NOVEL FAST SWEEPING METHOD BASED MPPT FOR ASSESSMENT OF PV FED WATER PUMPING SYSTEM UNDER PARTIAL SHADING CONDITION

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Abstract: *In this article novel fast sweeping method is proposed as MPPT for PV fed water pumping system. Solar photovoltaic (PV) array which is exposed to the uniform solar irradiance shows the non-linear P-V characteristic. Though, the P-V characteristic becomes further complex with numerous maximum power points (MPP) when the array is functioned in partially shading condition. PSC results hotspots, power loss and reduces the reliability of the solar power generation system. Furthermore PV characteristic curves of solar panel array reveal several peaks. The main disadvantages of traditional MPPT methods are that they are unable to track global peak under non-uniform irradiance/insolation. Under this condition traditional MPPT methods frequently are unsuccessful to provide optimum MPP. In this paper novel Fast sweeping method is proposed as MPPT to track global MPPT. The performance of proposed MPPT is compared with existing intelligent controllers such as Fuzzy logic controller, artificial neural network controller and adaptive Neuro Fuzzy inference system based MPPT in a partial shading condition. Entire system is analysed using Matlab. Experimental analysis is done to validate the simulation.*

Keywords: *Photovoltaic, Partial shading, MPPT, fuzzy, ANN, ANFIS, Fast sweeping method.*

1. Introduction:

In an energy environment where the energy requirement is persistently developing, the fossil resources are declining and the planetary warming is dramatically increasing, many nations have preferred for the adoption of bills to cut down energy consumption and for an energy transition using renewable energy sources. Among the renewable energy sources Solar photovoltaic field has attracted the world's interest since solar energy is a promising option of renewable energy which the conversion of solar energy to electrical energy is static, quite, free of moving part and it has no negative impact to the environment [1, 2]. Moreover, the world PV production has been development yearly of average 30% for the period of the past decade [3].

For standalone PV power system, water pumping is the best application which pays attention by many people nowadays.

Water pumping is mandatory in agricultural field, household and in industries. Among various applications of water pumping agricultural pumping pays more attention for its power consumption. When PV is planned to power a pump in field, the main problem to be considered is shading on the panel.

Every change of solar irradiation or temperature makes variations in the PV power and current which desires to identify a new point of function. Consequently, a Maximum Power Point Tracking (MPPT) is usually brought into play in PV systems. Various MPPT schemes have been analyzed and executed in earlier studies including [4], perturb and observe (P&O) method [5], incremental conductance (Inc-Cond) algorithm [6], open-circuit voltage and short circuit current [6], fuzzy logic controller (FLC) [7], and Adaptive neuro fuzzy inference system (ANFIS), etc. [8]. These techniques have high tracking accuracy under stable conditions. It nevertheless still exposes some trade-offs among tracking reliability and tracking speed when weather conditions or load values rapidly change. Shading may change the solar irradiance and temperature on the panels. These shading effects may be unchanging, or may be very active. The conventional techniques for MPPT yield non-optimal execution because of the presence of various local maxima that emerges because of partial shading condition (PSC). In order to negotiate detrimental effect of partial shading, special techniques are developed to track MPP under such conditions.

S.Choudhury and P.K.Rout applied Adaptive Takagi–Sugeno Fuzzy Logic controller as MPPT for PV system of having 5 modules under PSC [9]. Allataifeh et.al discussed 2 module PV system MPPT control under constant irradiance, sudden changing and PSC using Mamdani fuzzy logic controller [10]. An artificial neural network of feed forward type is applied as MPPT for 2*4 PV system in [11] and performance of ANN MPPT system is compared with the fuzzy and P&O methods of

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MPPT. A hybrid based MPPT is applied with 17000 points, 6 varying irradiance conditions in 4 modules PV system under partial shading condition. Hybrid is the combination of ANN and conventional MPPT discussed in the paper for tracking GMPP. Belhachat, F. and Larbes, analysed ANFIS as MPPT controller to track GMPP in a 2 string PV system [12]. The ANFIS trained to track GMPP is intended with hybrid learning method which combines the back propagation gradient descent method and least squares method with number epoch of 2500. Radianto, D et.al analysed TCT photovoltaic system with ANFIS based MPPT under partial shading condition [13]. The configuration of 5*2 TCT is analysed with ANFIS trained using hybrid learning combining back propagation, gradient descent and least square algorithm to decide duty ratio for boost converter.

