

SCA Based Interval Type-2 Fuzzy PID Controller for Solar MPPT



Raj Kumar Sahu, Binod Shaw, Jyoti Ranjan Nayak

Abstract: In this publication section, novel interval type-2 fuzzy-PID controller (T2FPID) based Maximum Power Point Tracking (MPPT) is implemented in proposed a standalone photovoltaic (PV) system, type-1 fuzzy-PID controller (FPID), and PID controller with strategic control of online set point tracking in association with DC-DC boost converter is enforced in PV system to track maximum power point (MPP) in solar PV system is depicted. The opted controllers are appropriately composed by picking sine-cosine (SCA) algorithm. The proposed T2FPID based MPPT technique is espoused to dig out maximum power under certain circumstances of temperature and irradiance. System performance is enhanced by the act of T2FPID controller. The maximum output power, voltage & current, duty cycle for DC-DC boost converter is relevantly controlled by the novel T2FPID controller tuned by SCA algorithm. The T2FPID based MPPT technique is authenticated by comparing it by P&O based technique. Finally, it is scrutinized that, the supremacy of intended controller is proved over conventional P&O technique, conventional PID & T1FPID controller; conceding the oscillation, time response, settling time and maximum values of voltage, current & power of the solar system. Robustness analysis is performed by varying the irradiance and temperature partly keeping one parameter constant. The proposed work is further validated on OPAL RT system.

Keywords : Fuzzy Logic controller (FLC), Photo Voltaic system (PV), Sine-Cosine algorithm (SCA), Type-2 FLC (T2FLC).

I. INTRODUCTION

At present era meeting the world's power demand through conventional energy sources are believed to reach the expectation demand level in a very low extent. So, for a durable and a viable supply of energy, it is indispensable to make use of and consume the non-conventional sources of well-built scale. Due to the enormous amount of availability of non-conventional sources among which the solar photo-voltaic is anticipated to be the major well-known in terms of large quantity and low maintenance. In the era of future energy mix solar photovoltaic (PV) is predicted to be an imperative part in the energy world. Though it is a less polluted it fuels up the "cleanliness mission" of some

developing country. But the main encumbrance of solar energy is going prevalent, due to its preliminary soaring capital cost of solar modules. However, the approach to hike the efficiency of energy conversion (solar to electrical) is on its own constraints. Though energy conversion is very low, dignifies for a fairly vast surface to produce power. In power generation through PV cells silicon semiconductor materials plays a vital role but its physical limitation forces to think about the efficiency of system, but nowadays new and more bizzare semiconductor materials for PV is expressed in [1,2]. So, MPPT is a vital ingredient in the PV system that ensures power conversion of the solar array. It minimizes oscillations due to varying weather condition. Many researchers have implemented the strategies and controlling effect of solar cell by increasing its efficiency by enhancing MPPT techniques. In ref [3] 19 different MPPT techniques are demonstrated. AI-Diab et al. [4] suggested the variable step size of P&O, tuned automatically. Subudhi & Pradhan in [5] depicted a comparative study for PV system on MPPT. Meza et al. [6] revealed the energy can be balanced through single phase grid inverters. Salhi & Bachtiri [7] proposed PI control strategy. GA optimized PI controller has been demonstrated in ref. [8]. In ref [9] Hui & Sun, offered a dual mode adaptive fuzzy controlled by conventional PID for voltage regulation of boost converter. Beshar & Adyl [10] have illustrated ACO based PI controller for MPPT. Kumari et al. [11] described the MPPT for PV system of short circuit current. In ref [12] ANN was implemented for PV system of short circuit current. In ref [12], ANN was implemented for PV supplied DC motors. Karanjkar et al. [13], implemented novel fuzzy adaptive PID control strategy in solar photo voltaic system. Satish & Mahesh [14] represented a short circuit current (Isc) based adaptive perturb to extort the maximum power from PV panel under precipitous swift of irradiance. Garcia et al. [15] depicted a novel scheme to model solar modules based on symmetric switched Gompert & functions. Ahmed & Salam [16] demonstrated an approach to shorten the steady state oscillation & to moderate the anticipation of falling the tracking diversion. In ref [17-18], adaptive fuzzy-PI controller is implemented as MPPT & the role of climate change on PV module. Elgendy et al. [19] revealed the energy exploitation competence of commercial photo voltaic pumping systems can be drastically improved by utilizing uncomplicated perturb. Ahmed & Salam [20] proposed an approach to enhance the proficiency of the P&O MPPT by diminishing the steady state oscillation and by diminishing the probability of algorithm to fail to detect its tracking direction. In reference [21], authors have deployed the traditional P&O MPPT scheme under augment solar irradiation condition & its deeds beneath revolutionized load condition.

