Swarm Algorithm for the System of Maximum Power Point Tracking

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Abstract— A novel model-free solution algorithm, swarm algorithm for efficiently solving the maximum power point tracking (MPPT) problem of PV systems under partial shading conditions. A PV system which controls the power generation with its operating voltage is considered. A swarm algorithm (SA) model is incorporated into the iterative search process to guide the update of candidate solutions (operating voltage settings) in the SA and such extension is capable of improving the tracking performance. Simulation studies and experiments are conducted to validate the effectiveness of the proposed SA algorithm for better addressing PV MPPT problems considering a variety of partial shading conditions. The performance of the proposed algorithm is benchmarked against the JAYA and the particle swarm optimization (PSO), which has been widely considered in the model-free MPPT, to demonstrate its advantages. Results of simulation studies and experiments demonstrate that the SA algorithm converges faster and provides a higher overall tracking efficiency.

Key words: Boost Converter, Maximum Power Point Tracking, Swarm Algorithm, PV Modelling

I. INTRODUCTION

The application of photovoltaic (PV) has achieved an exponential rise for past two decades from off- grid to grid connected PV systems. The electric energy produced by the PV array can be utilized in the best way by delivering it directly to utility grid, without using storage system (battery banks) [1]. The performance analysis of newly developed systems requires mathematical functional models for PV module research. Field professionals do not readily adopt these developed systems for minimising failure rate. Therefore, it requires simplified Simulink modelling of PV module for analysis purpose. In the literature [2–11] basic structure of single diode PV system have been represented. For adjusting the *I-V* curve by using artificial intelligence [12, 13] some authors have put forward some indirect methods. Although interesting but these methods are complex, inapplicable and needs more calculation. Modelling was confined to PV module characteristics simulation in all the above. The mathematical expressions determining the PV module (as well as PV cell) are also represented. For each expression, Simulink model is represented with numerical results for constant irradiation values (1000W/m^2) and temperature. When building a new photovoltaic power system it is very important to consider maximum power point tracking (MPPT) as it is required for extraction of maximum power output from a PV array under varying atmospheric conditions for maximum power output. Many researchers and industry delegates from all over the worldhave developed several MPPT algorithms. Some of these algorithm like perturbation and observation(P&O) method, fuzzy logic control method, linear approximation method, incremental conductance method, voltage feedback method, hill climbing method, actual measurement method and so on [14-15]. Appropriate MPPT method alongwith good weather conditions are required for implementing maximum performance of a photovoltaic system [9-11]. This paper mainly focuses on studying and comparing execution efficiency, advantages, disadvantages for two power-feedback type MPPT methods, including jaya algorithm and swarm logic (FL) methods. For implementation of modelling and simulations tasks, and to compare execution efficiency and accuracy for selected MPPT methods Matlab/Simulink is used in this paper.

II. DESIGNING OF PV MODULE

A. *Equivalent Circuit*

Figure 1 represents a single diode model which is widely used as compared to other PV module design. In this circuit, R_{sh} is shunt resistance, I is open circuit current of a solar cell, I_o is diode saturation current, I_{ph} is the light-generated current which depends upon solar radiation and cell temperature, I_{sh} is shunt resistance current which flows through R_{sh} and flows between the n and p layers, R_{se} is series resistance which represents the losses due to flowing current across highly resistive emitter and contacts, V_{oc} is terminal voltage of a solar cell, respectively.

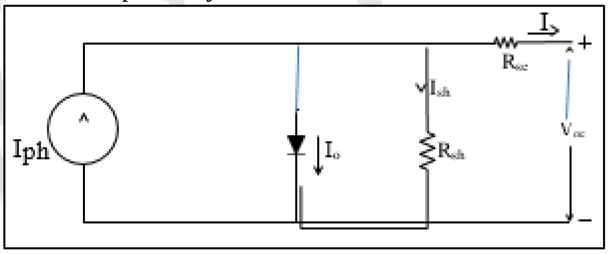


Fig. 1: Solar cell equivalent circuit

In this circuit the mathematical expression for cell current in single diode model is obtained by applying KCL,

$I = I_{ph} - I_o - I_{sh}$ (1) Where,

$$I_{ph} = [I_{sc} + K_i (T_k - T)] * G/1000 \quad (2)$$

I_{ph} is photocurrent under standard test conditions (STC), with reference solar radiation of 1000 W/m^2 at solar spectrum of 1.5*A* and reference temperature of solar cell T_k of 25°C. T is instantaneous solar cell temperature, K_i is current temperature coefficient *and* G is an instantaneous solar radiation.