From the study of previous researches it is noted that ANFIS has better performance than conventional MPPT and FLC MPPT under PSC. From the review it is noted that ANFIS creates least oscillations in the region of the GMPP under partial shading conditions and for any PV array configuration . To overcome the oscillations around GMPP and to track the GMPP promptly, in this paper novel algorithm of fast sweeping method is proposed as MPPT. The objective of the FSM is to utilize nonlinear upwind difference and Gauss-Seidel iterations with alternating sweeping ordering. A finite number of iterations are required to execute this algorithm which minimizes the complexity. Even though it has a finite number of iterations the accuracy is same as other methods. Hence to minimize complexity and for quick tracking with accuracy in this paper FSM is proposed as MPPT.

2 . Proposed PV System:

The proposed PV system consists of PV modules, Buck boost converter, MPPT controller, inverter, filter and a single phase pump load. Block diagram of proposed system is shown in Figure 1.

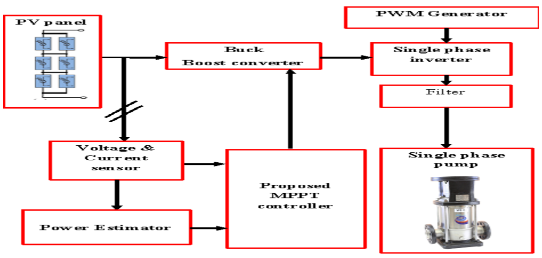

Fig. 1. Block diagram of proposed system

Each block in the Figure 1 are discussed as follows.

2.1 PV panel:

Normally, a PV array comprises a large number of modules connected with each other in both series and parallel combinations. Regarding PV panel configuration system, numerous schemes have been produced such as simple series (SS), series parallel (SP), bridge link (BL), Honey Comb (HC), and Total Cross Tied (TCT) configuration to conquer partial shading conditions [15- 16]. From the configuration which is mentioned above, total configuration tied (TCT) has superior configuration if compared with other configuration. This can be established that TCT has the uppermost of peak power relatively than other configuration such as HC and BL [14]. In this paper 6 modules are considered for an analysis. To regulate the voltage output from the PV panel to supply the load a DC-DC converter is mandatory between PV panel and a load. In this analysis boost converter plays role for voltage regulation. Among the various MPPT methods for GMPP in PSC, initially FLC is chosen to find the best configuration of PV panel. 6 modules are connected as 1*6 in a simple series configuration. 2*3 is combination for other configurations. Specification of a single panel is given in table1.

Table 1
Specifications of a Single Panel

Maximum Power	67w
Optimum operating voltage(Vmp)	21
Operating operating current (Imp)	3.2
Open circuit voltage (Voc)	22.6
Short circuit current(Isc)	3.75

In this paper, 6 number of 67w panels are connected in various configurations. Each configuration is tested with the irradiance of PSC. For an analysis irradiance of PSC is considered as shown in table 2.

Table 2
Irradiance of PSC

PV1		PV2		PV3		PV4		PV5		PV6	
Time	Irad	Time	Irrad	Time	Irrad	Time	Irad	Time	Irrad	Time	Irrad
[02.55]	[8001000700]	[024.5]	[750900800]	[024.5]	[750900800]	[02.55]	[8001000700]	[024.5]	[750900800]	[024.5]	[750900800]

Performance of various configurations is shown Figures 2 and 3.

