

Intelligent Algorithm Based Maximum Power Point Tracking of Photovoltaic Solar Pump



B.Hari Sankar Reddy, K..Nagabhushanam, R.Kiranmayi

Abstract - Solar Photovoltaic (PV) system is pollution free energy source. PV panel have maximum power at unique point that point depends on temperature and irradiance of environment. Therefore it is necessary to track maximum power point for maximum efficiency. PV water pump system based on ANFIS controller produces poor performance under different irradiation and temperature condition. To improve performance of PV water pumping system PSOMPPT controller was implemented .compare the transient behavior of PV water pump by PSOMPPT with ANFIS based MPPT.

Keywords - Particle Swarm Optimization Maximum Power Point Tracking (PSOMPPT); ANFIS; Boost converter; PMDC pump; PV System.

I. INTRODUCTION

The burning of fossil fuels to produce electricity is one of the largest sources of CO2 emissions. The solar PV system is of more interest and the most promising source of future demand. In the future will be all fossil fuels are disappearing because more than used we needed. So we preferred to use renewable energy sources to have free of cost and available in nature. Here taken the source of solar energy becomes the most reliable source, clean and pollution-free and produced electrical energy by using photovoltaic cells. PV cells made of silicon material manufactured by different stages. This PV panel requested to establish in rooftops of the house and porticos of buildings. The electric power acquired from the PV panel is mainly contingent on atmospheric conditions. PV panel efficiency is very low. To enhance the efficiency of the PV system become used in different tracking systems. To obtained the crest power of PV module from source to load

using a tracking system, in the crest with tracking is known as maximum power point tracking (MPPT) controller. Single junction solar cells having a large band gap of fleck results in a less amount of energy produced. Proposed module multi-junction [1],[2] solar cells having a haughty energy band gap to develop maximum energy. Based Upon links classified into two types of cells there lateral multiple junction solar cells and vertical multi-junction solar cells. The vertical multi-junction cell gets extravagant open-circuit voltage and expertise agrees with single-junction solar cells and the potential to get majority beneficial efficiency by using material placements. Solar cells normally continent on expert diffraction process. Several cells connected series of multiple strings [4] are tied in parallel [3] to the solar panel. The power output of solar cells swinging concerning Temperature and irradiation so MPPT controller needed.MPPT is used to select the operating point by the load, these are divided into three categories. The prime category is shown as traditional class like an Incremental Conductance and the Perturb & Observe method. The demerit of this group is its stagnant tracking ability, study state oscillation at Maximum power point (MPP) and decrees competence. To overcome limitations soft evaluating techniques are involved. The techniques [5] that are merged in this category are the Evolutionary Algorithms, Fuzzy and Neural Network. These groups also have some defects because of a few entanglements like it requires periodic training and it utilizes more memory will become difficult to develop in bio-inspired methods. The final category is shown under the type of augmentation computing, Particle Swarm Optimization, Bacterial foraging algorithm, Ant colony optimization and Genetic Algorithm perceived in functional applications like the PMDC pump.

MPPT techniques strategies (adopted from [6])

Table 1:

#	Tracking methods	A/D	Sensors	Speed	Stability	Periodic tuning
1	Constant voltage	A	V	Fast	Not stable	Yes
2	Open-circuit voltage	A	V	Fast	Not stable	Yes
3	Perturb and observe	A/D	V&C	Slow	Not stable	No
4	Linear reoriented coordinates	D	V&C	Slow	Stable	No
5	Curve-fitting	D	V	Fast	Not stable	Yes
6	dP/dV or dP/dI feedback control	D	V&C	Slow	Stable	No
7	Incremental conductance	D	V&C	Slow	Stable	No
8	Fuzzy logic control	D	V&C	Very fast	Very stable	No
9	Neural network	D	V&C	Very fast	Very stable	No
10	Biological swarm chasing algorithm	D	V&C	Very fast	Very stable	No

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To increase output power and decline the charge of the PV system, it is required to control PV panels at PSO. The power output characteristics mostly depend on solar irradiations and cell temperature variations. Intending to achieve much power, the output is collinear and depends upon temperature and irradiance conditions. They are clean, naturally replenished, no greenhouse gases, and don't affect human health. Present days PV system became more popular in the rapidly growing markets due to low maintained cost, the high level of investments involved, and the technological progress.



II. MODELING CHARACTERISTICS OF PV MODULE

Mathematical modeling very crucial part of to design to any system. Here PV module modeling needs a Matlab software and first develops a mathematical equation after the Simulink model diagram developed. In PV module number of cells connected series to boost the voltage, if parallel-connected increase current. if you need to revise any parameter in the whole module is easily in simulation. In this modeling parameter unique and output, waveforms are did not analyzing to other models [6]. In practical PV module modeling depends on some factors like the voltage, current, wattage, irradiation, location, the efficiency of the battery, dust level of the working environment, and temperature. These parameters help to improve the performance of the system. Below equations [7] to determined to output power.

