"A variable step size INC MPPT method for PV systems",* IEEE Transactions on industrial electronics, *55*(7), pp.2622-2628, 2008

[4] Xiao, Weidong, and William G. Dunford. *"A modified adaptive hill climbing MPPT method for photovoltaic power system*s", 35th annual power electronics specialists conference (IEEE Cat. No. 04CH37551), vol. 3, pp. 1957-1963. IEEE, 2004.

[5] E.Koutroulis, K.Kalaitzakis, N.C Voulgaris, *"Development of a microcontroller-based, photovoltaic maximum power point tracking control system",* IEEE Transactions on power electronics, 16(1), pp.46-54, 2001.

[6]Jalil, M. F., Khatoon, S., Nasiruddin, I., & Bansal, R. C., "*Review of PV array modelling, configuration and MPPT techniques",* International Journal of Modelling and Simulation, 1–18, 2021.

[7]Danandeh, M.A.; Mousavi G., S.M., "*Comparative and comprehensive review of maximum power point tracking methods for PV cells",* Renewable and Sustainable Energy Reviews, 2017.

[8] T.Esram, P.L Chapman, "Comparison of photovoltaic array maximum power point tracking techniques", *IEEE Transactions on energy conversion*, *22*(2), pp.439-449, 2007.

[9] A.M. Eltamaly, "Performance of MPPT techniques of photovoltaic systems under normal and partial shading conditions," *Advances in renewable energies and power technologies*, pp. 115-161, Elsevier, 2018.

[10] N.A. Kamal, A.M. Ibrahim, "Conventional, intelligent, and fractional-order control method for maximum power point tracking of a photovoltaic system,-a Review", *Fractional Order Systems,* pp. 603-671, Academic Press, 2018.

[11] Ali, M. N., Mahmoud, K., Lehtonen, M., & Darwish, M. M., *"An efficient fuzzy-logic based variable-step incremental conductance MPPT method for grid-connected PV systems"*, Ieee Access, 9, 26420-26430, 2021.

[12]Femia N, Petrone G, Spagnuolo G, and Vitelli M. *" Optimization of perturb and observe maximum power point tracking method", IEEE Transactions on Power Electronics*,vol.20,no.4,pp.963-973.2005.

[13] J.M Enrique, E.Duran, M.Sidrach-de-Cardona, *"Theoretical assessment of the maximum power point tracking efficiency of photovoltaic facilities with different converter topologies",* Sol. Energy, vol. 81, no. 1, pp. 31–38, 2007.

[14]Liao, Zhiling, and Xinbo Ruan., *"Control strategy of bi-directional DC/DC converter for a novel stand-alone photovoltaic power system", IEEE Vehicle Power and Propulsion Conference*, pp. 1-6. IEEE, 2008.

[15] Bhattacharyya S, Puchalapalli S, Singh B*., "Battery Management and Operation of a Wind-PV Based Microgrid",*IEEE International Conference on Computing,Power and Communication Technologies (GUCON), 2020.

[16]Sivamani, D., et al. "Solar Powered Battery Charging System Using Optimized PI Controller for Buck Boost converter." *IOP Conference Series: Materials Science and Engineering*. Vol. 1055. No. 1. IOP Publishing, 2021

[17] Chao, P. C. P., Chen, W. D., & Cheng, C. W., *"A fast battery charging algorithm for an intelligent PV system with capability of on-line temperature-compensation",*Microsystem technologies, 19(9-10), 1289-1306, 2013.

[18] Parise, G., Martirano, L., Kermani, M., & Kermani, M., Designing,*"A power control strategy in a microgrid using PID/fuzzy controller based on battery energy storage",*IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe),pp. 1-5,2017.

[19]Samadi, M.F. and Saif, M., *"State-space modeling and observer design of li-ion batteries using Takagi–Sugeno fuzzy system",*IEEE Transactions on Control Systems Technology, 25(1),pp.301-308,2016.

[20] Samadi, M.F. and Saif, M*., "Takagi-Sugeno fuzzy model identification of Li-ion battery systems".*In 2014 World Automation Congress(WAC),pp.421-426, 2014.

[21] Patankar, M. M., Wandhare, R. G., & Agarwal, V., *"A high performance power supply for an electric vehicle with solar PV, battery and ultracapacitor support for extended range and enhanced dynamic response",*IEEE 40th Photovoltaic Specialist Conference (PVSC) ,pp. 3568-3573, 2014.

[22] Raiker, G. A., B, S. R., Ramamurthy, P. C., Umanand, L., Abines, S.G.,& Vasisht, S. G*., "Solar PV interface to Grid-Tie Inverter with Current Referenced Boost Converter",* IEEE 13th International Conference on Industrial and Information Systems (ICIIS), 2018.

[23] Chao, P. C. P., Chen, W. D., & Cheng, C. W*., "A fast battery charging algorithm for an intelligent PV system with capability of on-line temperature compensation",* Microsystem technologies, 19(9-10),1289-1306, 2013