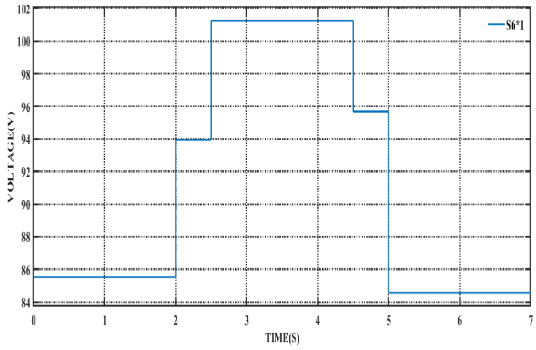

Fig. 2(a). voltage performance of series configuration

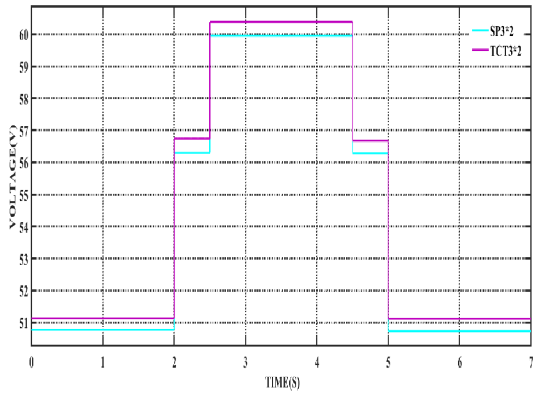

Fig. 2(b). voltage performance of 3*2 configuration

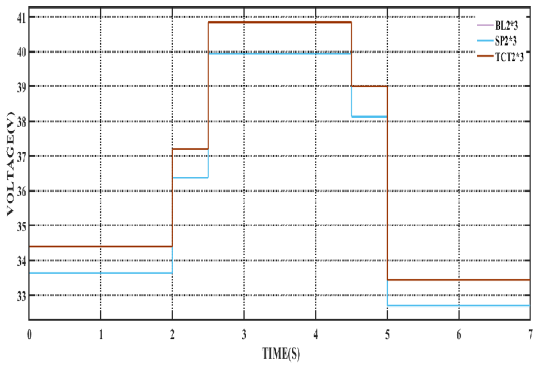

Fig. 2(c). voltage performance of 2*3 configuration

Figure 2 Voltage Performance of various configurations under PSC

From the Figure 2 it is noted that series configuration produces high voltage compare to other configurations. Whether it is 3*2 or 2*3 the TCT produces better voltage compare to SP and BL.

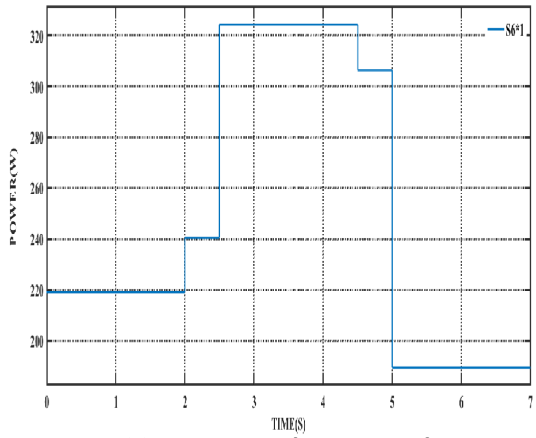

Fig. 3(a). Power performance of series configuration

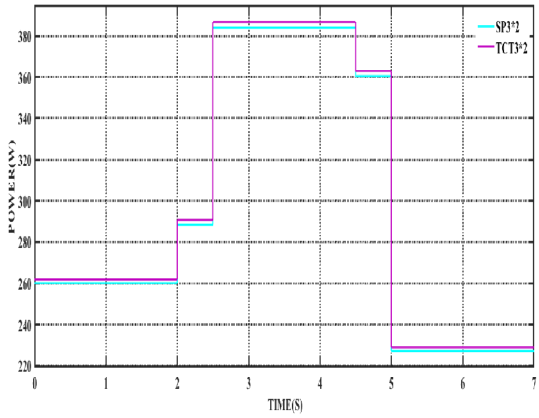

Fig. 3(b). Power performance of 3*2 configuration

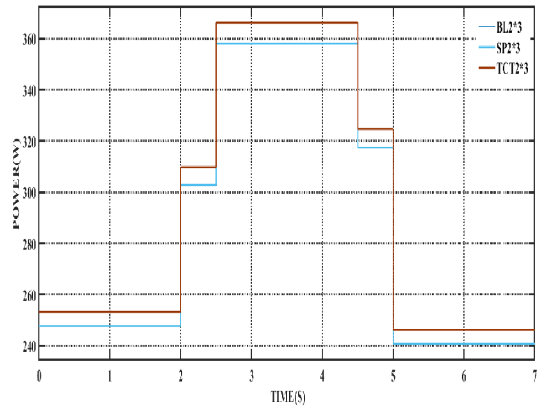

Fig. 3(c). Power performance of 3*2 configuration

From the Figure 2 and 3 it is noted that, in a series connection when any cell is (partly) shaded, the impact is the same in all modules. This leads to drastic drop in the power output even if it produces high voltage. In case of series parallel connection any cell in series connection is subject to shade, it determines the current of the entire string. It reduces power output. The TCT configuration produces better power than all other configurations. .

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Table 3
Performance of various configurations PV panel

Sl.No	Configurations of PV module	Parameters		
		V_{MPP}	I_{MPP}	P_{MPP}
1	TCT 3*2	60.38	6.4	387
2	SERIES PARALLEL 3*2	59.95	6.4	384
3	TCT 2*3	40.85	8.965	366.25
4	BRIDGE LINK 2*3	39.95	8.965	358.1
5	SERIES PARALLEL 2*3	39.95	8.965	358.1
6	SERIES 1*6	101	3.20	324

From the Table 3 it is proven that among all configurations TCT offers maximum power compare to all others. Hence in this paper further analysis for MPPT are proceeded with TCT configuration.

