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RESEARCH ARTICLE

Investigation on Maximum Power Point Tracking Algorithm (INC and FLC) for Effective Utilization of Power Under Partial Shaded Photovoltaic System

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ABSTRACT

Aim: This paper makes a comparative analysis on two types of maximum power point tracking algorithm to trace the global peak power efficiently with minimum oscillation and less tracking time under partial shaded photovoltaic green energy systems.
Materials & Methods: Incremental conductance (INC) and fuzzy logic (FLC) MPPT algorithm are implemented to analyze the tracking efficiency under varying insolation conditions. **Results:** FLC MPP algorithm extracts peak power of 97.6 W with tracking time of 0.003s while INC extracts 94 W with tracking time of 0.004s. **Conclusion:** FLC MPPT algorithm provides better efficiency compared to INC algorithm for the selected data set.

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Introduction

Photovoltaic (PV) energy generation has become a promising alternative energy resource. The usage of PV source has increased rapidly in recent years. The main purpose of this research work is to efficiently utilize the generated power without any loss. PV systems play a vital role in recent applications such as grid, battery charging, PV inverter and Electric vehicle (Saxena et al. 2018; Bagalini et al. 2019).

Various MPPT algorithms have been analysed and its performance has been listed based on the PV system parameters (Gupta and Saxena 2016). Under nonlinear load conditions in the hybrid system the power extraction is analysed (S. Kumar and Singh 2018).

Ripple free Power extracting under varying climatic factors using the INC algorithm has been discussed (N. Kumar et al. 2018). LIC technique is an improved form of an incremental conductance algorithm, where inherent problems of the traditional InC technique, such as steady-state oscillations, slow dynamic responses, and fixed-step-size issues, are successfully mitigated (N. Kumar et al. 2019).

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.

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2019; Jose, Ajitha, and Subbaiyan 2020). Now the growing trend in this area motivated us to pursue this project.

Extraction of maximum power from the PV system is a challenging factor under partial shading due to the presence of multiple peaks. Various maximum power point tracking (MPPT) techniques have been presented to determine the maximum tracking power. Some of the conventional algorithms are perturb and observe, incremental conductance, fuzzy logic, neural network control methods, etc. These methods do not efficiently trace the peak power with minimum oscillations. Hence an improved peak power tracking method is developed to track the global peak under partial shading condition. In this paper, a comparison of two MPPT algorithms, incremental conductance (INC) and fuzzy logic Controller (FLC) is implemented and analyzed.

Materials and Methods

This study was conducted in a Renewable Energy lab at Saveetha School of Engineering. Sample size was calculated by using previous study results (Dhaouadi et al. 2019). Using GPower software sample size is determined for each algorithm requires 7 samples and totally 14 sample tests have been carried out (g power setting parameters: statistical test-difference between two independent means, α-0.05, power-0.80, effect size-0.5, mean FLC- 0.917, mean INC - 0.87, sd-0.033). The system is simulated using the MatLab Simulink© model.

Photovoltaic System

The PV panel is modelled using one diode model (1)-(4) which consists of a current source in parallel with a diode (Zevallos et al. 2021; Ramaprabha and Mathur 2008; Villalva, Gazoli, and Filho 2009), a shunt resistance and a series resistance as shown in Fig.1.

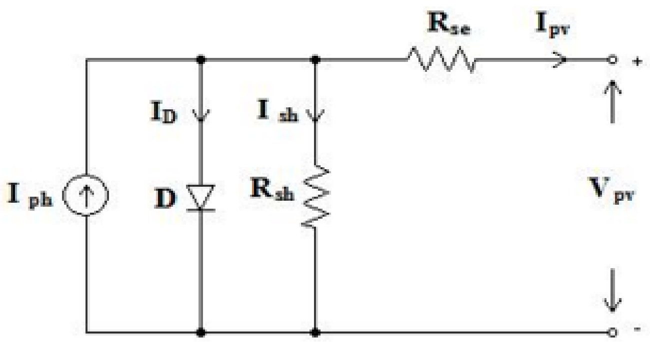

Fig. 1. Circuit model used for modeling PV panel

$$I_{pv} = I_{ph} - I_D - I_{sh} \quad (1)$$

$$I_0 = \frac{K_0(T-T_n)+I_{scn}}{exp[(K_v(T-T_n)+V_{ocn})/V_{ta}]-1} \quad (2)$$