B. *Module Reverse Saturation Current (Irs)*

Module reverse saturation current, I_{rs}, is expressed as,

$$I_{rs} = I_{sc} / [\exp (q * V_{oc} / N_s * k * A * T) - 1] \quad (3)$$

Where q is the electron charge (1.6 × 10−19 C), V_{oc} is Solar module open-circuit voltage (21.24V), N_s is the number of cells connected in series (36), A is the ideality factor (A=1.6). and k is the Boltzmann constant (k= 1.3805 × 10^{-23} J/K).

C. *Module Saturation Current (I0)*

Variation of module saturation current I_0 takes place with respect to cell temperature. It is expressed as, $I_0 = I_{rs} [T/T_r]^3 * \exp [q * E_{g0} / A k * \{(1/T_r) - (1/T)\}]$ (4) Where E_{g0} is the band gap energy of semiconductor (For polycrystalline Si at 25○C, $Eg0$=1.1 eV). Simulation of equation (4) has been done and represented in Figure 4. Here, the inputs are module reverse saturation current, module operating temperature and reference temperature.

D. Module Output Current (IPV)

The PV module output current of single diode model is IPV represented in Figure 1 is described by a basic equation and is expressed as,

$$Ipv=Np*Iph-Np*I0\ [exp\ \{q*(Vpv+Ipv*Rse)*Ns*A*k*T-1] \quad (5)$$

E. Simulink Model of IPV

Inputs for this model are insolation, V_{PV} is Varied from 0 to 21.5V. With the help of setup shown in Fig. 5, simulink model of I_{PV} is simulated.

To get the *I-V* and *P-V* characteristics of I_{pv} model under varying irradiation with constant temperature and constant irradiation with varying temperature, simulation steps have been discussed in details.

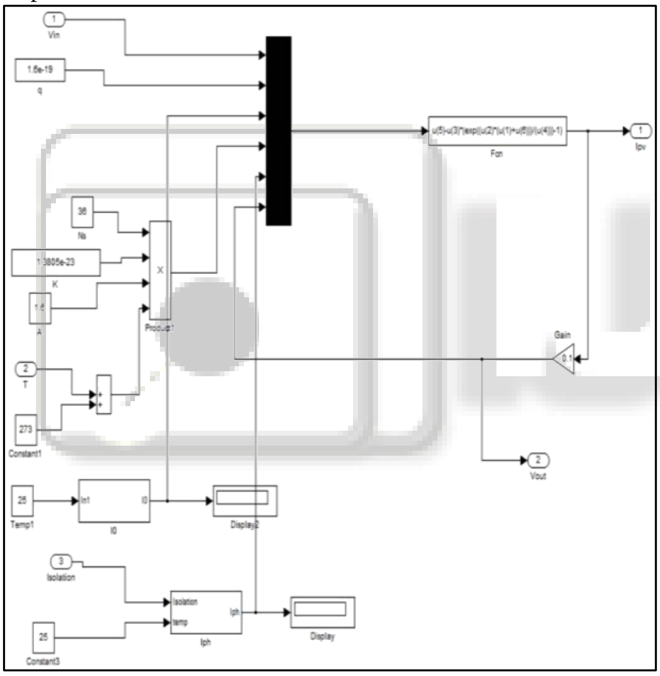


Fig. 2: Simulation Module output current I_{pv}

III. PV MAXIMUM POWER EXTRACTION SYSTEM DESIGN

The PV module output power changes significantly as there is variation in irradiation and temperature. To extract the maximum power of from solar photovoltaic module and transfer this power to the load, the maximum power point (MPPT) algorithm is used [15]. To transfer the maximum power of the PV module to the load, a DC-DC converter is used as shown in Figure 14, which acts as an interface between the load and the module. Here, step up/step down type DC-DC Converter is used. The load impedance as seen from source side is changed by varying the duty cycle of PWM control signal and hence it coincides with the maximum power point of the source to transfer the maximum power.