2.2 Buck Boost converter:

Buck boost converter is a step down/up converter that is the amplitude of output voltage can be decreased or increased compared to the input voltage [15], so this configuration of converter can be applied to connect nearly matched load or battery and module voltages. The configuration is also the only one capable to track the load resistance, which ranges from 0 to infinite. Figure 4 shows the Operational region of I–V curve for Buck-Boost DC–DC converters.

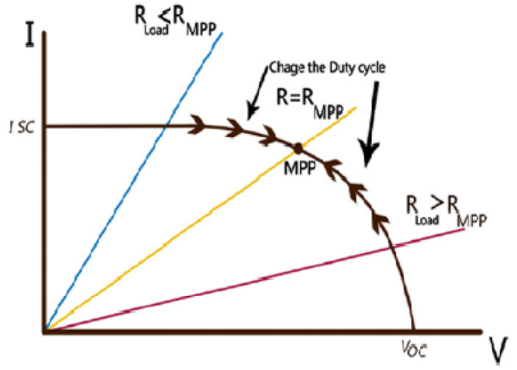

Figure 4. Operational region of I–V curve for Buck- Boost DC–DC converters.

From the Figure 4 it is noted that Buck-boost converter thus does not have a non-operational zone, so varying the duty cycle facilitates function from short-circuit current to open-circuit voltage.

2.3 MPPT :

MPPT is of dominant significance to the system as it not only enhances system efficiency however also minimizes the return of investment on the PV installation [16]. To guarantee maximum extraction of power, the maximum power point (MPP) should first be established prior to the system's operation point is driven to that point. When the numerous cells within a module in a PV array are shaded, the array is said to be under the PSC. Since the solar irradiance decides the current of every PV cell within a module, partial shading reduces the current for PV cells under shading, whereas the other unshaded cells generate high currents. Since the current pass through every modules connected in series should be equal, this leads the cells under shading to function in the reverse bias region and bring on the equal current as the non-shaded modules. The cells in the partial shaded module do not have the equal current in this condition, which leads to several peaks in the power-voltage characteristic curve. Consequently, conventional MPPT methods will be unsuccessful to track the global maximum power point (MPP) due to the local peaks. In this paper FLC, ANN, ANFIS and proposed novel FSM are applied as MPPT controller. All controllers produce duty ratio as output which is converted into pulses by comparing it with the high frequency sawtooth wave, to control switching device in a buck boost converter.

2.3.1 FLC based MPPT:

Fuzzy logic controller (FLC) is a nonlinear control method with the advantage of capability to function at uncertainty conditions like weather change and load fluctuations. Besides, it does not depend upon the precise model of the organization. For this reason, it can be well applied to nonlinear characteristics of the PV system to track the maximum power point. In this paper FLC MPPT is designed with two inputs such as change in PV power and change in PV voltage to produce a single output as Duty ratio. Mamdani type of fuzzy is selected for MPPT. All variables such as change in voltage, change in power (ΔP), change in voltage (ΔV) and duty ratio (D) are designed with triangular membership functions. Membership functions of ΔP and ΔV are {NB, NM, NS, Z, PS, PM, PB} named as Negative Big, Negative Medium, Negative Small, Zero, Positive Small, Positive Medium and Positive Big. Membership functions of D is {NVB, NB, NM, NS, Z, PS, PM, PB, PVB} it is alike to the input variables apart from Negative Very Big and Positive Very Big. To produce optimum duty ratio fuzzy is tuned with 49 rules. Centroid method of defuzzification is selected in this fuzzy. Figure 5 shows the Membership functions of input and output variables.