$$I = N_p * I_{pv} - N_p * I_s \left[\exp\left(\frac{q(V + R_s I)}{N_s K_s T}\right) - 1 \right] - \frac{V + R_s I}{R_p} \quad 1$$

$$I_{pv} = [I_{sc} + K_i(T - T_{ref})] * G \quad 2$$

$$I_{k_s} = I_{rs} \left(\frac{T}{T_{ref}}\right)^3 \exp\left[q * E_g \left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right] \quad 3$$

$$I_{rs} = \frac{I_{sc}}{\exp\left[\frac{qV_{oc}}{N_s K_s a T}\right] - 1} \quad 4$$

I_{pv} is photocurrent, I_s is reverse saturation current, q charge of electron ($1.602 * 10^{-19}c$), k Boltzmann's constant ($1.38 * 10^{-23} J^0/K$), T operating temperature of cell (0K), N_p parallel connected cells, N_s series connected cells, a ideality factor of diode, K_i is the current temperature coefficient of a cell at short circuit condition,

T working temperature of cell, T_{ref} reference temperature of cell, G irradiance of solar (KW/m^2), I_{rs} reverse saturation current, E_g energy band gap semiconductor in cell (1.1ev). The V-I characteristics of a PV modules are given by Eq [7]

$$I = N_{par} * I_{pv} - N_{par} * I_s \left[\exp\left(\frac{q(V + R_s I \left(\frac{N_{ser}}{N_{par}}\right))}{N_{ser} K_s T}\right) - 1 \right] - \frac{V + R_s I \left(\frac{N_{ser}}{N_{par}}\right)}{R_p \left(\frac{N_{ser}}{N_{par}}\right)} \quad 5$$

Here N_{par} is number of cells are linked in parallel in module;

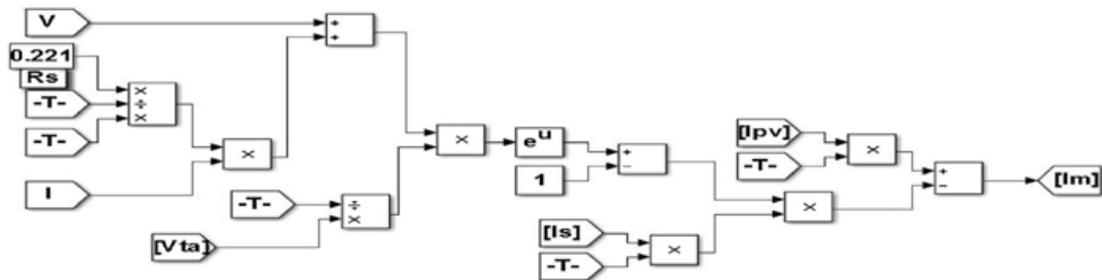


Fig .3 module current simulink model

N_{ser} is the number cells are linked series in the module . In this module 27 multi crystalline silicon cells are arranged in series to increase in voltage to get the 100w power as a output. below shown table 2 selected required parameters .

Fig. 1 shows R_p model for single diode which shown by Esq. (1)-(4) for simulation.

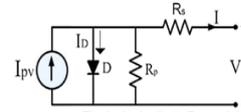


Fig 1. single diode R_p model

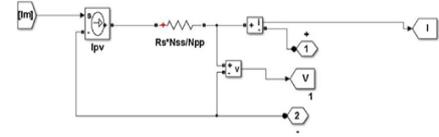


Fig 2 PV module circuit model.

Table 2 100W Photo Voltaic panel [8]

variable	value
P_{max}	100W
V_{max}	17.3
I_{max}	4.6
I_{sc}	5
V_{oc}	21.9
Temperature coefficient of V_{oc}	$-1.23 * 10^{-1} V/^0c$
Temperature coefficient of I_{sc}	$3.18 * 10^{-3} A/^0c$