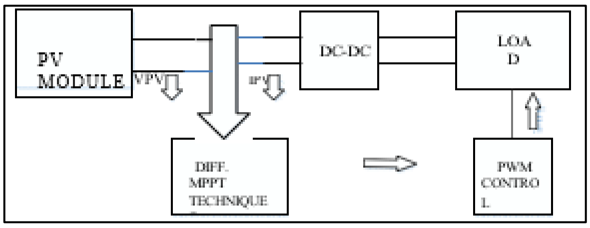


Fig. 3: Block diagram of the DC-DC converter for MPP operation

A. Power Electronic Circuit

To obtain the maximum performance of the maximum power point, PV modules are always used with DC-to-DC converters. Buck, boost, and buck-boost are types of converters used for this purpose. For grid-connected applications boost converter is used whereas buck-boost configuration is used for battery charging applications. Figure 4. represents the configuration of boost converter and it is composed of load resistance *R*, filter capacitor *C*, diode *D*, control switch *S*, boost inductor *L*, and DC input voltage source V_S.

The voltage gain of boost converter when switch operated with a duty ratio *D* is expressed as,

$$M_V= V_O/V_S= 1/1 - D \quad (6)$$

Where V_O is output voltage, V_S is input voltage, and *D* is duty cycle of PWM (pulse width modulation) signal and used to control ON and OFF states of MOSFET

Table 1. Electrical Parameters of 250W Panel

Description	Rating
Swtiching frequency	20 kHz
Power diode	1N5408
MOSFET	IRF P460
Capacitor	330 µF
Resistive Load	50fi, 50W
Inductor	120 µH

Table I: DC-To-DC Boost Converter Component Values

For value of inductance $L > L_b$, the operation of boost converter is in continuous conduction mode where,

$$L_b= (1 - D^2)\ DR/\ 2\ f \quad (7)$$

Where L_b is smallest inductance value required for continuous conduction. As current supplied to output RC circuit is discontinuous. Therefore, to limit the output ripple voltage a large filter capacitor is required. C_{min} is minimum value of filter capacitor. It supplies output DC current to the load when diode *D* is off. The smallest value of filter capacitance results in ripple voltage V_C *and it* is expressed as,

$$C_{min} = DV_O/\ V_rRF \quad (8)$$

Table 1 gives the DC-DC boost converter design component values which are used for simulation.

B. Design of MPPT

Figure 7 shows the DC-DC converter (with component values in Table.1andconfiguration given in Figure 4) simulation with battery supply. The solar cell has very low efficiency. Therefore, to boost the efficiency some methods are implemented to balance the source and load properly. Maximum Power Point Tracking (MPPT) method is one of the methods which are used to obtain the maximum possible power from a variable source. It is difficult to use photovoltaic systems to power certain load because the I-V curve in photovoltaic systems is non-linear. So boost converter is used and its duty cycle is varied by using a MPPT algorithm. By the help of simulation with developed circuit mode lthe data is collected for the design of MPPT. The results are represented in Table 2.

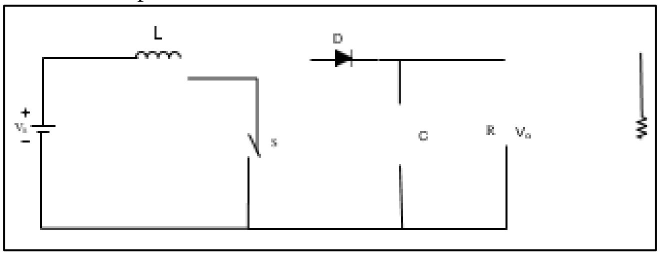


Fig. 4: DC to DC boost converter configuration

C. MPPT Methods

For maximum power point tracking many methods are used. Some of the methods are:

- Constant Current method
- Constant Voltage method
- Parasitic Capacitance method
- Incremental Conductance method
- Perturb and Observe method
- JAYA based algorithm method
- Swarm algorithm method