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* Correspondence Author

Raj Kumar Sahu*, Department of Electrical Engineering, National Institute of Technology, Raipur, India.. Email: rajkumarsao@gmail.com

Binod Shaw, Department of Electrical Engineering, National Institute of Technology, Raipur, India.. Email: binodshaw2000@gmail.com

Jyoti Ranjan Nayak Department of Electrical Engineering, National Institute of Technology, Raipur, India. Email: bapi.jyoti.2@gmail.com

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Sahu & Shaw [22] depicted a strive approach by enforcing ALO optimized PID based MPPT controller. Nayak et al. [23] have suggested adaptive–SOS tuned T2FPID controller in AGC. The research editorial transacts with the construction and functioning of T2FPID, T1FPID, and PID controller to perk up over P&O technique. A DC-DC converter conducts as a crossing point to achieve MPP by altering the gate signal of boost converter. To extract maximum power a lately expanded optimization technique, SCA is enforced to T2FPID controller to come across the gain constraints. The SCA based T2FPID controller is compared to T1FPID, conventional PID along with conventional P&O technique. The proposed experiment was established on MATLAB/SIMULINK. A prototype hardware model is considered where four MPPT techniques are considered in standalone PV system using Real Time Simulation.

Main attributes of this editorial are as follows: -

- (i) Establishment of a boost converter in MATLAB climate.
- (ii) Design of T2FPID, T1FPID, & PID controller in MATLAB environment for the recommended model.
- (iii) Accomplishment of SCA algorithm
- (iv) Hardware set up for proposed MPPT technique in opal RT environment.

II. MODEL INVESTIGATED

As shown in Fig.1 an inverted diode along with current source can be connected in parallel with a typical solar cell. The existence of resistance in series connection is due to the interruption in the path of electron flow and the flow of leakage current in the circuit enhances to include a parallel resistance. Various types of PV modules can be in a series/parallel constitution to originate PV arrays.

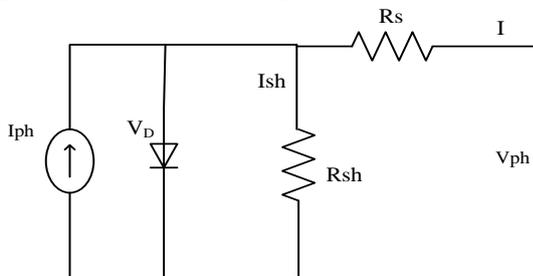


Fig.1. Equivalent circuit of solar cell [10].

Normally a series/parallel formation is present in a PV module. Voltage of the module increases for series configuration, whereas the increase of current is due to parallel connection. The non-linear characteristics nature of current-voltage (I-V) & power-voltage (P-V) characteristics of an emblematic solar cell, at a consistent temperature irradiation; shown in Fig.2.

The extent of the (I-V) curve fluctuates from short circuit current (I_{sc}) to open circuit voltage (V_{oc}). The constraint of I_{sc} is 6.14A and V_{oc} is 64.6V. The turn of phrase for output current of PV module can be conveyed as characterized in (1).

$$I = n_p I_{pv} - n_p I_0 \left[\exp\left(\frac{qV}{k T_a n_s}\right) - 1 \right] \quad (1)$$

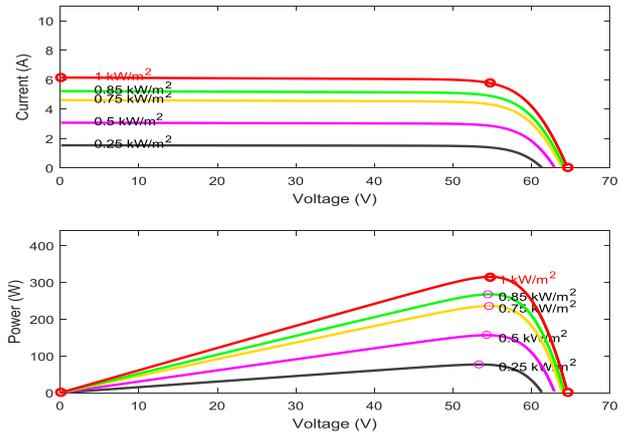


Fig.2. Irradiance and Temperature of applied in PV system.

Where, I , I_{pv} and I_0 are PV current, photo current and reverse saturation current respectively, n_p and n_s are cells in parallel and series connection, q is charge of electron ($1.6 \times 10^{-19} C$), k is Boltzmann's constant ($1.38 \times 10^{-23} J / K$), a -pn junction ideality factor ($1 < a < 2, a = 1$) being the idea value and T -PV module temperature.

The basic equation by inclusion of additional parameters of a practical PV module [25] is characterised in (2).

$$I = n_p I_{pv} - n_p I_0 \left[\exp\left(\frac{qV}{k T_a n_s}\right) - 1 \right] - \frac{V + R_s I}{R_p} \quad (2)$$

Where, V_t is the thermal voltage ($N_s kT / q$) of the module with n_s cells connected in series. R_s & R_p are corresponding series and parallel resistances. The value of series & parallel resistances are 0.43042Ω & 430.0559Ω respectively. Although in practical devices the value of series resistances is less and a parallel resistance is large, so $I_{sc} \approx I_{pv}$ is being widely used in PV modules. The PV current is depicted in (3).

$$I_{pv} = (I_{pv,n} + K_I (T - T_n)) \frac{S}{S_n} \quad (3)$$

Where, $I_{pv,n}$ is current of PV at ostensible condition ($25^\circ C$ and $1000W/m^2$), T and S are actual and nominal temperature and radiation respectively. 'n' depicts the nominal quantity. K_I is the temperature coefficient. Diode saturation current is characterized in (4) by conceding solar radiation and temperature.

$$I_0 = I_{0,n} \left[\frac{T_n}{T} \right]^3 \exp\left(\frac{qE_g}{ka} \left[\frac{1}{T_a} - \frac{1}{T} \right]\right) \quad (4)$$

Where E_g is the band gap energy of the semiconductor and

$I_{0,n}$ is the nominal saturation current as depicted in (5).

$$I_{0,n} = \frac{I_{sc,n}}{\exp(V_{oc,n} / \alpha V_{t,n}) - 1} \quad (5)$$

Where $V_{t,n}$ being the thermal voltage at the nominal temperature T_n . The short circuit current is equal to photo voltaic current.

