

Voltage Stabilization in PV based Buck Boost Converter Using Pi and FLC Controllers due to Input Voltage Variation

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Abstract

Aim: The aim of this paper is to present innovative voltage stabilization in PV fed buck boost converter systems due to input voltage variation. One of the Artificial intelligence (AI) controllers known as fuzzy logic controller is used in this project. **Materials & Methods:** Proportional Integral (PI) and Fuzzy Logic Controller (FLC) based MPPT algorithm are implemented to analyze the Buck Boost converter output voltage under varying input conditions. **Results:** Based on the results obtained, it is inferred that the FLC based Buck Boost converter efficiently stabilizes the voltage under varying insolation conditions in the PV panel. **Conclusion:** FLC based MPPT provides better stabilization (35.67V) compared to PI algorithm (31.65V) for the selected data set.

Key-words: Photovoltaic System, Perturb and Observe(PI), Artificial intelligence, Fuzzy Logic Controller, Buck-Boost Converter, Innovative Voltage Stabilization.

1. Introduction

Developments on PV systems have increased rapidly in the past few years. Applications associated with PV systems are preferred over other Renewable Energy Systems (RES) due to its cleanliness and its environment friendly in nature (Cakmak, Altas, and Sharaf 2012). The research is about stabilizing the output voltage using controllers that helps to stabilize the output voltage obtained from the converter module (Elbaksawi 2019). To increase the generation of electricity and to satisfy the demand on electricity generation leads to the development of renewable energy sources which is

used widely in defense applications, inverter (Rubavathy, Jaanaa Rubavathy, and Murugesan 2017), battery operated vehicles and communication circuits (Balakishan, Sandeep, and Aware 2015).

The high efficiency and high density single phase dual mode buck boost multilevel transformer less PV inverter using AC switches are presented in (Tang et al. 2016) (Jiang et al. 2013) which improves the PV efficiency to 97.8% at full load. A simple smooth transition technique for the Non-inverting Buck-Boost converter with a sensible improvement in voltage regulation during mode transition is discussed in (Restrepo et al. 2015) (Islam et al. 2016). A Fuzzy logic based buck boost DC-DC converter for solar energy battery system discussed in (Altas and Sharaf 2008) [9(Yang, Liang, and Chen 2008)], gives faster transient response which is more robust than conventional methods . A hybrid fuzzy PID fed buck boost converter presented in (Cirstea et al. 2002), results in very short rise time.

Previously our team has a rich experience in working on various research projects across multiple disciplines (Sathish and Karthick 2020; Varghese, Ramesh, and Veeraiyan 2019; S. R. Samuel, Acharya, and Rao 2020; Venu, Raju, and Subramani 2019; M.S. Samuel et al. 2019; Venu, Subramani, and Raju 2019; Mehta et al. 2019; Sharma et al. 2019; Malli Sureshbabu et al. 2019; Krishnaswamy et al. 2020; Muthukrishnan et al. 2020; Gheena and Ezhilarasan 2019; Vignesh et al. 2019; Ke et al. 2019; Vijayakumar Jain et al. 2019; Jose, Ajitha, and Subbaiyan 2020). Now the growing trend in this area motivated us to pursue this project.

The conventional controllers used in PV systems do not track the maximum voltage efficiently with the proposed converter. In this paper, a comparative study on PI and FLC based Buck Boost converter is modelled and implemented, which suggests that the FLC controller gives better stabilization than conventional controllers.

2. Materials and Methods

This study was conducted in a Power Electronics Lab at Saveetha School of Engineering. Sample size was calculated using previous literature (Dida and Benattous 2015). In this work there are no human or animals samples used so no ethical approval is required. In this work two groups are taken and 7 samples for each group so total samples considered are 14. The GPower is calculated using GPower software which is 0.801. GPower setting parameters: Statistical test - difference between two independent means, $\alpha - 0.05$, power - 0.8, effect size-1.41419, mean FLC- 0.017, mean PI- 0.038, sd- 0.14849. The system is simulated using the MATLAB simulink model.