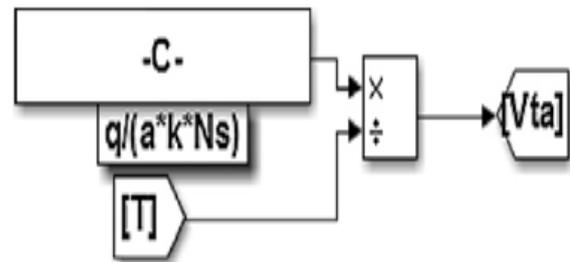


Fig4 Vta simulink model

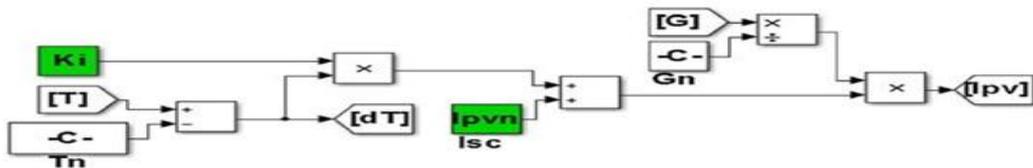


Fig .5 photocurrent simulink model

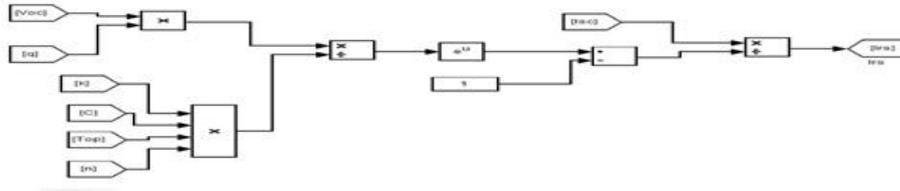


Fig 6 Reverse saturation current simulink model

Fig.7 Characteristics of PV Module at various temperature

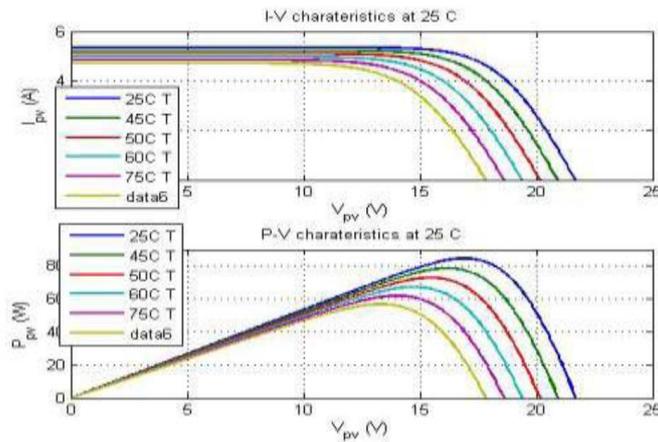


Fig.8 Characteristics of PV module at various irradiances

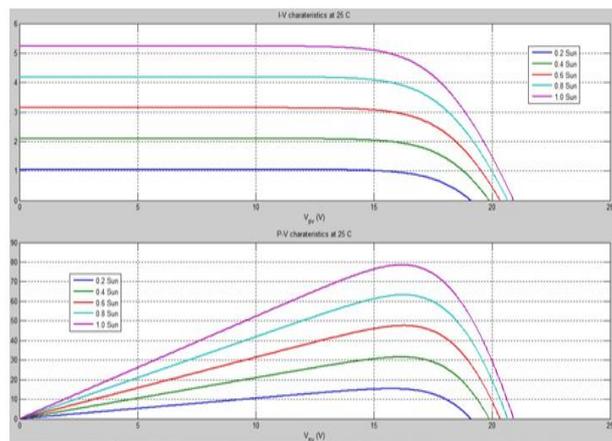


Fig 6 shows pv module operated different temperature and irradiances. fig (7,8) P- V curves drawn at the constant temperature (25°C) and different irradiation level (300-1000) respectively.

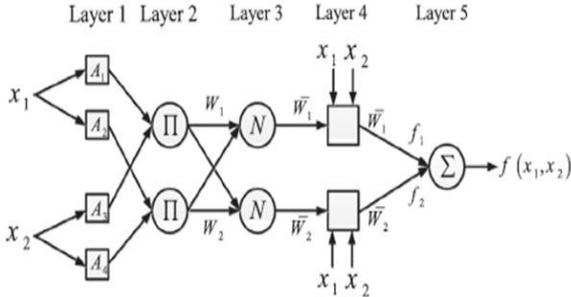
III. ADAPTIVE-NEURO FUZZY INFERENCE SYSTEM (ANFIS) STRUCTURE AND TUNING

ANFIS is an artificial intelligent system, which is having amalgamation of fuzzy logic and neural networks. In this model taking two inputs like temperature, irradiation and gives power at crest value[9].

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The output achieved by using Sugeno type optimization method depending on rule based and input membership function has a gauss method. ANFIS used as modeling, controlling and universal estimator. The structure of ANFIS consists of five layers, The function of each layer is presented as follows [10]. In which the task of each layer is as follows

- 1 .fuzzy layer
- 2 .fuzzification layer
- 3 .inferences process layer
- 4 .defuzzification layer
- 5 .output layer



Layer1: In this layer output fuzzy values as given input values and membership function A_i at each node. Output of i -th node layer1 given by eq(6).

$$O_{i,1} = \mu_{A_i}(x_1) \quad 6$$

$O_{i,1}$ the i -th node of output at layer 1, A_i is a linguistic variable related with this node. System input of each node (x_1).

Layer 2: fuzzification layer the output of this layer produces the weights of the membership functions multiplication of their inputs. For example,

$$W_2 = A_2(x_1) * A_4(x_2) \quad 7$$

Layer 3: inferences process layer produces the rule based individual weight of network is standardized by the adding of the sum of weights according to Eq.

$$\bar{W} = \frac{W_k}{\sum_{i=1}^n w_i} \quad 8$$

Layer 4: In this layer defuzzification of the outputs is achieved, the output of the layer at node is as

$$O_i = \bar{W}i * f_i = \bar{W}i * (p_i x_1 + q_i x_2 + r_i) \quad 9$$

Layer 5: The final output layer determine the ultimate output of the controller as Eq.

$$f(x_1, x_2) = \sum_i \bar{w}_i \quad 10$$

Rule based representation

1. If (irradiance is irrmf1) and (temperature is tempmf1) then (power is powmf1) (1)
2. If (irradiance is irrmf1) and (temperature is tempmf2) then (power is powmf2) (1)
3. If (irradiance is irrmf1) and (temperature is tempmf3) then (power is powmf3) (1)
4. If (irradiance is irrmf2) and (temperature is tempmf1) then (power is powmf4) (1)
5. If (irradiance is irrmf2) and (temperature is tempmf2) then (power is powmf5) (1)
6. If (irradiance is irrmf2) and (temperature is tempmf3) then (power is powmf6) (1)
7. If (irradiance is irrmf3) and (temperature is tempmf1) then (power is powmf7) (1)
8. If (irradiance is irrmf3) and (temperature is tempmf2) then (power is powmf8) (1)
9. If (irradiance is irrmf3) and (temperature is tempmf3) then (power is powmf9) (1)