The short circuit current I_{SC} of the PV module is not strappingly temperature reliant on rather it increases to some extent with an escalation in module temperature. The short circuit current can be established as in (6) [25].

$$I_{SC} = I_{SC,n} \left(\frac{S}{S_n} \right)^\alpha \quad (6)$$

Where $I_{SC,n}$ & I_{SC} are the short circuit current under normal irradiance & radiance respectively; α is the exponent responsible for all non-linear effects that the photo current depends on. The α can be determined mathematically as depicted in (7).

$$\alpha = \frac{\ln(I_{SC,n} / I_{SC,1})}{\ln(S_n / S_1)} \quad (7)$$

Where $I_{SC,n}$ & $I_{SC,1}$ are the short circuit currents of the PV module under radiation S_n and S_1 respectively.

The crucial intention to design a boost converter is to boost the output voltage of the dc system. The output of the converter is enormously persuaded by the switching frequency (gate pulse). The output of the converter may be characterized in equation (8)

$$V_{out} = \frac{1}{1-D} V_{in} \quad (8)$$

D is the duty cycle of the converter and is characterized in equation (9).

$$D = \frac{t_{on}}{t_{on} + t_{off}} \quad (9)$$

On time, and off time of the switch are expressed in equations (10) and (11) respectively by conceding switching period (T_s).

$$t_{on} = DT_s \quad (10)$$

$$t_{off} = (1-D)T_s \quad (11)$$

III.OPTIMAL DESIGN OF PROPOSED CONTROLLERS

Design and execution of T2FPID, T1FPID, and PID controller is presented in this article. Configuration of these proposed controllers are shown in Fig. 3-8. A brief narration of the opted controllers is conferred in sections III.1-III.3.

III.1 Conventional PID controller

The most familiar and competent industrial controller is the proportional, integral, and derivative (PID) controller shown in Fig. 3.(a) If 'e' is the error signal to be lessen by PID controller, its output in time domain and Laplace domain is depicted in (12) and (13).

$$u(t) = K_p e(t) + K_i \int e(t) dt + K_d \frac{de(t)}{dt} \quad (12)$$

$$U(s) = K_p E(s) + \frac{K_i}{s} E(s) + K_d s E(s) \quad (13)$$

II.2 Type-1 fuzzy-PID controller

Factors like fastness, robustness, simplicity a well as subsistence of preset aliance amid gains of PID controller beside performance of the system makes PID controllers are extensively preferred in process industries. On the other -

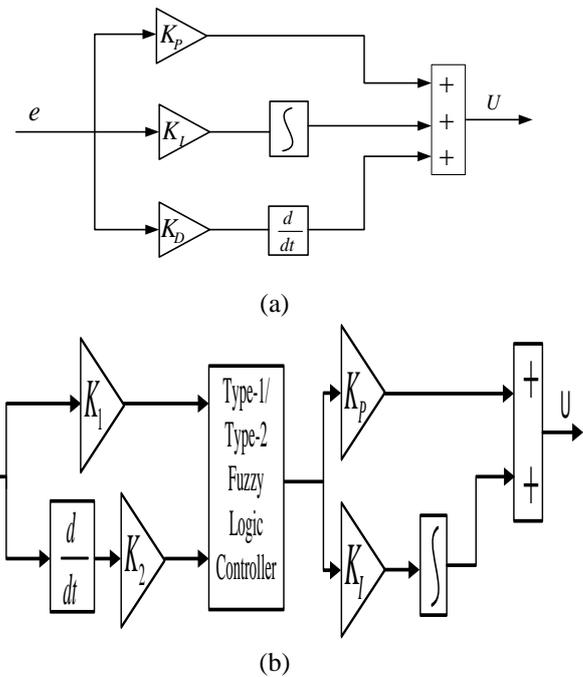


Fig.3. Proposed structure of controller, (a) Structure of PID controller and (b) Structure of T1FPID/T2FPID controllers [22].

hand, adaptation of PID controller is not appropriate and proficient for hugely obscured, nonlinear and time-variants plants having time delay. The expertise of human operator boosts up the response of the process/plant intactly equipped with PID controller. Sequentially to conquer the above teething troubles controllers enhances the relevance of fuzzy logic in diverse fields. Fuzzy logic controller (FLC) is a soft computing tool based on the perception of computing with words and affords a manner to compact with haziness.