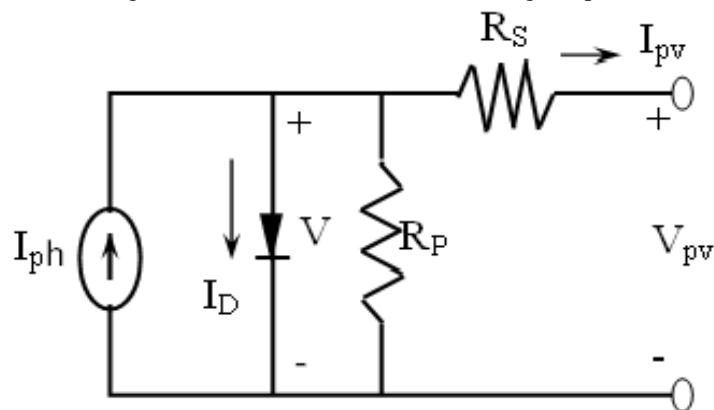
The electrical equivalent circuit of PV cell composes photon current source in parallel with a diode and shunt resistance, all in series with a series resistor as shown in Fig. 1. The basic equation from the theory of semiconductor that mathematically describes the I-V characteristics of the ideal PV cell is given in eq (1-3).

$$I_{ph} = \frac{[I_{scr} + K_i(T - 289)S]}{1000} \quad [1]$$

$$I_0 = I_{rs} \left[\frac{T}{T_r} \right]^3 e^{\frac{qE_{go}}{BK(1/T_r - 1/T)}} \quad [2]$$

$$I_{PV} = N_{PH} - NI_0 \left[e^{\frac{q(V_{PV} + I_{PH})R_S}{N_SKT}} - 1 \right] \quad [3]$$

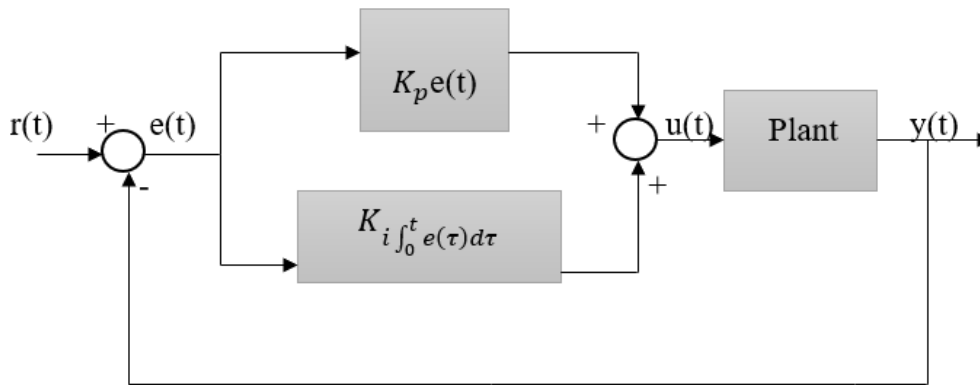
Fig. 1 - Circuit model used for modeling PV panel



Where, I_{ph} = Module photo-current, I_0 = Module saturation current, I_{pv} = Current output of PV module, I_{scr} = Short circuit current, K_i = temperature coefficient (0.0017), E_{go} = Band gap oscillation = 1.1eV, V_{oc} = open circuit voltage, S = Reference insolation = 1000 W/m². The parameter values used in the PV array simulation circuit are: Maximum power $w=250.205$, open circuit voltage $V_{oc}(v)=37.3$, voltage at maximum power point $V_{mp}(v)= 30.7$, Temperature coefficient of $V_{oc}(\%/deg.c)=-0.36901$, cells per module= 60, short circuit $I_{sc}(A)= 8.66$, current at maximum power point $I_{mp}(A)= 8.15$ and Temperature coefficient of $I_{sc}(\%/deg.c)=0.086998$.

A proportional integral controller in a feedback is used to calculate the error in a system output by comparing it with preset value is shown in Fig. 2. Any modification in input voltage results in variation of converter output voltage (Restrepo et al. 2015). This variation causes error signal $e(s)$, which is then processed by the controller by adjusting its gains. The PI controller indirectly controls the power being utilized, by directly modifying the PWM control signal applied to MOSFET switches.

Fig. 2 - Block diagram of PI -PO Controller based system



Where K_p is the proportional gain, K_i is the integral gain, and $e(t)$ is the error at the current time t , and \mathcal{T} is the integration variable. The integral integrates from time 0 to the current time t . We use \mathcal{T} for the integration because we need a variable to take on multiple values throughout the integral, but we cannot use t because we already defined that as the current time (Elbaksawi 2019).