Surface & rule viewers

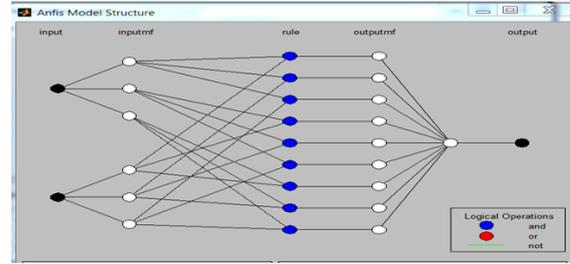
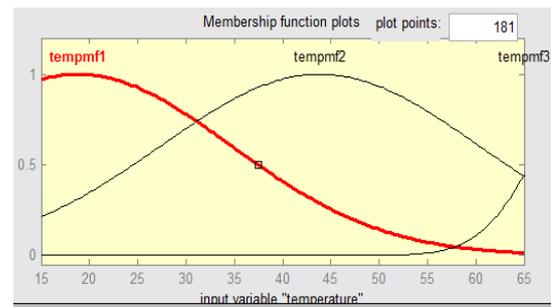
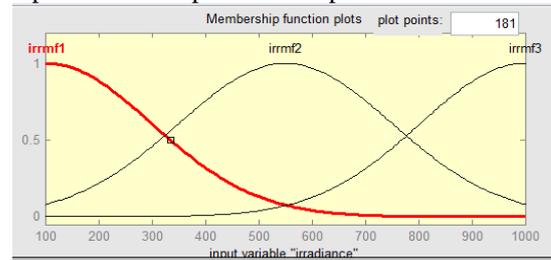


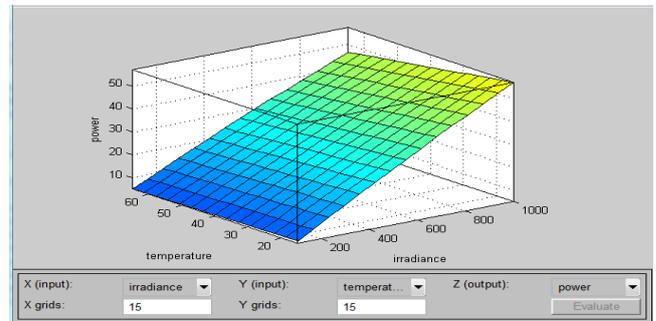
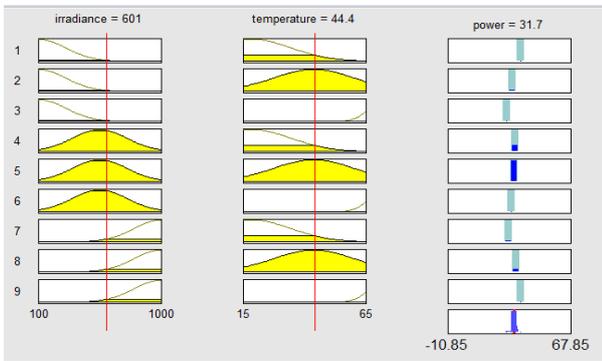
Fig.10 Five Layer ANFIS structure provided by Matrix laboratory

Selection of network parameters and determination of training and testing data

ANFIS model applied to a input membership function set of data represented in graphically(guess) method, multiplication of some weights, written in rule based, normalized the weights of parameters and final output shown in surface views (3D view).the output errors are throw away to generate important parameters by using back propagation algorithm. The direction parameters modify using sugeno fuzzy inference system by using ANFIS controller.

Input membership function representation





Number	Irradiance (W/m ²)	Temperature (°C)	Power output (W)
1	500	15	740.5256
2	500	20	74.1192
3	500	25	727.7175
4	500	30	721.3214
5	500	35	714.9322
6	500	40	708.5511
7	500	45	702.1794
8	500	50	795.8187
9	500	55	789.4703
10	500	60	783.1359
11	500	65	776.8174

Table 3. sampling data sheet

ANFIS model taken two inputs like temperature, irradiance and gives crisp power output by using hybrid optimization which have least square and back propagation

based on sugeno type inference system. The range of temperature (15-65°C) and irradiance (100-1000W/m²).