$$I_{pv} = [K_i dT + I_{pvn}]\frac{G}{G_n} \quad (3)$$

$$V_{ta} = \frac{N_s aKT}{q}$$

$$I_m = I_{pv}N_{pp} - I_0 N_{pp} exp\left[\frac{V_t}{N_s}\left(V + IR_{se}\frac{N_{ss}}{N_{pp}}\right) - 1\right] \quad (4)$$

Where,

V_{ocn}=21.24; I_{scn}=2.55; N_{ss}=14; N_{pp}=1; R_s=0.47; R_p=145.67; a=1.5, q=1.6022e^{-19}; k=1.3807e^{-23}; N_s=36; K_i=0.0032; I_{pvn}=2.5546; K_v=-0.1230; T_n=298.15;G_n=1000

Maximum Power Point Tracking Algorithm

Incremental Conductance (INC) Controller

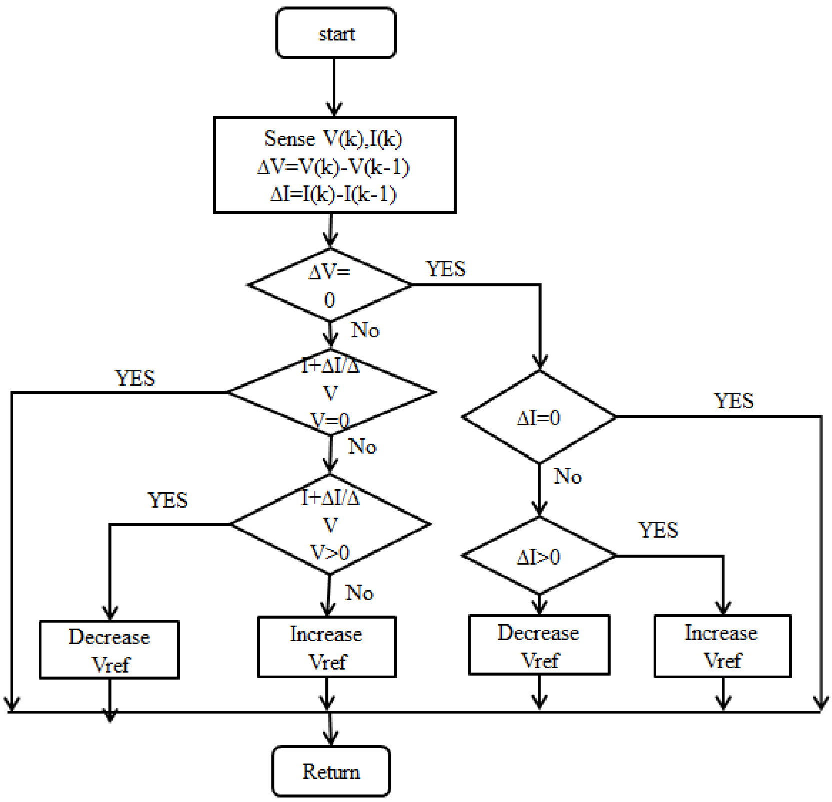

Fig. 2. Flow Chart of INC Algorithm

In the INC MPPT algorithm, MPP is determined by comparing conductance (I/V) and incremental conductance (dI/dV) (Safari and Mekhilef 2011; Saidi, Maamoun, and Bounekhla 2017; Bulle, Patil, and Kheradkar 2017). At MPP point the slope of the PV curve is zero. When MPP is at a certain distance from the operating point, step size will be high and when MPP is close to the operating point the step size will be less (Farayola, Hasan, and Ali 2017). Return, if instantaneous conductance exceeds the inverse of incremental conductance, during the next cycle, the duty cycle will be increased. Otherwise the duty cycle will be decreased. The flow chart of INC MPPT algorithm is shown in Fig. 2.