FLC has been generally utilized for domestic and industrial applications since it is characterized as a theory of vagueness & uncertainties (Yang, Liang, and Chen 2008). The flowchart of FLC controllers shown in Fig. 2. It is a nonlinear control technique which is utilized by the converter to improve the dynamic response of a system as proposed in the literature. The centroid defuzzification technique is utilized in this work. (Samosir, Taufiq, and Yatim 2011). The output voltage is needed to be stabilized under varying insolation conditions. The FLC controller is modelled with five membership functions as Negative Large (NL), Negative Small (NS), Zero (Z), Positive Small (PS) and Positive Large (PL) (Al-Gizi et al. 2017).

The FLC controller uses a triangular membership function, (Ushakumari and Mithila 2017) and the fuzzy rules are formed based on output requirements which is shown in Table 1. The output of FLC is used to vary the duty cycle of MOSFET switches and stabilizes the voltage effectively.

Table 1 - Rule base with FLC Controller for ‘D’ output variables

E/ΔE	NL	NS	ZE	PS	PL
NL	ZE	ZE	NL	NL	NL
NS	ZE	ZE	NS	NS	NS
ZE	NS	ZE	ZE	ZE	PS
PS	PS	PS	PS	ZE	ZE
PL	PL	PL	PL	ZE	ZE

Table 2 - Simulation results of PI and FLC algorithm

Input voltage variation	Expected output Voltage	Output Voltage with PI controller	Output Voltage with FLC controller
15	34.46	31.69	34.17
20	35.10	31.67	34.65
21	35.18	31.65	34.68
22	35.35	31.66	34.65
23	35.75	31.66	35.66
24	35.85	31.71	35.65
25	35.90	31.65	35.67

For testing the proposed system the Matlab simulink software by considering a PV array with a capacity of 250W has been used and the results are determined by varying insolation set parameters. The results are obtained by changing the isolation value of the PV panel. The obtained output voltage in both controllers have been tabulated for the given change in input voltages as shown in Table 2. It infers that the stabilized output voltage in an FLC controller based system is better than the PI controller based system with variations in input voltage.

SPSS is used for statistical analysis of PI & FLC algorithms. The independent variable is solar irradiation and the dependent variable is output voltage. Two independent group analysis tests are carried out to determine the voltage stabilization in both algorithms.

3. Results

Fig. 4 & 5 show that the Input and Output voltage waveforms obtained from PI and FLC controllers respectively. It is observed that FLC based MPPT is preferred than PI based MPPT for Buck-Boost converter with minimum ripples in its output (Hajighorbani et al. 2015) (Kheldoun et al. 2016) (Sahin, Okumus, and Kahveci 2015). Because the FLC controller is designed to accept the varying step change input, and also it effectively traces the maximum output power with minimum ripple magnitudes.