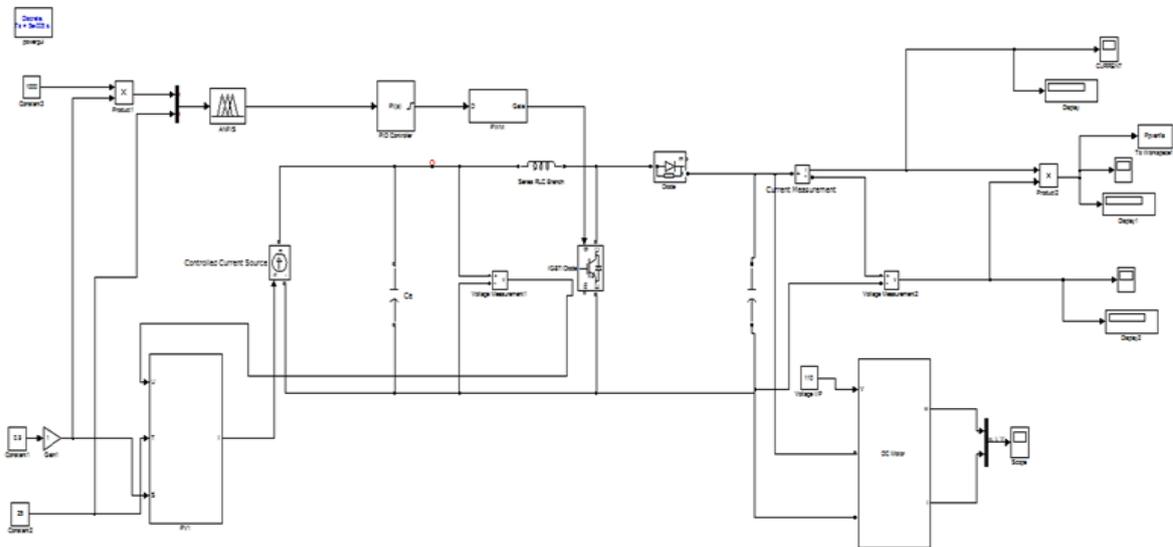


Fig.11 Simulation model of ANFIS MPPT controller with solar pump

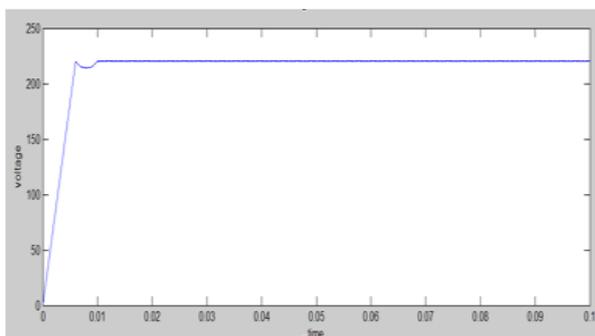


Fig no 12 voltage waveform using ANFIS

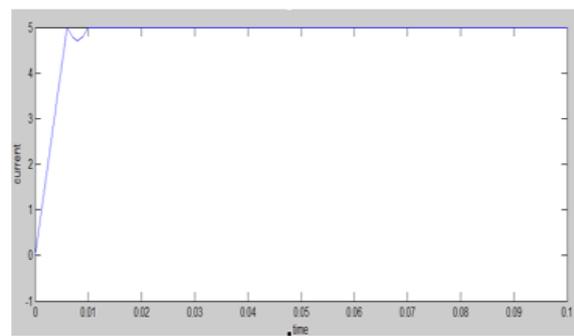


Fig no13 current waveform using ANFIS

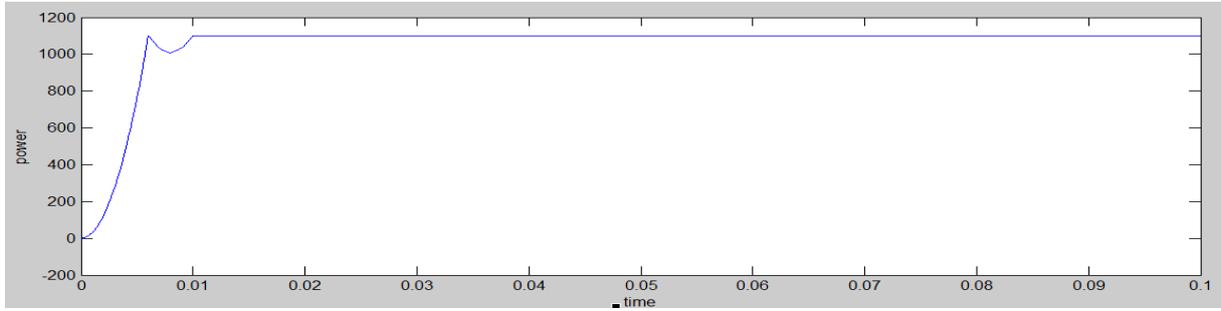


Fig .14 Power output waveform using ANFIS

Table: 4 ANFIS MPPT controller using pump performance at constant temperature and variable irradiance.

Irradiance	Temperature	Motor speed	Pump torque	Load power
1000	25	1215	5.854	1100
900	25	1125	5.691	1050
800	25	1091	5.475	995.5
700	25	1042	5.171	814.6
600	25	966	4.72	798
500	25	950	4.073	645.2
400	25	889	3.294	579.4
300	25	815	2.475	431.5

IV. PARTICLE SWARM OPTIMIZATION (PSO) STRUCTURE AND PROGRAMMING

PSO was first introduced by Kennedy and Eberhart to optimize the problem in search space. It is an intelligent, stochastic and population-based algorithm. In this algorithm first invented related to community behavior of animals like a group of fish and flocks of birds pervasive for their food [11]. The flock is usually designed by particles in multidimensional that we have position and velocity. Each particle remains on updating itself by differentiating it to the optimal position up to getting the global best position[12]. The Fitness of particle denoted by best value is known as global best and it leads to other individual particles [18]. PSO algorithm contains some tuning parameters that mostly influence the performance of the algorithm stated as the exploration-exploitation tradeoff exploration to test the various region and located the best solution. PSO very easy concept and efficient compared to other iterative algorithms. It has less iteration, easy recognition, and fast convergence.