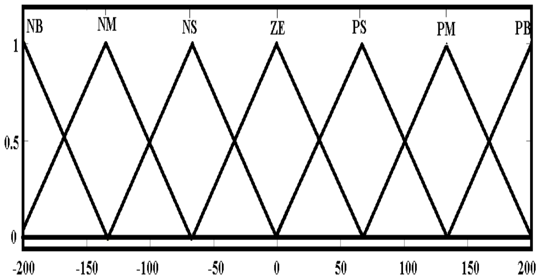

Fig. 5(a). Membership functions of ΔP

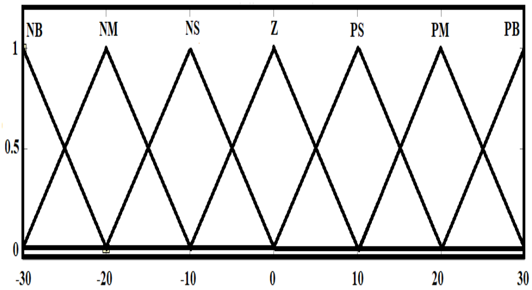

Fig. 5(b). Membership functions of ΔV

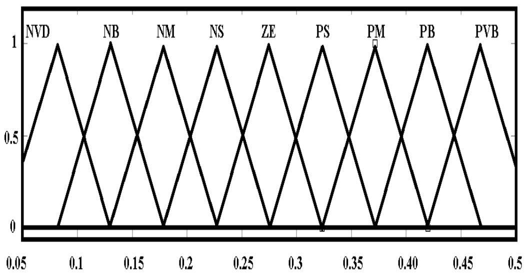

Fig. 5(c). Membership functions of D

Fig. 5. Membership functions of input and output variables

Fuzzy rules are shown in table 4.

Table 4 Fuzzy rules

ΔV / ΔP	**NB**	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
NB	NVB	NB	NM	NS	Z	PS	PM
NM	NVB	NB	NM	NS	PS	PM	PB
NS	NVB	NB	NM	NS	PS	PM	PB
Z	NB	NM	NS	Z	PS	PM	PB
PS	NB	NM	NS	PS	PM	PB	PVB
PM	NB	NM	NS	PS	PM	PB	PVB
PB	NM	NS	Z	PS	PM	PB	PVB

From the Figure 5 and table 4 it is noted that based on change in voltage and power, the duty ratio is controlled by fuzzy logic controller such as D is increased to move the voltage to the left region of IV curve while the D is decreased to move the voltage to the left region of IV curve (which is shown in Figure 4). Therefore the fuzzy rules are framed in order to track the maximum power of PV panel. When multiple peaks are present in the curve it decreases the performance of FLC MPPT.

2.3.2 ANN based MPPT:

In recent times, Artificial Neural Network (ANN) has been unequivocally created not only in theory but also in application. A general ANN, has numerous layers like input, hidden and output layers. Artificial neural networks are usually offered as systems of interconnected "neurons" which transfer information to each other [17]. The connections have numeric weights which are tuned based on knowledge of system, building neural nets versatile to data inputs and equipped for learning. In this analysis 2 inputs neural network is trained using back propagation with levenberg-marquardt method to produce duty ratio output. Change in PV panel voltage (ΔV) and change in PV panel power (ΔP) are given as inputs to the network. Three layers network such as input layer, hidden layer and output layer are framed to tune duty ratio. To find the optimum duty ratio for a variation in inputs the hidden layer is framed with the 10 number of neurons. The structure of ANN for MPPT is shown in Figure 6.

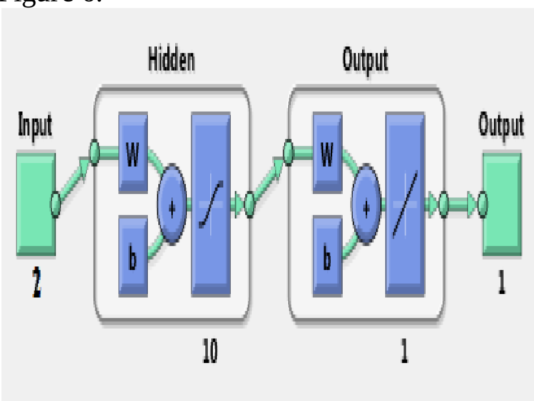

Fig. 6. structure of ANN for MPPT

The D is tuned to track the MPP based on ΔV and ΔP, with the help of ANN trained using 200 epochs.

2.3.3 ANFIS based MPPT:

Adaptive Neuro-fuzzy inference system is an intelligent technique, which is the combination of artificial neural network and fuzzy logic controller has also been utilised by some

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researchers to locate the global maximum [18]. FL deals very well with uncertainties and it is known for its organized learning representation. The ANN is known for their learning capabilities. Thus ANFIS has the advantages of both FL and ANN to track GMPP. The adopted ANFIS network has two inputs and one output. The two inputs of the proposed ANFIS consist of ΔV and ΔP while; the output is the duty ratio. Furthermore, the ANFIS network uses a hybrid learning algorithm that combines the leastsquares estimator and the gradient method with maximum number epoch of 300. The training error is presented in Figure. 7.