Fig. 3 - Flow chart of FLC controller

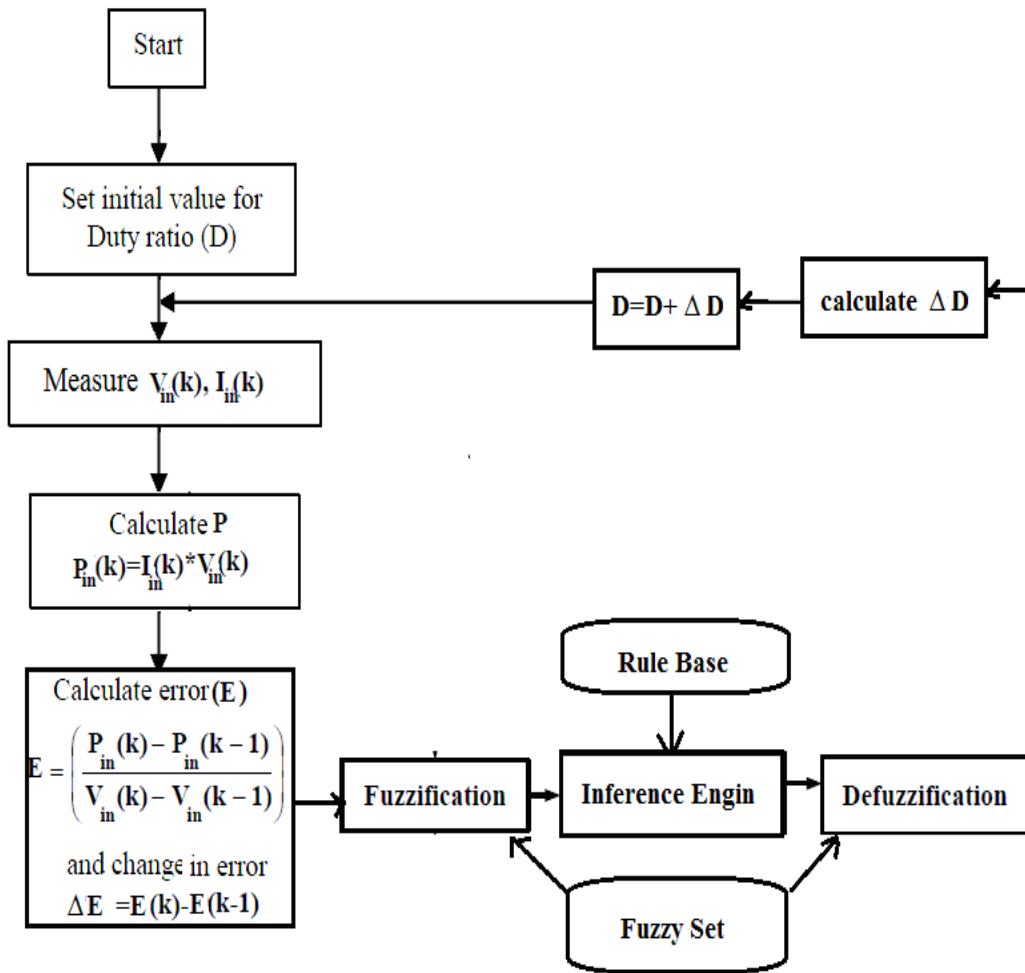


Fig. 4 - Simulation results with PV fed Buck Boost Converter with PI_PO control. It indicates that the converter gives stabilized output voltage of 31.65V with a ripple magnitude of 1.5V

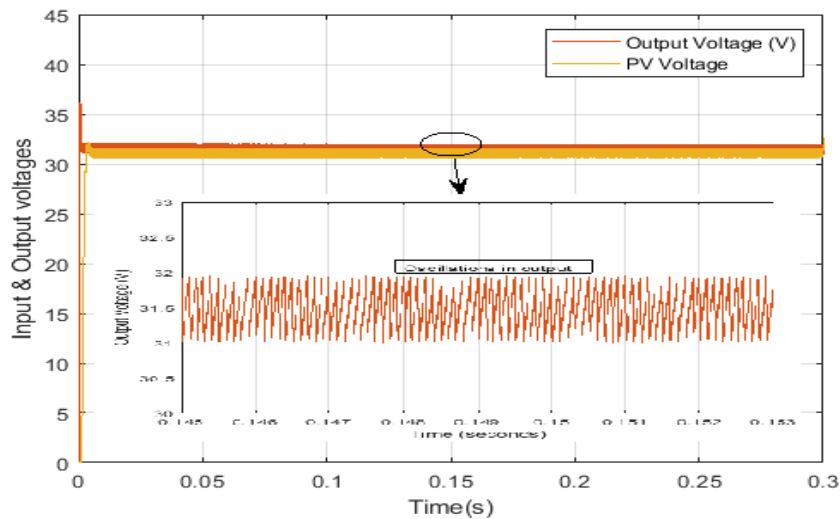


Fig. 5 - Simulation results with PV fed Buck Boost Converter with Fuzzy_PO control. It indicates that the converter gives stabilized output voltage of 35.67V with a ripple magnitude of 1V