IV. DESIGN OF JAYA ALGORITHM FLOWCHART

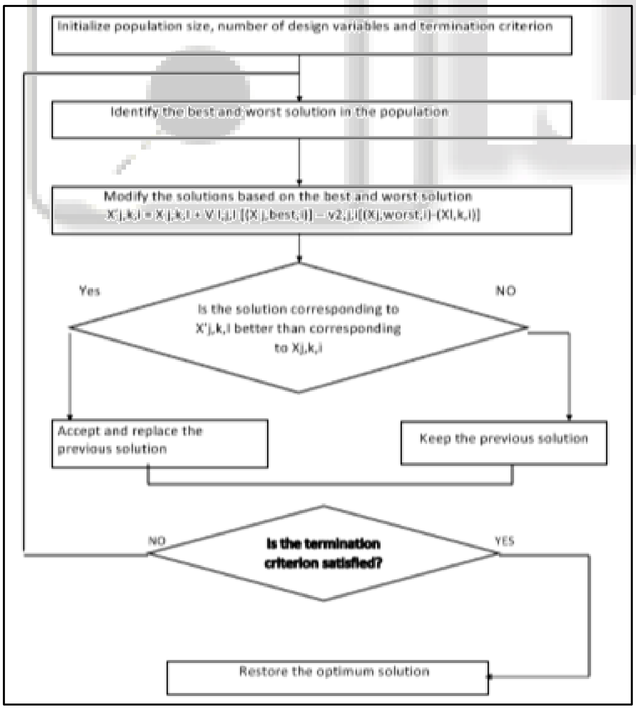


Fig. 5: MPPT jaya flowchart

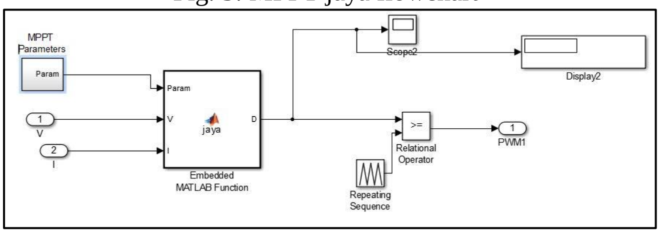


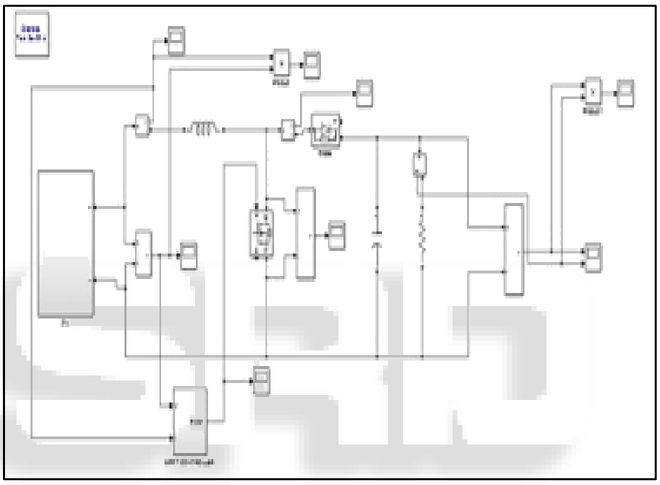
Fig. 6: Simulink model of Jaya algorithm

A. Jaya algorithm method

It is widely used method. Minimum sensors are used in this method. In this method, sampling of operating voltage is done and operating voltage is changed in a specific direction by using algorithm and therefore it samples dP / dV. The algorithm increases the voltage value towards MPP until dP / dV is negative if dP / dVis positive. This iteration continues until the algorithm arrives at MPP. When there is a large variation in solar irradiation then this algorithm is not suitable. The voltage perturbs around the maximum power point (MPP) and never actually reaches an exact value. The Jaya is deployed in the inverter to obtain the optimal voltage setting for MPPT through an efficient iterative interaction with the PV system.

MPPT algorithm based on Jaya provided higher tracking efficiency and required less iterations in the convergence compared with Perturb and observe method.

B. Simulation of Jaya MPPT



This article provides the guidelines to develop the Maximum Power Point Tracking controller, as developed in the automotive and aeronautical applications, this by following the V-cycle development process, which means that our controller will be validated by using Model In the Loop/ Software in the Loop/Processor in the Loop tests. In order to have the possibility of integrating the MPPT embedded software in automotive and aeronautical areas, and on the other hand to propose a low-cost option to test the hardware implementation of the MPPT algorithm. Therefore, a novel and new JAYA algorithm is proposed in this study which increases the tracking speed under sudden irradiance