Fuzzy Logic MPPT Controller

The FLC MPPT method depends on the membership function and rule base. Triangular membership function is considered to limit the computation complexity. FLC consists of three main stages such as fuzzification, rule base and defuzzification. In this algorithm five membership functions are considered such as negative small (NS), negative big (NB), Zero (ZE), positive small (NS), positive big (NB). Two input functions such as error (E) and change in error (CE) and the output variable is duty cycle (D) ((Otmane, Malika, and Ihssane 2017; Li and Wen 2016; Attia 2018). In the inference engine the duty cycle is adjusted based on the ΔP/ΔV value which is listed in the rule base Table 1. The defuzzification is responsible to transform the linguistic variable into original data value The flow chart of the FLC MPPT algorithm is shown in Fig. 3.

Table 1. Rule Base framed for 'D' Output Variables (Desired) for various input Membership function of Inputs

E/ΔE	**NB**	**NS**	**ZE**	**PS**	**PB**
NB	ZE	ZE	NB	NB	NB
NS	ZE	ZE	NS	NS	NS
ZE	NS	ZE	ZE	ZE	PS
PS	PS	PS	PS	ZE	ZE
PB	PB	PB	PB	ZE	ZE

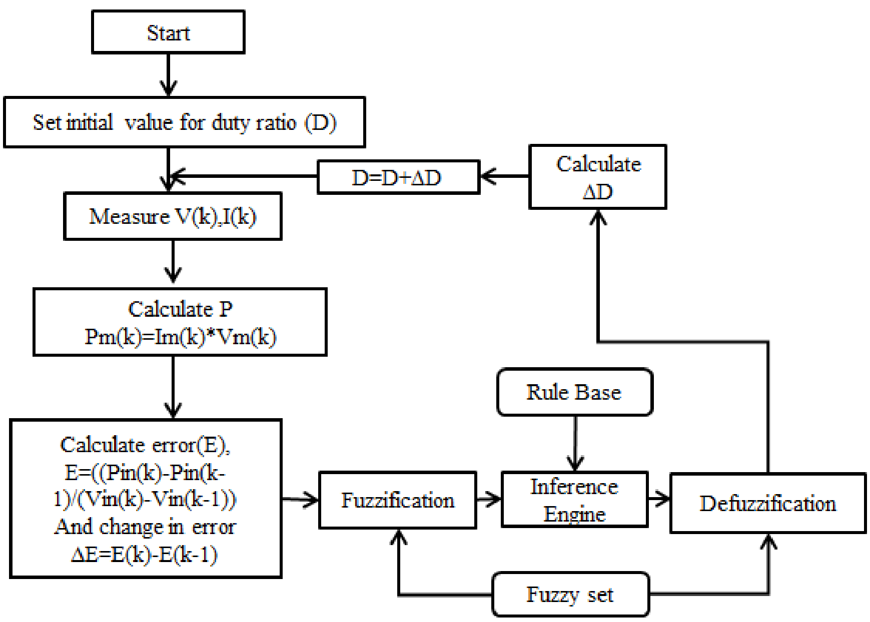

Fig. 3. Flow chart of fuzzy based global MPPT

For testing the proposed system, MatLab Simulink Software has been used. Results are validated by changing the input insolation value from the PV source so that there will be deviation in the obtained output power (Table 2).

Table 2. Efficiency calculation of Simulated results of INC and FLC algorithm for various Insolation Values

	Insolation (G)	Expected output	INC Attained output	FLC Attained output	INC Efficiency	FLC Efficiency
1.0	1000, 800, 500	61.3	58.0	59.8	94.6	97.6
2.0	800, 700, 400	52.0	49.6	48.7	95.4	93.7
3.0	1000, 400, 700	54.0	48.6	49.6	90.0	91.9
4.0	900, 600, 400	47.3	40.5	41.3	85.6	87.3
5.0	800, 500, 700	59.6	48.3	54.1	81.0	90.8
6.0	900, 400, 700	53.2	44.8	49.7	84.2	93.4
7.0	400, 700, 200	29.3	22.8	25.1	77.8	85.7

Statistical Analysis

SPSS software is used for statistical analysis of INC and FLC algorithms. The independent variable is input insolation to the PV system and the dependent variable is output power extracted. Two independent group analysis tests are carried out to determine the efficiency of both the algorithms.