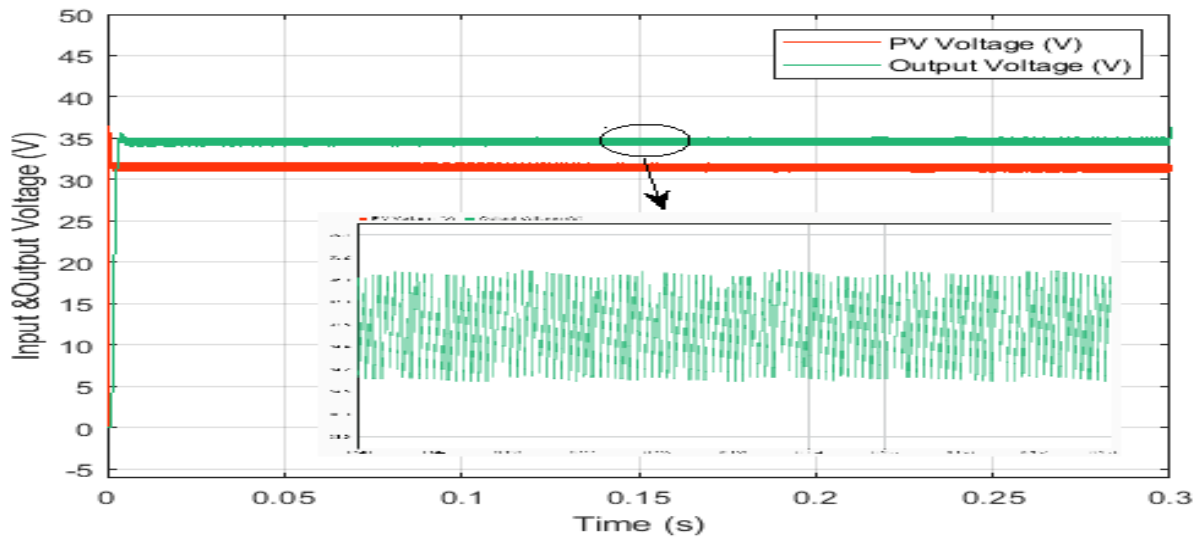
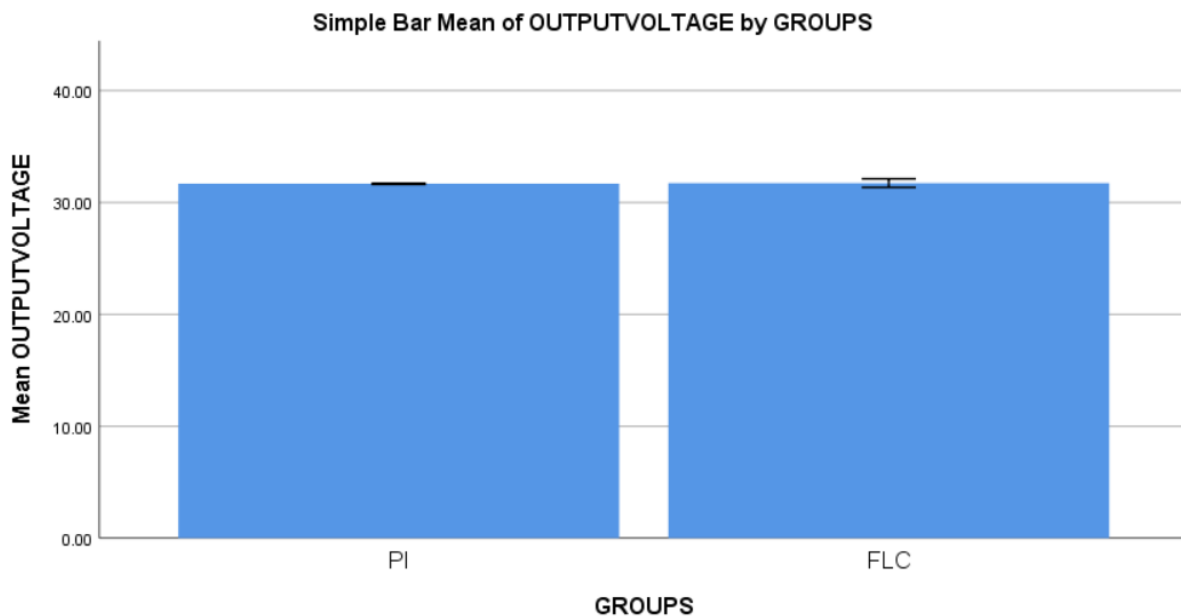


Fig. 6 - Comparison of PI and FLC controllers in terms of mean output power. The mean output power of FLC is better than PI and the standard deviation of FLC is better than PI. X axis: PI vs FLC controllers, Y axis: mean output power of detection $\pm 1SD$



In performing statistical analysis of 7 samples, FLC controller obtained 0.62462 standard deviation with 0.23608 standard error while PI controller obtained 0.2236 standard deviation with 0.00845 standard error (Table 3). Significance value is smaller and is equal to 0.062, with respect to changes in input voltage (Independent variable) the corresponding output voltage (Dependent variable) also changes (Table 4).

Table 3 - T- test comparison of FLC and PI algorithm is carried out by changing the input voltage from 15 to 25V. For this selected data set, FLC has a higher mean value of 35.0186, whereas the mean of PI is also almost 31.67. The value of standard deviation in FLC is observed to be higher (0.23608) than PI controller (0.00845)

Group statistics					
	Groups	N	Mean	Standard deviation	Std.Error Mean
Output power	PI	7	31.6700	0.02236	0.00845
	FLC	7	35.0186	0.62462	0.23608

Table 4 - Independent Sample Test: The independent sample test has been carried out and has markable differences in stabilized output between FLC and PI algorithms. There is a significance difference between the two groups since $p < 0.05$ (t value is -14.175 and mean difference is -3.34857)