Structure of a type-1/type-2 fuzzy-PID controller is illustrated as in Fig.3. (b). 'error' and 'Change in error' are adopted as input parameters for most of the FPID controller. In this study, triangular MFs are demonstrated for both the input and the output [22]. Five linguistic variables expressed in table1, are exploited for mutually input and output. Rule base of the FLC is tabulated in Table I. Progression of fuzzification and defuzzification is illustrated clearly as in Fig. 4 (a).

TABLE I
RULES ADOPTED FOR TYPE-1/2 FLC

e	Δe				
	HN	LN	Z	LP	HP
HN	HN	HN	LN	LN	Z
LN	HN	LN	LN	Z	LP
Z	LN	LN	Z	LP	LP
LP	LN	Z	LP	LP	HP
HP	Z	LP	HP	HP	HP

III.3 Type-2 fuzzy-PID controller

The basic of Type-2 FLC (T2FLC) is derived from the type-1 FLC. The incompetence of Type-1 FLC (T1FLC) to administer uncertainties of rules is the main purpose to introduce T2FLC in [27-29]. T2FLC is introduced to conquer the incompetence of T1FLC to administer the nonlinear information.

T1FLC membership functions (MFs) contribute two dimensional crisp values. The interval type-2 MFs are composed by blending two distinct MFs of T1FLC.

Upper MF (UMF) and Lower MF (LMF) are designed by adopting two different type-1 MFs in such a way to achieve the boundary between UMF and LMF entitled as Foot of Uncertainty (FOU). This FOU of T2FLC originates three dimensions (3-D) with higher degree of freedom to conduct uncertainty gracefully. The grade of fuzziness of input is enhanced by interval MFs of T2FLC. So interval type-2 fuzzy set enhances the fuzziness, which benefits the system to regulate the vague data in a sensibly strict form. Specified process associated in type-2 FLC is illustrated in Fig.4(c). Featured action of a type-2 FLC in block diagram form is publicized in Fig.4(d). The basic steps entailed in type-2 FLC are:

Fuzzifier: The inference and rule base elicit fuzzifier to transform these crisp inputs to 3-D interval type-2 fuzzy sets. The primary variable of T2FS 'A' by conceding MF $\mu_A(e, u)$ can be defined as in (14).

$$A = \{((e, u), \mu_A(e, u)) \mid \forall u \in J_e \subseteq [0,1]\} \quad (14)$$

'A' can be portrayed as in (15) for universe of discourse [29].

$$A = \int_{e \in X} \int_{u \in J_e \subseteq [0,1]} \frac{\mu_A(e, u)}{(e, u)} \quad (15)$$

Where 'e' and 'u' are the variables with domain 'X' and J_e respectively. $\int \int$ is the association of all permissible e and u [30]. FOU of the T2FS is originated by two distinct type-1 MFs entitled as UMF ($\mu_{\bar{A}}(e, u)$) and LMF ($\mu_{\underline{A}}(e, u)$). The UMF and LMF are characterized in (16) and (17).

$$\mu_{\bar{A}}(e, u) = \overline{FOU(A)} \quad \forall e \in X, \forall u \in J_e \subseteq [0,1] \quad (16)$$

$$\mu_{\underline{A}}(e, u) = \underline{FOU(A)} \quad \forall e \in X, \forall u \in J_e \subseteq [0,1] \quad (17)$$

Where J_e for T2FIS is

$$J_e = [\mu_{\underline{A}}(e, u), \mu_{\bar{A}}(e, u)] \quad \forall e \in X \quad \forall u \in J_e \subseteq [0,1]$$

In this work, e1 and e2 are considered as two inputs of T2FLC. The interval type-2 MF is illustrated in Fig.4 (b). The interval type-2 fuzzy sets adopted for this work are similar as type-1 FPID.

Knowledge Base: Rule base and inference engine are the two constraints for knowledge base as shown in Fig. 7. The rule base adopted for both T1FLC and T2FLC is depicted in Table I. In type-2 FIS, antecedents and consequent are characterized in (18) by interval type-2 fuzzy sets.

$$\underline{f}^n = \min(\mu_{\underline{A}^n}(e, u), \mu_{\underline{A}^n}(\Delta e, u))$$

$$\bar{f}^n = \min(\mu_{\bar{A}^n}(e, u), \mu_{\bar{A}^n}(\Delta e, u))$$

$$F^n = [\underline{f}^n, \bar{f}^n] \quad n = 1, 2, \dots, 25 \quad (18)$$

Type Reducer and Defuzzifier: The basic function of type reducer is to transform fuzzy sets from type-2 to type-1 fuzzy. Various approaches [22] are preferred to defuzzify the fuzzy data by many researchers for various engineering problems. Center of Sets (COS) is the highly adopted method among them.

$$Y_{COS} = \frac{\sum_{n=1}^{25} F^n Y^n}{\sum_{n=1}^{25} F^n} = [y_l, y_r] \quad (19)$$

$$y_l = \frac{\sum_{n=1}^{25} \underline{f}^n y^n}{\sum_{n=1}^{25} \underline{f}^n}, \quad y_r = \frac{\sum_{n=1}^{25} \bar{f}^n y^n}{\sum_{n=1}^{25} \bar{f}^n} \quad (20)$$