Results

Multiple peaks in Fig. 4 and Fig. 5 is due to bypass diodes present across the output end of the PV cell. Bypass diode across the PV cell is responsible for limiting the hotspot issue.

Automatic tuning of step size in FLC MPPT algorithm results in accurate tracking of peak power (Fig. 6). In case of the INC algorithm it has a fixed step change parameter so that oscillation around peak power is high compared to FLC algorithm and takes more tracking time (Fig.7).

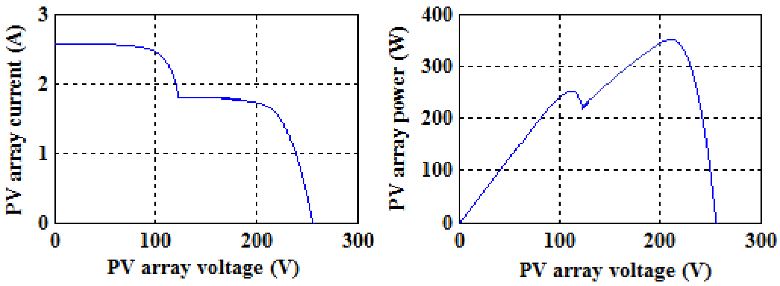

Fig. 4. Characteristics of PV array a) VI, b) PV under varying insolation condition with multiple peaks

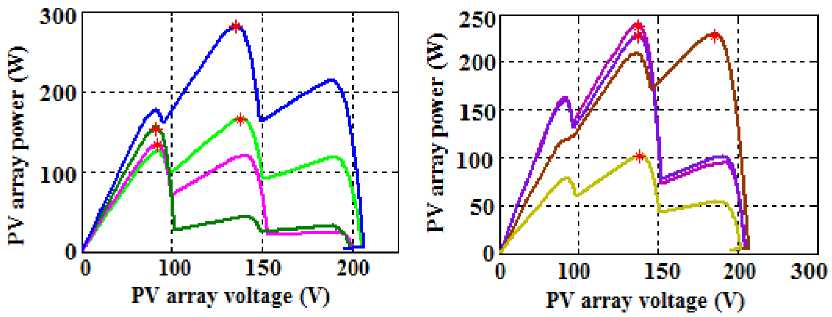

Fig. 5. Simulated VI & PV characteristics of PV array under different partially shaded pattern and Red dot (*) represents the global peak power point for different curves (blue, green, pink, yellow lines)

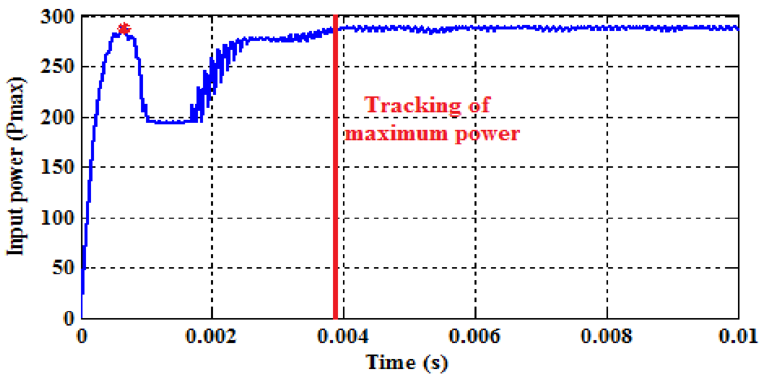

Fig. 6. Output power using INC algorithm, oscillation around the peak power (red dot) is high and tracking time is 0.0039 sec