Global Best (G_{best}) PSO:

It is a method where the position of each particle is influenced by a best –fit particle in the whole swarm .it is used star social network topology where the social statics achieved from all particles in the whole swarm.

Local Best (l_{best}) PSO:

In the method allows each particle to be achieved by the best-fit particle chosen from its neighborhood and it represents the ring social topology. The best position of particle had in the neighborhood found from initialization across time (t).

In this algorithm[12]given below,The position of particle represent yi changing randomly, velocity represent letter ai initially 0 value started. Below equation taken from [19]

$$a_i^{t+1} = sa_i^t + z_1 \text{rand}() (pbest_i^t - y_i^t) + z_2 \text{rand}() (gbest_i^t - y_i^t) \quad 11$$

and

$$y_i^{t+1} = y_i^t + v_i^{t+1} \quad 12$$

where a_i^{t+1} is the velocity of particle

y_i^{t+1} is the present position of particle.

y_i^t is previous position of particle.

y_i^{t+1} is latest position of particle.

S is load factor

Z_1, Z_2 is learning coefficients, normally value (1-2) the variable produced randomly.

$Pbest_i^t$ is the P_{best} , $gbest_i^t$ is the G_{best}

S.no	parameters	value
1	No of particles	20
2	Min duty cycle	0.01
3	Max duty cycle	0.9
4	Sampling time	0.1s
5	Max iteration	30
6	W min	1
7	W max	0.3
8	C1 min	0.1
9	C1 max	1.05
10	C2 min	0.1
11	C2 max	1.05

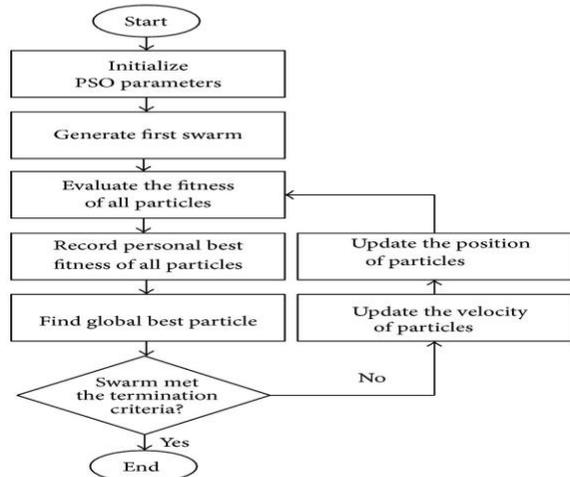


fig. 15.Table .5

PSO Algorithm Implementation

- 1) Set the velocity and position range when the parameters and particles in initialized.
- 2) Every particle the velocity and position are initialized abruptly.
- 3) For each particle the significance of P_{best} has been calculated.
- 4) Gbest value has been set when the best value of the particle has been reached.
- 5) The velocity and the position of values has been upgraded spontaneous depends on the Gbest.
- 6) Repeat steps 3 and 4 up to the achieved optimal solution.
- 7) The final optimized value has been decided at the last iteration based on Gbest.

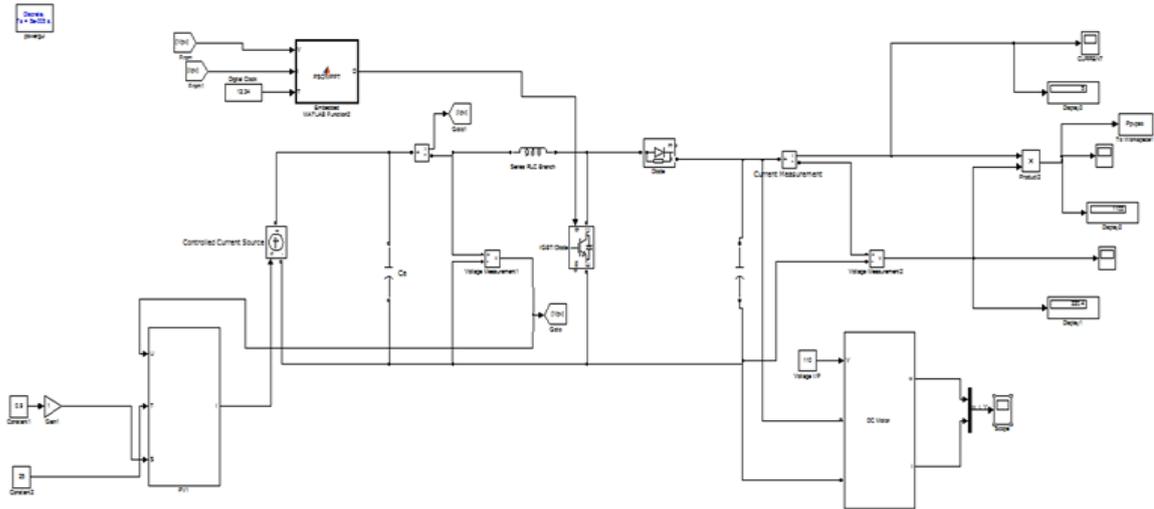


Fig 16. Simulation model of PSOMPPT system with DC motor pump load

The PSO algorithm is subjected to upgrade the Duty cycle of Boost Converter by trace the global crest point with persistent upgrade the position and velocity. The Triggering pulse given to converter by using pulse width modulation technique used.