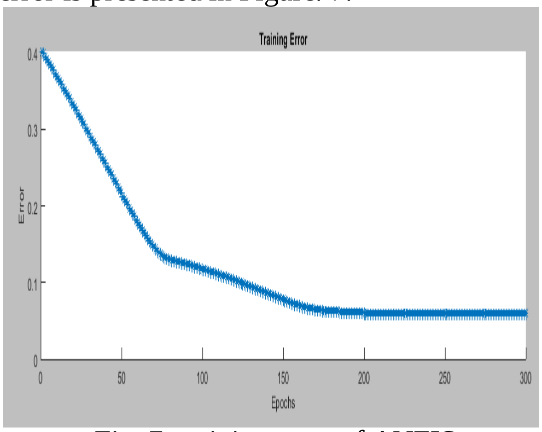

Fig. 7. training error of ANFIS

The generated ANFIS network structure is shown in Figure. 8.

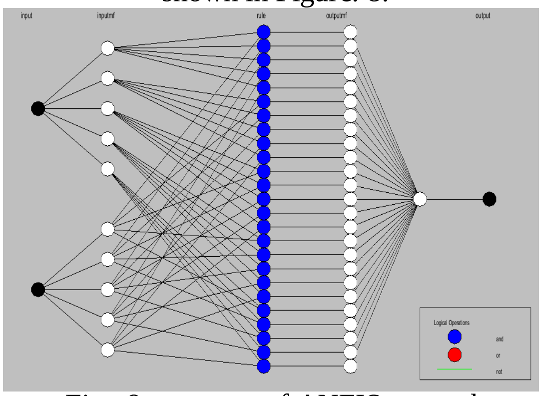

Fig. 8. structure of ANFIS network

Form the Figure 8 it is noted that ANFIS structure has a five layer with two inputs (ΔV and ΔP) and one output (D). Each input parameter has seven "triangular" membership functions which are learned by ANFIS method. Thus, 49 fuzzy rules are generated to track the maximum power for each value of PV voltage and current.

2.3.4 FSM based MPPT:

Fast sweeping method is an optimal controller to deal with non linearity and complex system. Unlike other conventional algorithms the FSM uses Eikonal equation solver to find the optimum value.

The fast sweeping algorithm is developed using the steps as follows,

1. Initialize the point source condition T(**xs**) = 0 and allocate high positive values to the remaining points of the grid which has to be updated.
2. Update grid points with Gauss–Seidel iterations with eight alternating sweeping orders. At every node, the result from eq. (3) mentioned as T* is compared with the old value (T^{old}) and the traveltime at this node T^{new} is updated with the least value among the old and estimated traveltime value, i.e. min(T^{old}, T*). It is significant to state that the sweeping order is not essentially functional in sequential order and can be executed in parallel on numerous processors.
3. Test the convergence by examining the criterion $\|T^{n+1} - T^{n}\|_{L1} \leq \varepsilon$ point-wise, for a specified convergence criterion ε>0.

For MPPT the FSM process with PV voltage and current to find optimum duty ratio. In the application of MPPT FSM the T is replaced with VGmpp. Flow chart of FSM as MPPT in PV system is shown in Figure 9.

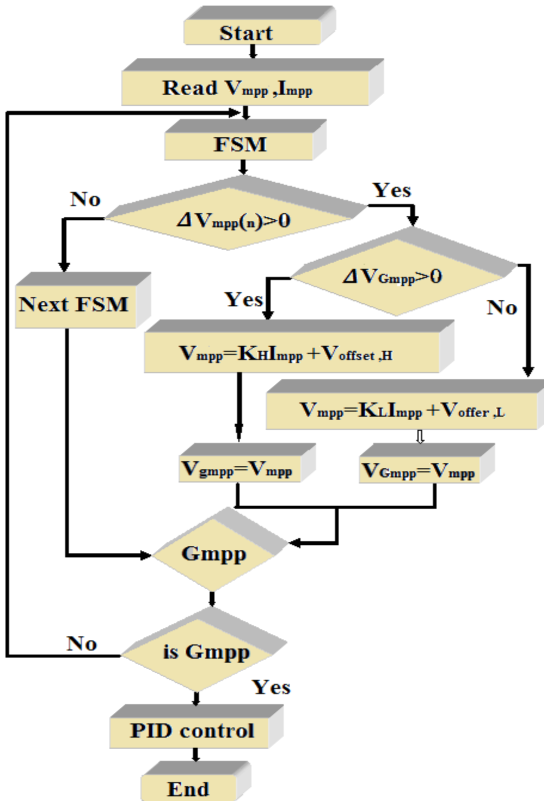

Fig. 9. Flow chart of FSM as MPPT

From the flow chart it is noted that Vmpp and Impp are given as input to FSM and Vgmpp is considered as T. Ftom the Figure 9 it is noted that FSM finds the VGmpp for a given PV panel voltage and current. The Vgmpp is converted into Duty ratio with the help of PID controller connected in series with the output of FSM.