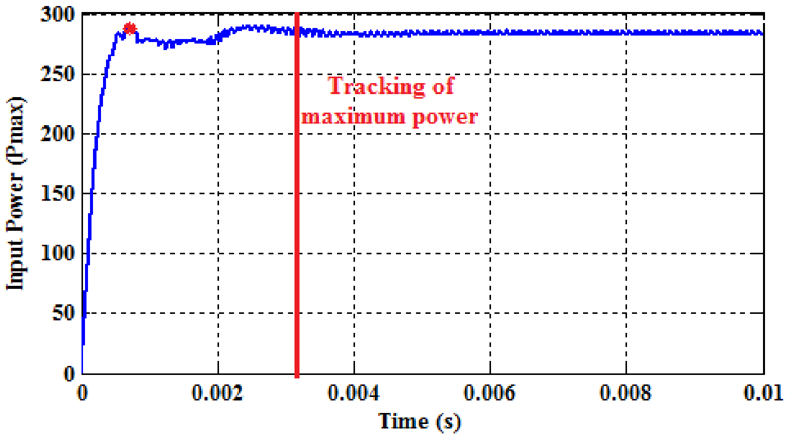

Fig. 7. Output power using FLC based MPPT algorithm, oscillation around peak power (red dot) is comparatively low and tracking time is 0.003sec

Table 3. Statistical analysis of FLC and INC MPPT controller. Mean Output voltage, Standard deviation and standard error values are obtained for 14 sample data sets. When compared FLC has better performance than INC controller

Group Statistics					
	Group	N	Mean	Std. Deviation	Std. Error Mean
Efficiency	FLC	7	91.57	4.117	1.556
	INC	7	86.43	4.117	1.556

Table 3 T-test Comparison of FLC and INC MPPT algorithm by varying insolation parameter between 200 to 1000. FLC and INC MPPT algorithm has a mean value of 91.57 and 86.43. The standard deviation of both the algorithms is almost the same 4.117.

Table 4 exhibits Independent Sample T test for the two groups and observed that Output voltage as (t = 2.337) & Mean Difference =5.143) and it having the same standard error difference is 2.2001. There is a significance difference between two groups is (mean difference is 5.143).

Table 4. Independent sample T-test t is performed for the two groups for significance and standard error determination. P value is less than 0.05 and it is considered to be statistically significant

Independent Sample Test									
		Levene's test for equality of variance				t-test for Equality of Means		95% Confidence Interval of the Difference	
		F	Sig	t	df	Sig (2-failed)	Mean Difference	Std.Error Difference	Lower	Upper
Efficiency	Equal variances assumed	.017	.898	2.337	12	.038	5.143	2.201	.348	9.938
	Equal variances not assumed			2.337	12.000	.038	5.143	2.201	.348	9.938

Comparative graph of INC and FLC algorithm. Comparison on efficiency of FLC is computed with INC. FLC produces better efficiency of 97.6 % (appr) compared to INC which has efficiency of 94% (appr) (Fig.7).