V. DC-DC BOOST CONVERTER

Boost converter is step up voltage or step down current from source to load. It consists of inductor, capacitor and switching devices. inductor is used boost up the

voltage/limiting the current and capacitor is used as filter to suppress the voltage ripples normally added to converter output(load side filter) and input (source side filter). Switching devices are IGBT,MOSFET used for switching operation.

$$\text{Output Voltage equation is } V_o = \frac{V_{dc}}{1-D}$$

Where D (duty ratio) $D = \frac{T_{on}}{T}$ [D<1]
 T_{on} is the switching time and T is the switching period.

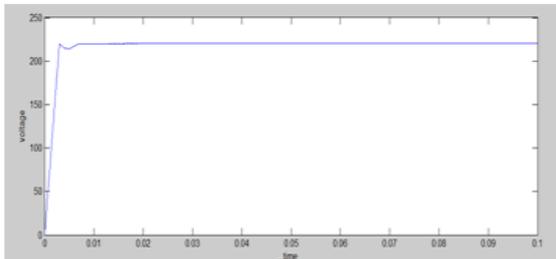


Fig 17. Voltage waveform using psomppt

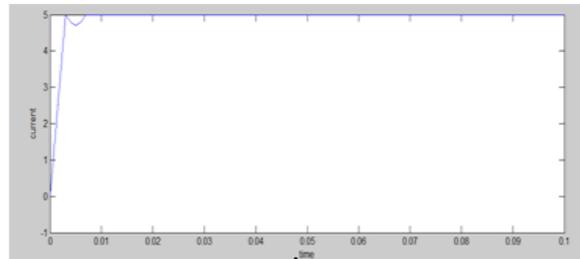


fig 18. Current waveform using psomppt

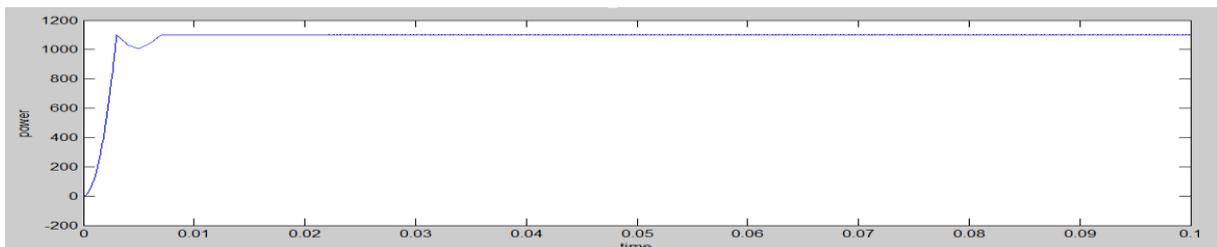


Fig 19 Power wave form using PSOMPPT

Table 6: PSOMPPT controller using pump performance at constant irradiance and variable temperature.

Irradiance	Temperature	Motor speed	Pump torque	Load power
600	25	933.0	4.546	843.5
600	35	927.5	4.523	839.6
600	40	921.2	4.495	835.3
600	45	913.9	4.466	830.3
600	50	905.2	4.43	824.4
600	55	994.4	4.386	817.3
600	60	980.3	4.329	808.2
600	65	959.9	4.248	795.6

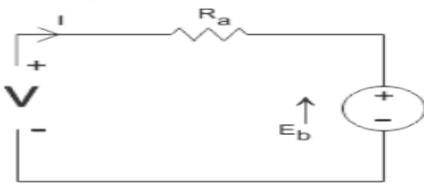
Table 7 PSOMPPT controllers using pump performance at constant temperature and variable irradiance.

Irradiance	Temperature	Motor speed	Pump torque	Load power
1000	25	1256	5.656	1102.2
900	25	1242	5.583	1065.3
800	25	1228	5.502	1045.4
700	25	1212	5.413	1024.1
600	25	1196	5.317	1001.5
500	25	1176	5.216	1000.8
400	25	1157	5.12	987
300	25	1137	5.004	902

VI. PMDC SOLAR PUMP

PMDC pump used permanent magnet dc motor operated on dc supply. Permanent magnets are made of alnico and remaining construction same as dc motor. Here it is used as load running at constant speed [13,14].

Equivalent ckt of pm dc motor



$V = E_b + I_a R_a$, Back emf of motor (E_b), armature current (I_a), armature resistance (R_a)

Pump is mechanical device moves the fluids from one place to another place by mechanical principal. In this classification centrifugal pumps [15] are operated only lower head, high discharge, poor suction of fluid and cavitations occurred. Positive displacement pumps have good suction power to lift the fluid, high head and low discharge. The submersible pumps are good suction, high head, high discharge, not happen cavitations but corrosion problem and seal damage [18] is there in this pumps. Finally the proposed positive displacement pump used with a standalone water pumping system effectively. PMDC pump consumes less power and operated 110v dc as input voltage gives mechanical power as output. In this motor not required for field supply known as single excited system.