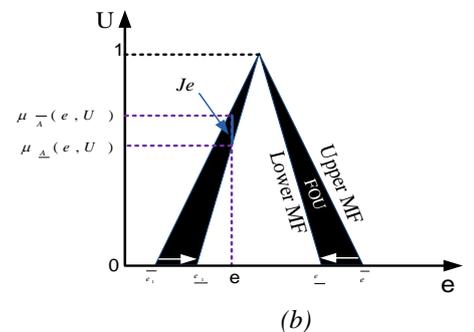
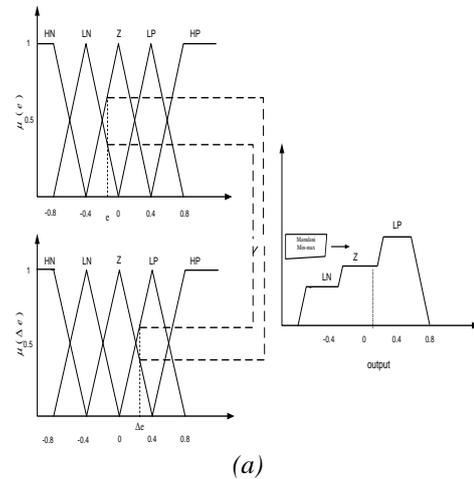
Where 'y_l' and 'y_r' are the solutions of LMF and UMF fuzzy sets respectively. This approach converts type-2 MF output into two distinct type-1 MFs (y_l and y_r) as depicted in (20).

The average of y_l and y_r (y) as characterized in (21) is the crisp output of T2FLC which considered as input of PI controller. The details of operation of T2FLC are illustrated in Figure 8. The output can be determined as: -

$$y = \frac{y_l + y_r}{2} \quad (21)$$

III.4 Type-2 Fuzzy-PID based MPPT Controller

Tracking maximizes power from the PV module with due concern of array voltage and power is the prime intention of a MPPT technique. As rendered in this article of Fig.5 reference voltage (V_{ref}) is developed by the correlation of instant power (P_K). The error signal accomplished by evaluating reference voltage with output voltage of boost converter is nourished to the T2FPID controller. To augment the power of the solar cell the output of T2FPID controller is utilized as gate pulse of the switch.



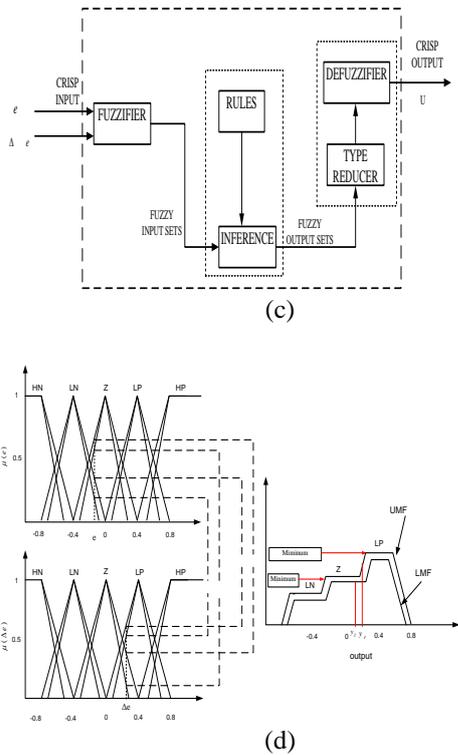


Fig.4. Process of Type -1 and Type -2 FLC,(a)Process of fuzzification and defuzzification in a type-1 FLC,(b) Structure of a type-2 fuzzy set MF,(c) Type-2 FLC block diagram and (d) Various steps involved in type-2 FLC [22].

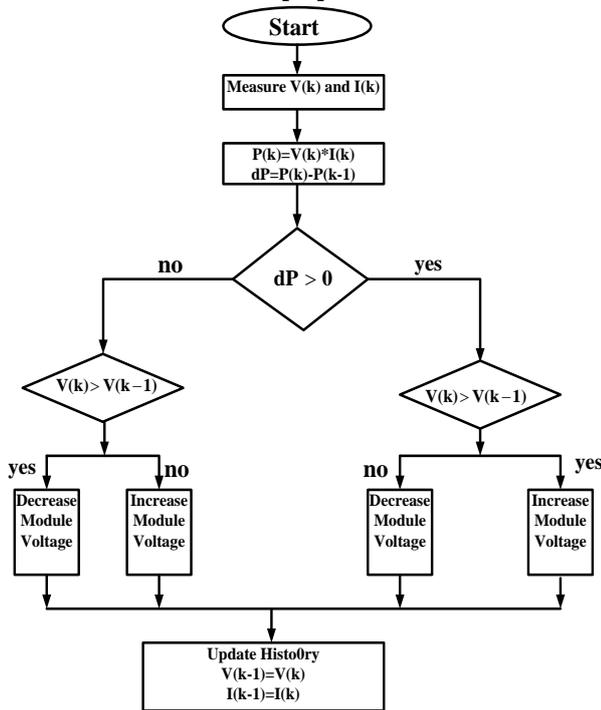


Fig.5. P and O algorithm to calculate Vref.