2.4 Inverter with Filter:

Single phase H bridge inverter using IGBT is connected in series with the Buck boost converter to converter controlled DC output voltage from converter into AC voltage for load. In this analysis single phase irrigation pump is considered as load. To improve the quality of voltage from the inverter LCL filter is connected between inverter and pump.

3. Simulation results and analysis:

To analyse the effectiveness of MPPT methods proposed various conditions of irradiance are considered such as constant irradiance in all modules, with PSC. The entire system is developed and analysed using Matlab/Simulink. Simulation model of the proposed system is shown in Figure 10.

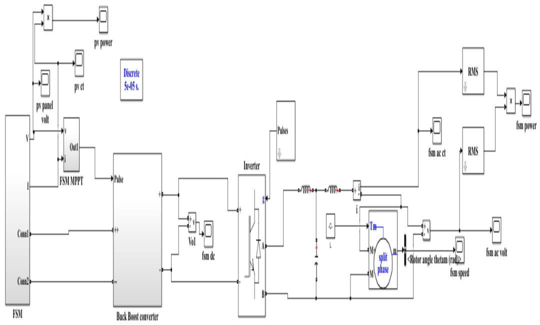

Fig. 10. Simulation model of the proposed system

Case 1: All modules are under PSC:

Performance of PV panel under a PSC (table 2) is shown in Figure 11. Performance of PV system using FLC, ANN, ANFIS and FSM based MPPT are shown in Figures 12-15 respectively.

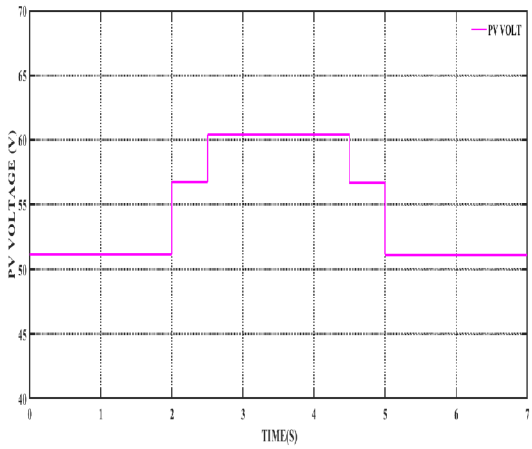

Fig. 11(a). PV Voltage

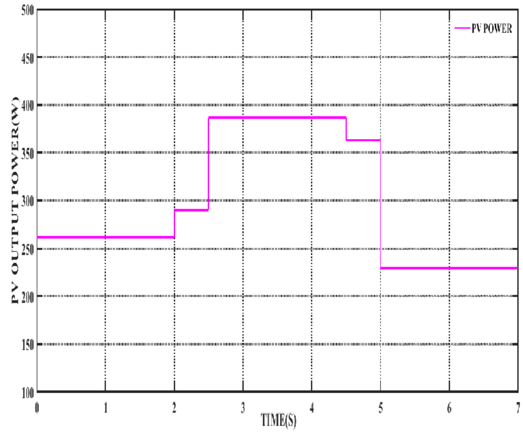

Fig. 11 (b). PV power

Fig. 11. Performance of PV array under PSC

From the Figure 11 voltage and power produced by the proposed 3*2 TCT configuration under PSC which is stated in table 2 are noted. This voltage and power are considered for analysis of various MPPT methods.