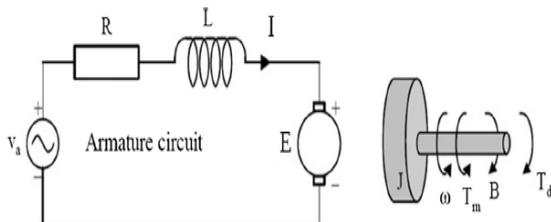


Fig 20. Pmdc motor

In a PMDC motor working principle is an armature conductors rotates inside a magnetic field. It experiences a force. The torque and voltage equations of permanent magnet dc motor are denoted equations [13, 14]. Load equations of positive displacement pump are given as in Eq. (15) (from [17]).

$$V_a = I_a R_a + L_a \frac{dI_a}{dt} + K_3 \omega \quad 13$$

$$T = A_3 + B_1 \omega + J \frac{d\omega}{dt} + T_{load} \quad 14$$

$$T_{load} = A_1 + C \omega^{1.8} \quad 15$$

V_a is armature voltage (V), I_a armature current (A), L_a inductance of armature (H), K_3 back emf constant (NM/A), R_a resistance of armature (Ω), T is motor torque (Nm), A_3 friction constant (Nm), B_1 damping constant (Nms/rad), J inertia of rotor (kgm^2), T_{load} load torque (Nm), A_1 friction constant (Nm), C constant of load torque (Nms/rad).

The solar water pump supplies an amount of water that is dependent on the power supplied to the pump, total dynamic head and the efficiency of the pump

$$\eta_p = \frac{\rho g h Q}{IV}$$

where η_p is the total efficiency of pump, I is the supply current to the pump, V is the supply voltage to the pump, ρ is the density of water, g is the acceleration due to gravity, h is the total head, Q is the volume flow rate of water.

VII. Conclusion

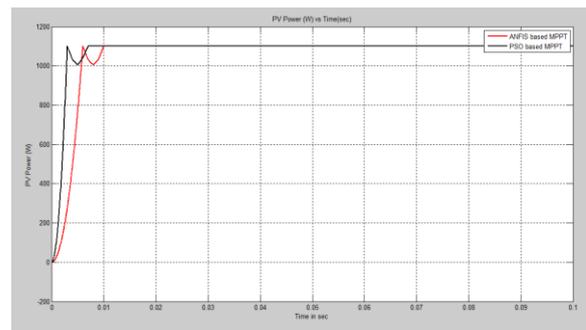


Fig 21 comparison between ANFIS and PSOMPPT

temperature	irradiance	ANFIS Controller		PSO MPPT Controller	
		Rise Time	Settling TIME	Rise Time	Settling Time
25	1000	0.006	0.01	0.003	0.008
25	900	0.0065	0.011	0.0062	0.009
25	800	0.0063	0.014	0.0061	0.0011
25	700	0.0061	0.015	0.0057	0.0012
30	1000	0.0058	0.009	0.0055	0.006
35	1000	0.0062	0.012	0.0059	0.010
40	1000	0.0064	0.013	0.0061	0.011
45	1000	0.007	0.016	0.004	0.012

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This paper introduced a PSOMPPT controller connected PV systems to run the PMDC pump effectively at different temperatures and irradiation. The PSOMPPT should matching impedance from the PV module as a source to PMDC pump as a load for maximum power transfer by controlling the duty ratio of the boost converter. PSOMPPT controller achieves maximum power and fast response under different temperature and irradiances. PSOMPPT response has less settling time comparing to ANFIS controller. PSOMPPT controller had Simple structure, Easy Execution and has a very fast convergence speed to the preferred solution and it has very high tracking speed. So PSOMPPT produced better performance compared to ANFIS controller.

REFERENCES

1. M.K.Alam,F.H.Khan and A.S.Imtiaz, "An efficient power electronics solution for lateral multi junction solar cell systems," in Proc.IEEE IECON,pp.4373-4378,2011.
2. L.Zhao,"High Efficiency Mechanically Stacked Multi-Junction Solar Cells for Concentrator Photovoltaics",Ph.D.dissertation,KatholiekeUniversity,LeuvenFaculte it,Ingenieurswetenschappen,Arenbergkasteel,Belgium, Mar. 2011.
3. L. Gao, R. A. Dougal, S. Liu, and A. P. Iotova, "Parallel-connected solarPV system to address partial and rapidly fluctuating shadow conditions," IEEE Trans. Ind. Electron., vol. 56, no. 5, pp. 1548–1556, May 2009 .
4. M.Meinhardt,G.Cramer,B.Burger,and P.Zacharias, "Multi-string converter with reduced specific costs and enhanced functionality,"Solar Energy,vol.69(Suppl.),n0.1-6,pp.217-227,2000.
5. Prakash J, Sarat Kumar Sahoo, S.Prabhakar Karthikeyan and I.Jacob Raglend "Design Of PSO- Fuzzy MPPT Controller for Photovoltaic Application," International Conference on Artificial Intelligence and Evolutionary Algorithms in Engineering Systems, pp.1339-1348, 2014.
6. Karami, Nabil, Moubayed, Nazih, Outbib, Rachid, 2017. General review and classification of different MPPT techniques. Renew. Sustain. EnergyRev. 68 (February (Part 1)), 1–18.

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