III. SINE COSINE ALGORITHM

Development of optimization techniques creates an environment for researchers to apply it on the conventional working problems. Optimization is a mechanism or a progression where optimal values for the constraints are uncovered. Over precedent years a nurturing curiosity has

been scrutinized in a move towards stochastic optimization [31]. Problems in optimization algorithms deems as black boxes [32], mean the derivation of mathematical models is not essential, as the paradigms only change inputs & monitors output. Classification of stochastic optimization algorithms based on inspiration and no. of random solutions. Despite noteworthy numeral of lately proposed algorithms in this field an elemental problem arises, why we need more techniques. In No free lunch theorem (NFL), it is sensibly proved that no can propose an algorithm for solving all optimization problems. Uncomplicated mathematical functions illustrate that it can be exploited to intend optimization algorithms in this field, notably by the algorithm. Sine & Cosine is exploited amid two resolutions to explore and exploit in search space. Crepinsek et al. [33] illustrated about the universal factor of exploration and exploitation. Random solutions are combined in the former phase. Steady variations in the random outcomes and randomly variations are noticeably a reduced amount in the last phase. In this algorithm, the following updating equations are proposed as characterized in (22) and (23).

$$\mu_i^{t+1} = \mu_i^t + r_1 \times \sin(r_2) \times |r_3 \gamma_i^t - \mu_i^t|$$

$$(22) \mu_i^{t+1} = \mu_i^t + r_1 \times \cos(r_2) \times |r_3 \gamma_i^t - \mu_i^t| \quad (23)$$

where μ_i^t is the location of the existing resolution in i_{th} dimension at the i_{th} iteration; $r_1 / r_2 / r_3$ are random numbers, γ_i is site of the objective element in i_{th} dimension and point outs fixed value.

These two equations are combined as follows:

$$\mu_i^{t+1} = \begin{cases} \mu_i^t + r_1 \times \sin(r_2) \times |r_3 \gamma_i^t - \mu_i^t| & 0.5 < r_4 \leq 0.5 \\ \mu_i^t + r_1 \times \cos(r_2) \times |r_3 \gamma_i^t - \mu_i^t| & \end{cases} \quad (24)$$

The above mentioned equations shows, $r_1 / r_2 / r_3$ & r_4 are four main strictures in SCA. The parameter r_1 dictates the subsequent position province or faction route that is moreover in space of destination or outside it. The movement should be en route for or away from the destination is characterized by r_2 . In defining distance r_3 fetches a random weight for the target. Amid sine & cosine r_4 toggles uniformly as in (24).

The utilize of sine and cosine in the codify it is named as sine-cosine algorithm. The cyclic prototype, sine-cosine function allocates a resolution to be re-positioned in the region of an additional solution. The random locations pattern likewise in the interior or exterior is attained by defining a random number for r_2 in $[0,2\pi]$ in (24). So, his mechanism exploration and exploitation of search space respectively. The balance between exploration and exploitation is to hit upon promising provinces of search space and ultimately converge to the global optimum. $r1 = a - t \frac{a}{T}$, where t is the current iteration, T is maximum of iteration & a is the constant.

IV. RESULTS & DISCUSSIONS

A global optimization technique called Sine Cosine Algorithm (SCA) is autonomously exhibited to tune the gains of Type2 Fuzzy PID (T2FPID), Type1 Fuzzy PID (T1FPID) & conventional PID controllers. Design parameters of abovementioned controller are specified within a range of $0.001 \leq K_p, K_I$ and $K_D \leq 2$. Population sizes along with maximum number of iterations are taken as 50. Optimal gains of controller are represented in Table II.

TABLE II
OPTIMAL GAIN PARAMETERS OF CONTROLLERS

Controller	K_1	K_2	K_3	K_4
T2FPID	0.0017	0.9906	0.0014	2.0000
T1FPID	0.0187	1.3435	1.8097	1.1453
PID	K_p	K_I	K_D	
	1.2218	0.0100	0.0100	