C. Result

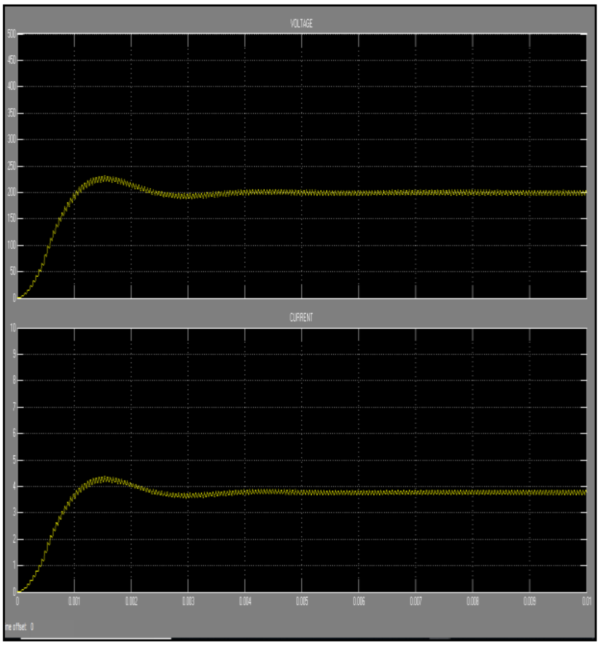
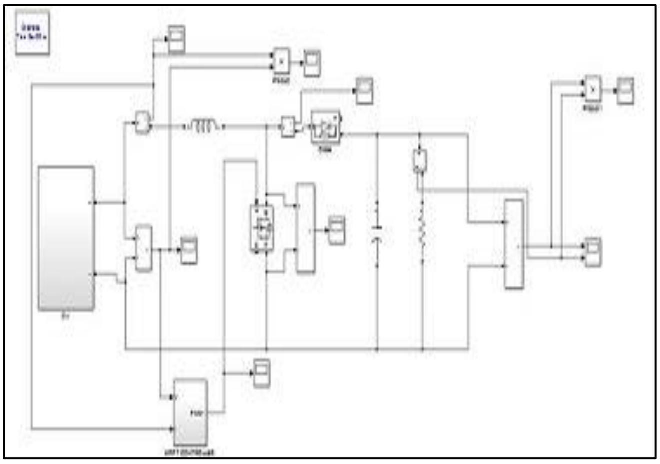


Fig. 7: Simulation of voltage and current output MPPT

D. Swarm algorithm method

A novel optimization algorithm called Salp Swarm Optimizer (SSA) is proposed. SSA is proposed to solve multi-objective problems. SSA algorithms are tested on several mathematical optimization functions. Salp Swarm Algorithm Optimization technique has been applied for multi-junction solar cell system. The solar panels are made up of different materials and give constant output from Boost converter. The main aim of SSA is to find out duty cycle to the Boost converter to maintain constant output voltage irrespective of power produced by solar panels. A detailed simulation of the proposed method has been simulated in Matlab/Simulink. The simulation result shows that this design can be effectively realized in practical applications Simulation of swarm MPPT

V. SWARM SIMULINK



A novel model-free solution algorithm, sala swarm algorithm for efficiently solving the maximum power point tracking (MPPT) problem of PV systems under partial shading conditions. A PV system which controls the power generation with its operating voltage is considered. A salp swarm algorithm (SSA) model is incorporated into the iterative search process to guide the update of candidate solutions (operating voltage settings) in the SSA and such extension is capable of improving the tracking performance. Simulation studies and experiments are conducted to validate the effectiveness of the proposed SSA algorithm for better addressing PV MPPT problems considering a variety of partial shading conditions. The performance of the proposed algorithm is benchmarked against the P&O and the particle swarm optimization (PSO), which has been widely considered in the model-free MPPT, to demonstrate its advantages. Results of simulation studies and experiments demonstrate that the SSA algorithm converges faster and provides a higher overall tracking efficiency.