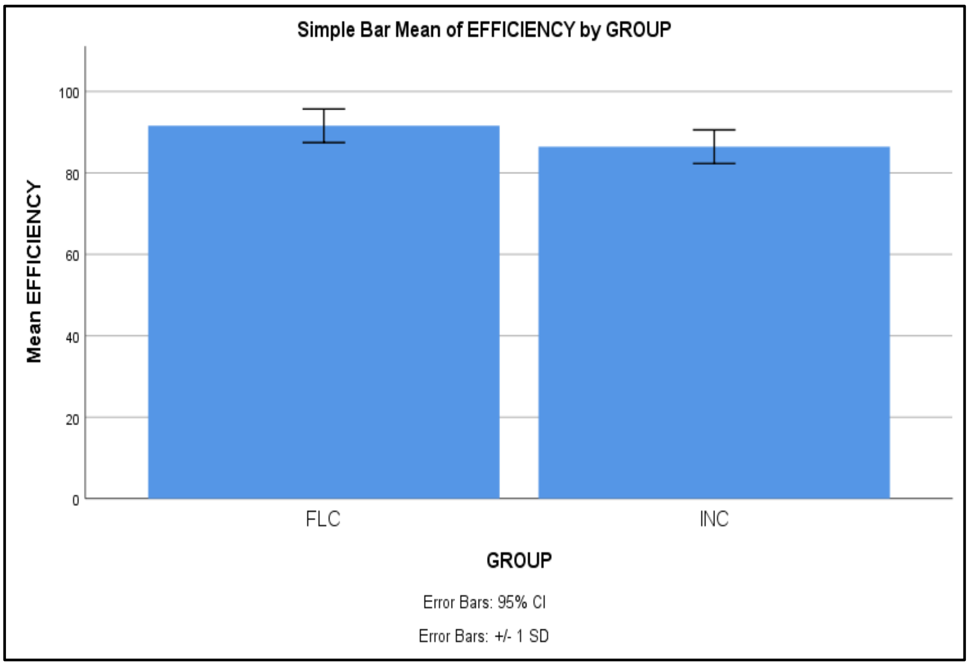

Fig. 8. Comparison of INC and FLC controller in terms of mean efficiency the mean efficiency of FLC is better than INC controller and the standard deviation of FLC is better than INC. X Axis: FLC Vs INC controller Y Axis: Mean output voltage of detection ± 1 SD

Discussions

INC and FLC algorithm is implemented and its peak power tracking efficiency is analysed and compared. From the obtained results it infers that FLC provides better efficiency compared to the INC algorithm.

Based on the previous literature study, the comparative analysis of PO, INC and FLC MPPT techniques have been carried out and it is found that FLC (0.5s to 1sec less oscillations) produces better efficiency based on maximum power extraction (Djalab et al. 2018; Guruambeth and Ramabadran 2016; Al-Gizi and Al-Chlaihawi 2016; Bataineh 2018). PO and FLC based GMPP algorithm is carried out and its performance is analyzed based on tracking time and efficiency which infers that FLC (0.1% THD) provides better results than PO (0.4% THD) MPPT ((Djalab et al. 2018;

Guruambeth and Ramabadran 2016; Al-Gizi and Al-Chlaihawi 2016; Bataineh 2018)). The comparative analysis of three MPPT algorithms is carried out under uniform and varying atmospheric conditions and its performance is analysed for different duty cycles based on accuracy and steady state response. It is found that FLC (150 W) provides better results based on power extraction compared to PO (146-148 W) and INC (148.5W) MPPT algorithm ((Djalab et al. 2018; Guruambeth and Ramabadran 2016; Al-Gizi and Al-Chlaihawi 2016; Bataineh 2018). Fuzzy logic and conventional PO algorithm is implemented in three different conditions such as uniform insolation, sudden variation and partial shading condition and its performance is analysed which results that FLC provides superior results over other algorithms ((Djalab et al. 2018; Guruambeth and Ramabadran 2016; Al-Gizi and Al-Chlaihawi 2016; Bataineh 2018).

Hybrid algorithm along with a P&O method is implemented in the PV system. Hybrid algorithm is combination of Cauchy preferential crossover (CC) with the flower pollination algorithm (FPA). The performance is analysed under partial shaded condition which provides better efficiency in the proposed system (99.6 %) over FLC method (94%) (Sundararaj et al. 2020; Phan, Lai, and Lin 2020)). Novel FLC mppt is implemented with adding one more input variable beta which may reduce the dependency of user knowledge and complicated rules. Because of this reason the proposed FLC (5.83 %) provides better tracking efficiency compared to conventional FLC (3.21%) methods (Sundararaj et al. 2020; Phan, Lai, and Lin 2020).

From the overall literature study, few papers cite that the novel MPPT technique provides better efficiency compared to the FLC algorithm. So we can infer that FLC MPPT can be implemented in tracking global peak power with high efficiency under varying climatic 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 changes in the step size parameters the tracking of peak power is not accurate. The oscillation around the peak power is still a changeling factor due to changes in the duty cycle value. Because of the complexity in the rule base using membership function the tracking time is also a bit high. Power loss is due to fluctuations in the load which may damage the system.

To report the above limitations a novel MPPT technique can be implemented to trace global peak power efficiently with minimum oscillation, high accuracy, low power loss and less tracking time by improvising the non linearity condition, complexity in membership function, rule optimization.

Conclusion

Based on the obtained results the FLC MPP algorithm provides 91% efficiency compared to the INC algorithm which results in 85% efficiency.

Declarations

Conflict of Interests

No conflict of Interest in this Manuscript

Author Contributions

Author RRP was involved in data collection, data analysis, and manuscript writing. Author RG was involved in data validation and review of manuscripts.

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