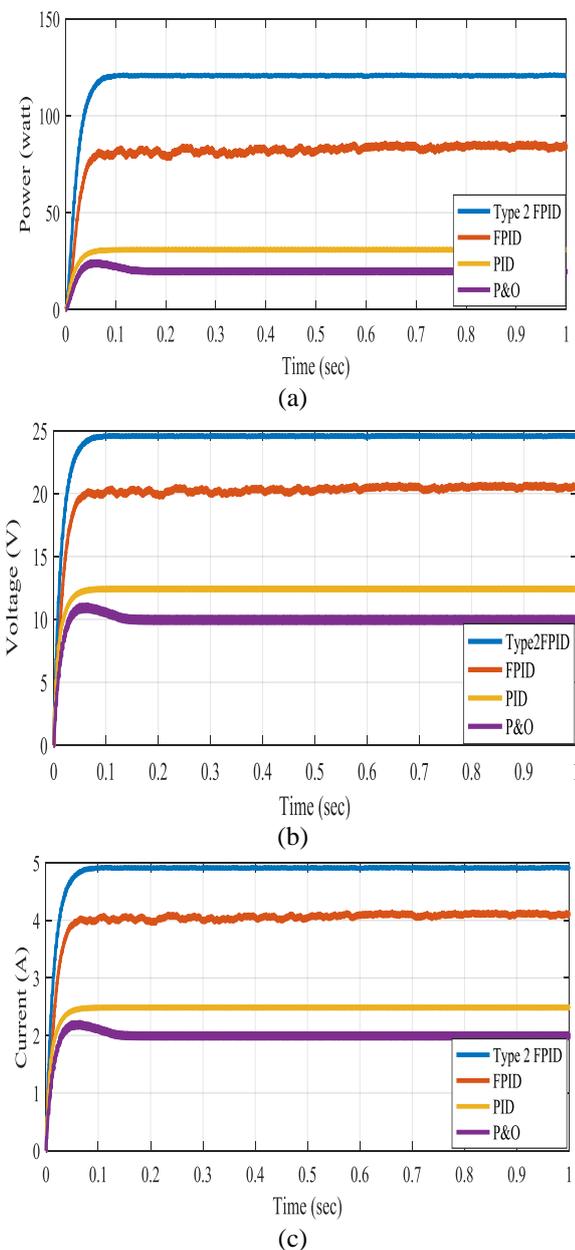


Fig. 6. Response of Fixed irradiance and Temperature. (a) Power Response, (b) Voltage response and (c) Current response.

The objective function of the controller optimized by SCA algorithm is to maximize power, voltage & current with respect to time. Dynamic performance of solar system with various controller optimized by ‘SCA’ algorithm in terms of power, voltage & current is given in Table III. Fig. 6 (a)-(c) depicts the transient response of output power, voltage & current respectively. The optimized optimal controller gains are taken into account to figure out maximum power, voltage & current with fixed irradiance (1000) as well as fixed temperature (25°C).

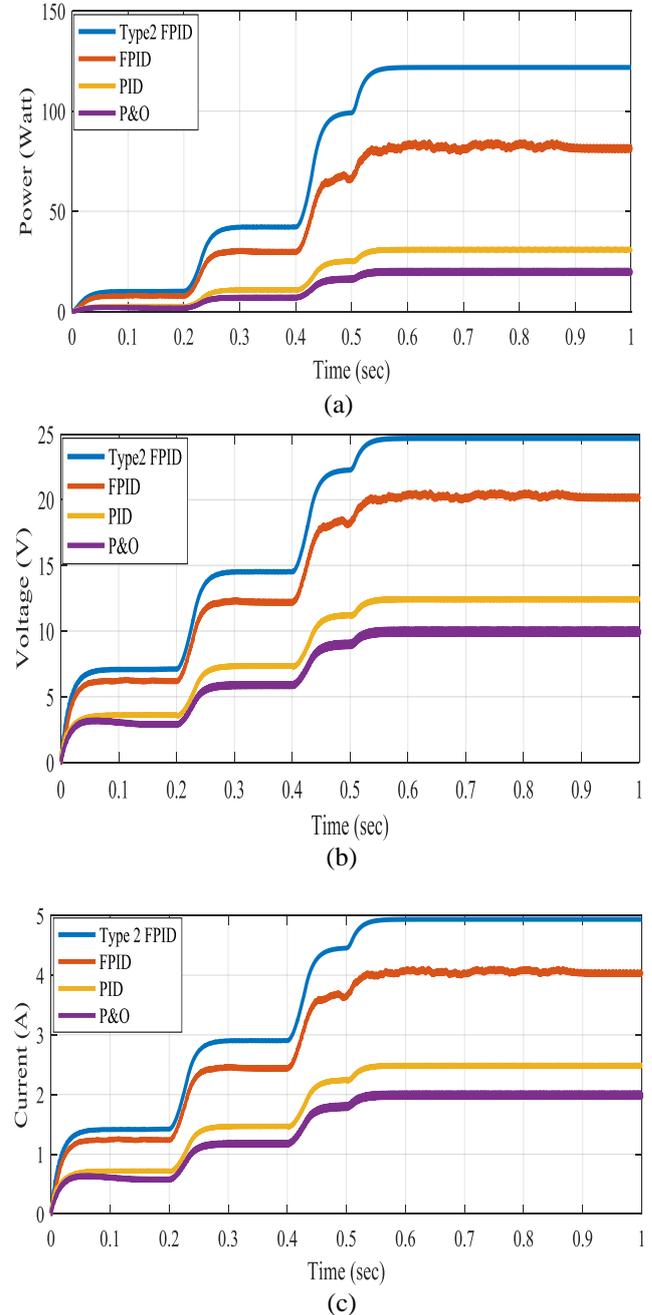


Fig.7. Response of Variable Irradiance of 1000W/m² with Constant Temperature. (a) Power Response, (b) Voltage response and (c) Current response.

V.1 Transient response in different environment

In the previous section, description about the solar system optimized by SCA algorithm with various controllers named as T2FPID, T1FPID, and conventional PID & P&O is provided.

Supremacy of T2FPID optimal controller is obtained over other controllers. Maximized power, voltage & current are obtained with T2FPID controller of 121W, 24.58V & 4.912A respectively, for T1FPID optimal controller power, voltage & current are 86.24W, 20.73V & 4.14A as well as for conventional PID power, voltage & current are 30.6W, 12.37V & 2.4789A and finally for P&O the parameters are 20.6W, 10.16V & 2.031A. The supremacy of T2FPID controller is clearly depicted in terms of maximum power, voltage & current over other controllers. Robustness analysis is performed for T2FPID controller gains in a different environment with a variable temperature of 25°C with constant irradiance as well as variable irradiance of 1000W/m² with constant temperature.