A. Flowchart of swarm algorithm

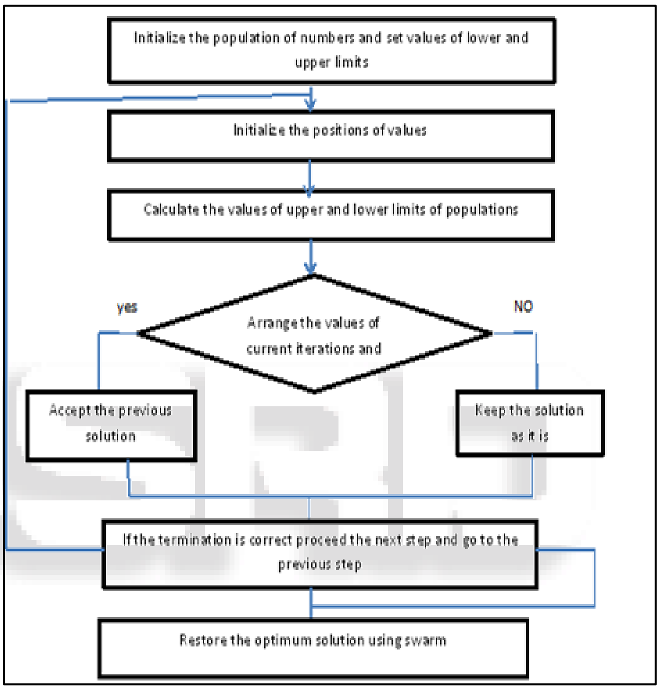


Fig. 7: flow chart of swarm algorithm

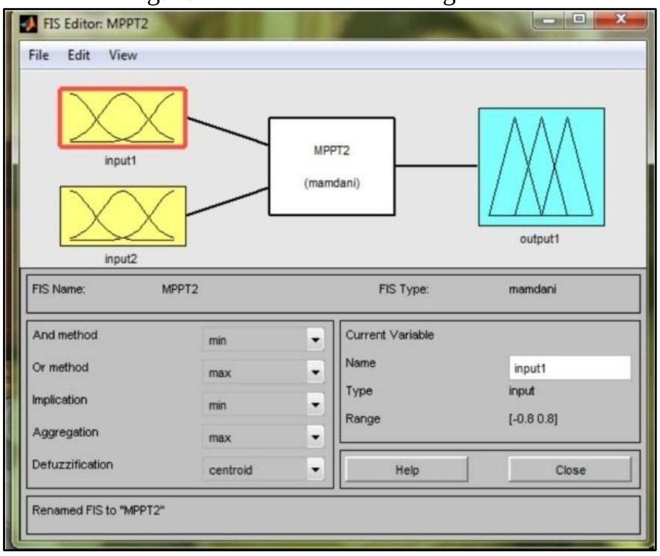


Fig. 11: swarm logic Implementation in Simulation

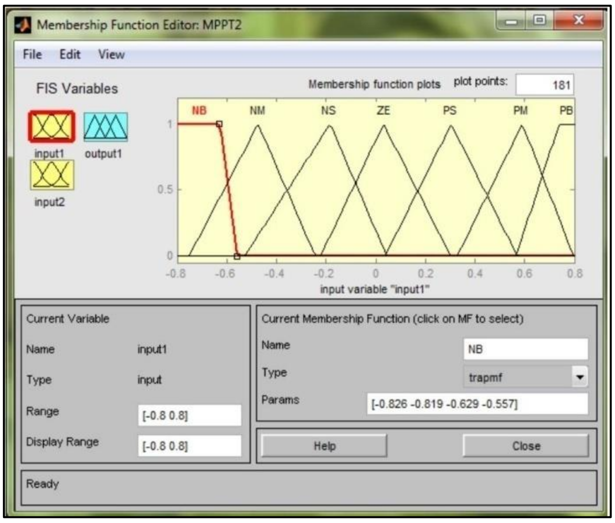


Fig. 12: swarm algorithm input Error (E)

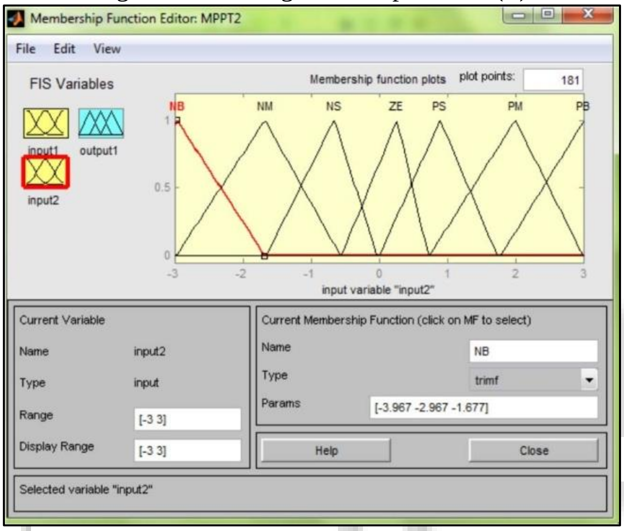


Fig. 13: swarm algorithm input change of Error (CE)