Independent Sample Test											
Levene's Test for Equality of Variances				T-test for Equality of Means							
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Differences	95% confidence Interval of the Difference		
										Lower	Upper
Output Voltage	Equal Variances assumed	4.223	.062	-.855	12	.409	-.06286	.07348	-.22295	.09723	
	Equal Variances not assumed			-.855	6.161	.424	-.06286	.07348	-.24151	.11580	

Independent T test was used to compare the accuracy of two controllers and a statistical significant difference was noticed. From Fig. 6, it is evident that stabilized voltage in FLC is 35.67V which is higher than PI of 31.65V for the same input settings. But the standard deviation range appears to be almost the same for both algorithms.

4. Discussions

PI and FLC algorithms are implemented and its voltage stabilization is analysed and compared. FLC has better voltage stabilization when compared to the PI algorithm.

Based on previous literature study, a fuzzy logic control based grid connected PV array with boost converter is analyzed using PI and FLC algorithms based on response time, overshoot and settling time. It is proved that the FLC (0.55s) controller tracks the maximum power with less time than PI(0.65s)(Lakshmi and Hemamalini 2018). Comparison of perturb and observe and fuzzy logic controller is carried out for maximum power point tracking in pv systems, the performance of fuzzy MPPT is better than PO(16.5v) for the nonlinear systems, also it has the capability of reducing

perturbed voltage when MPPT has been recognized. FLC(17.1v) preserves a more stable output power compared to P&O MPPT(15.4v)(Li and Wang 2009). A Comparative study is carried out between FLC and P&O MPPT algorithm under varying solar irradiance conditions to improve the PV system performance (Liu et al. 2014). It is found that the proposed FLC (0.4s) performs faster than PO(0.49s) at 1000 w/m² irradiance level. The novel controller proposed can be used to track the MPP under varying irradiance (200 w/m²), results have been proved that FLC(0.0428s) MPPT with indirect method has fast time response, less overshoot(0.15%) and better efficiency(0.95%) when compared to conventional PI(0.049s) method (Farhat, Barambones, and Sbita 2015).

Hybrid fuzzy PID controller is designed to use a DC-DC buck boost converter to enhance the solar energy battery systems. The results of hybrid fuzzy PID are compared with conventional (PID, fuzzy PI and fuzzy PD) controllers, which performed better than all conventional fuzzy systems in terms of rise time(0.12sec), overshoot(0.0939V), reduced voltage oscillations (0V) and a steady state voltage of 12V.(Mustafa E. Sahin and Okumus 2011). A comparative study is carried out between ANN and FLC Controller in DC-DC boost converter. It is found that the ANN performs better than FLC as it is fast-moving and precise in tracking MPP. ANN has the efficiency of 99.86% and 98.93 kW power delivered to the grid while FLC has efficiency of 95.48% and 94.47 kW power delivered to the grid (Singh, Shahid, and AL-FALAH UNIVERSITY 2016).

From the above literature, few papers quote that the FLC provides better results than PI algorithm. So it infers that FLC MPPT can be implemented in tracking global peak power with high efficiency under varying insolation conditions.

Our institution is passionate about high quality evidence based research and has excelled in various fields ((Vijayashree Priyadharsini 2019; Ezhilarasan, Apoorva, and Ashok Vardhan 2019; Ramesh et al. 2018; Mathew et al. 2020; Sridharan et al. 2019; Pc, Marimuthu, and Devadoss 2018; Ramadurai et al. 2019). We hope this study adds to this rich legacy.

Due to different step size parameters the tracking of peak power is not precise. And also the oscillation around the peak power affects the value of duty cycle used in the converter, resulting in power loss in the load circuit which may lead to damage to the equipment. Because of the difficulty in the framing rule base using membership function the tracking time is also a little high.

To rectify the above said limitations a novel MPPT technique can be implemented to trace global peak power efficiently with minimum ripples to give better stabilization, high accuracy with less tracking time.

5. Conclusion

The maximum power point tracking in solar cells is varied with respect to changes given in the input of the PV array. Based on the simulation study, it infers that the FLC algorithm reported slightly higher stabilized output voltage (35.67V) compared to the PI algorithm (31.65V) for the same input settings.

Declarations

Conflicts of Interest: No conflict of interest in this manuscript.

Author Contributions

Author BHB was involved in data collection, data analysis and manuscript writing. Author SJR was involved in conceptualization, data validation and critical review of manuscripts.

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