V.2 Variable Irradiance of 1000W/m² with Constant Temperature

TABLE III
PERFORMANCE RESPONSE OF OUTPUT

Parameters	Maximum				Settling Time			
	T2FPID	T1FPID	PID	P&O	T2 FPID	FPID	PID	P&O
Power	121	86.24	30.6	20.6	0.045	0.048	0.05	0.1223
Voltage	24.58	20.73	12.37	10.16	0.04	0.035	0.04	0.1124
Current	4.912	4.14	2.479	2.031	0.038	0.032	0.02	0.1023

From Fig. 8 (b)-(d) it is seen that the output response of power, voltage & current obtained in OPAL RT system approximately matches the Simulink results of power, voltage & current. The scaling factors of the transient response in OPAL RT system for power, voltage & current are depicted in Table IV-VI.

At fixed temperature of 25°C at time [0 0.2 0.4 0.5 0.7], irradiance determined are [250 500 750 850 1000]. The below mentioned Fig. 7 (a)-(c) are of power, voltage & current with variable irradiance & fixed temperature. The below depicted Fig. 7 (a)-(c) shows that the amount of power, voltage & current has no change in its magnitude even if there is a variation in parameter of irradiance.

V.3 Validation of proposed work

In this work, four MPPT techniques are implemented in standalone PV system. These systems validated using Real Time Simulation OPAL RT OP5600 in order to calculate the efficiency of solar system, an OPAL RT setup as shown in Fig. 8(a). Some primary preparation is required before using the Simulink model in OPAL RT. System should be divide in two sub systems are Master subsystem (SM_System) and



(a)



(b)



(c)



(d)

Fig.8. OPAL RT system setup and response, (a) PV system with OPAL RT OP5600 setup, (b) Power response, (c) Voltage response and (d) Current response.

TABLE IV

SCALING PARAMETER FOR POWER RESPONSE IN OPAL RT SYSTEM.

Colour	Controller	Power per division	Time per division	Simulation Output
Yellow	Type 2 FPID	20	500ms	121.8 W
Blue	FPID	20		82.16 W
Purple	PID	20		30.88 W

TABLE V

SCALING PARAMETER FOR VOLTAGE RESPONSE IN OPAL RT SYSTEM

Colour	Controller	Voltage per division	Time per division	Simulation Output
Yellow	Type 2 FPID	10	500ms	24.68 V
Blue	Type 1FPID	10		20.27 V
Purple	PID	10		12.45 V

TABLE VI

SCALING PARAMETER FOR CURRENT RESPONSE IN OPAL RT SYSTEM.

Colour	Controller	Current per division	Time per division	Simulation Output
Yellow	Type 2 FPID	1	500ms	4.936 A
Blue	Fuzzy PID	1		4.054 A
Purple	PID	1		2.489 A

VI. CONCLUSION

In this paper, two novel exertions have been put into action to enhance the efficiency of the solar system by implementing a type-2 Fuzzy-PID based MPPT scheme. To augment the efficiency of the solar system, controller designs, as well as assortment expedient algorithm, are the two vital factors. A novel type-2 Fuzzy-PID controller is implemented for the first time in PV solar system and other two controllers like Type1-FPID, conventional PID are used to validate the supremacy of T2FPID controller. The T2FPID based MPPT controller is also authenticated over P&O of the solar system. The optimal constraints of the proposed controller are optimized by SCA algorithm. Irradiance & temperature are the crucial factors which persuade the power, voltage &

current of the solar cell. The T2FPID based MPPT controller is executed by varying the irradiance (1000W/m²) and temperature (25 °C). The output voltage is enormously influenced by the duty cycle of the gate pulse. The SCA optimized Type2 FPID based MPPT technique is authenticated over P&O technique to achieve maximum power, voltage & current along with minimum settling time. The recommended work is authenticated by OPAL RT system which exploits that the output response of power, voltage & current obtained in OPAL RT system approximately matches the Simulink results of power, voltage & current.

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of Technology, Raipur, India. His current research interests include power system optimization, power system stability and power system control.

AUTHORS PROFILE



Raj Kumar Sahu, B.E. (ECE) from NIT Bhopal, India in 2004. M. Tech. (DE) from C.S.V.T.U Bhilai in 2009. and presently pursuing Ph. D. in electrical engineering from NIT Raipur, India. His present research area is renewable energy and artificial intelligence technique.



Binod Shaw received the Ph.D. degree in electrical engineering from the Indian Institute of Technology (ISM), Dhanbad, Jharkhand, India. He is currently working as an Assistant Professor with the Department of

Electrical Engineering, National Institute of Technology, Raipur, India. His research interests include Power system control, optimization techniques, renewable energy systems and application of AI in RES.



Jyoti Ranjan Nayak, received the B.Tech. degree in electrical engineering from Siksha 'O' Anusandhan University, Bhubaneswar, India, in 2012 and the M.Tech. degree in power system and power electronics engineering from Siksha 'O' Anusandhan University, Bhubaneswar, India, in 2015. He is currently working

toward the Ph.D. degree in electrical engineering with the National Institute