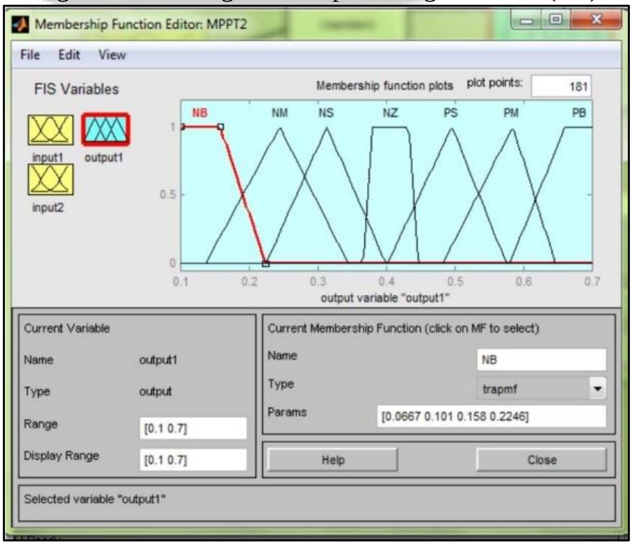


Fig. 14: swarm logic output (D)

Graphic view of the membership function for (a) error signal (b) change of error signal and (c) duty cycle. Different number of subsets has been used for rule settings of fuzzy logic MPPT. In this case, seven subsets based on forty-nine rules were used. The tuning of forty nine rules represents a better precision and dynamic response but it is time consuming.

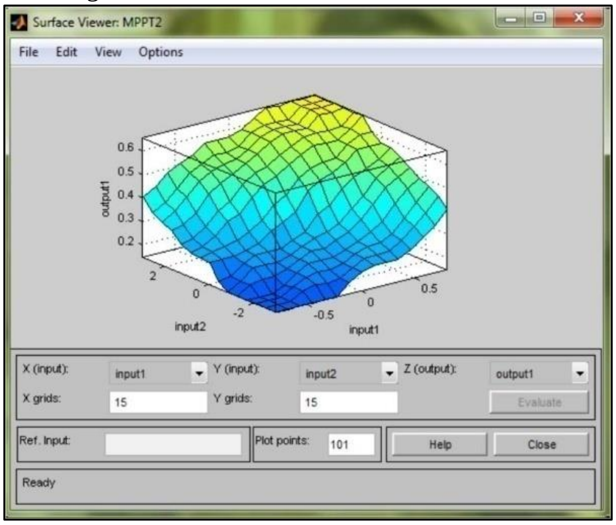


Fig. 15: swarm algorithm rule view

VI. Results of Simulation & Discussion

The proposed model of swarm MPPT based solar PV system is realized in the MATLAB SIMULINK environment which is represented in Fig. 9 .Here a comparison has been made with traditional jaya technique and swarm MPPT technique under the operating conditions, accepting constant temperature and an isolation of 1000 W/m^2. In jaya technique, the incremental current step size uses the appropriate value that is processed by trial and error technique. Jaya algorithm and swarm algorithm are two important parts of MPPT control which is represented in Fig.

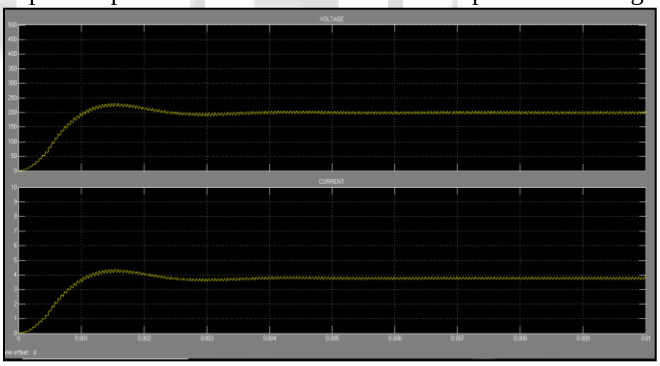


Fig. 16: Result of swarm MPPT

Simulation run time 8 msec						
Different MPPT system	Vin	Iin	Pin	Vo/p	Io/p	Po/p
JAYA	2	4	970	2.5	4.5	975
SWARM	2.5	4.5	975	2.7	4.8	978

Table II: Comparison between Different MPPT Systems

VII. Conclusion

The proposed method of MPPT is faster in comparison to conventional JAYA method when parameters like output voltage, output current and efficiency are compared. From Table. II it is clear that the system performance can be improved by proposed MPPT technique using SWARM algorithm. The proposed technique can be implemented in the real PV system for future work.

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