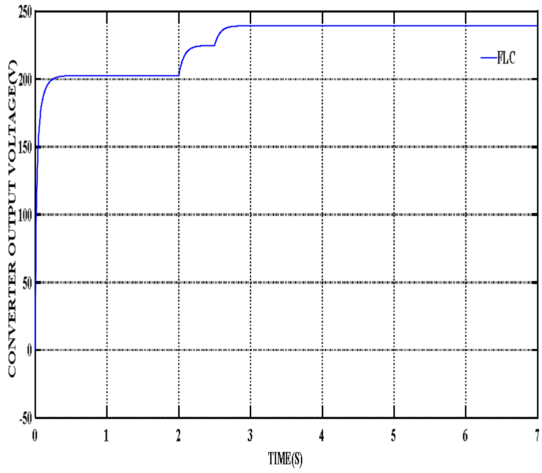

Fig. 12(a). Converter output Voltage

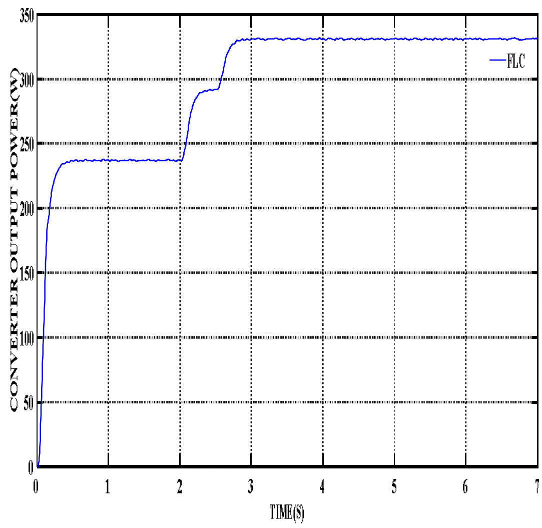

Fig. 12(b). Converter output power

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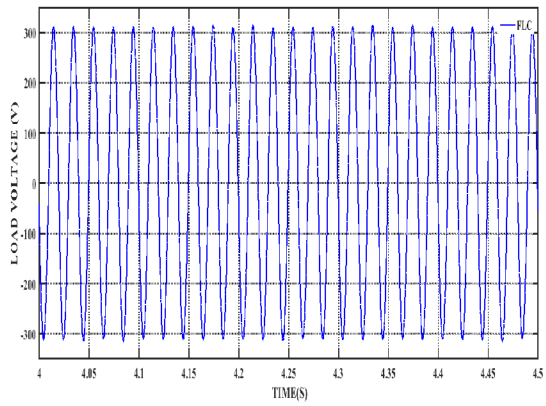

Fig. 12(c). Inverter output voltage

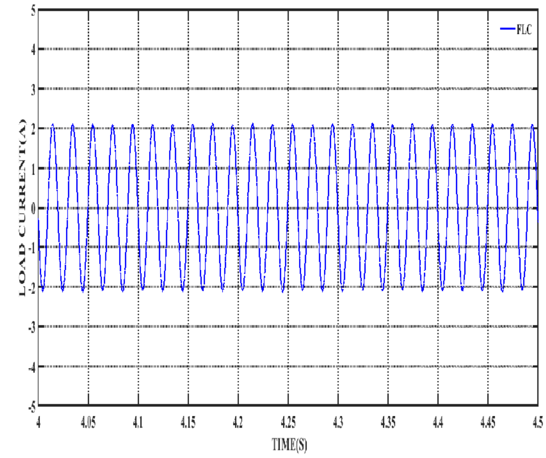

Fig. 12(d). Inverter output current

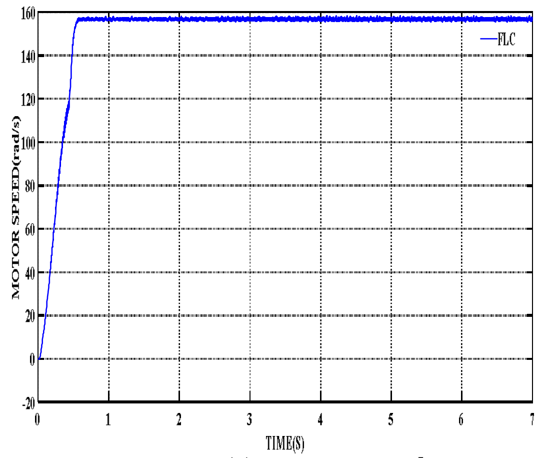

Fig. 12 (e). Motor speed

Fig. 12. Performance of PV system using FLC based MPPT

The input voltage and power for FLC MPPT based PV fed water pump system is presented in Figure 11. From the Figure 12 stage by stage output of system analysed is noted. It is observed that when PV output reaches maximum power, FLC MPPT controlled DC-DC buck boost converter reaches its maximum power and sustain in it, even when input power reduces.

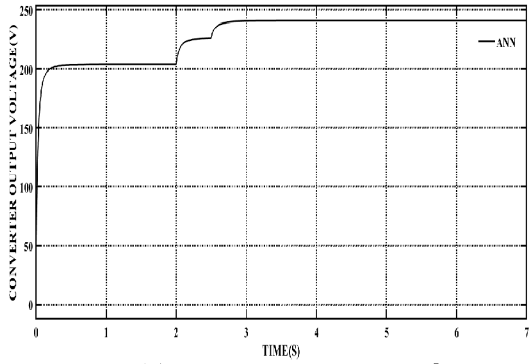

Fig. 13(a). Converter output Voltage

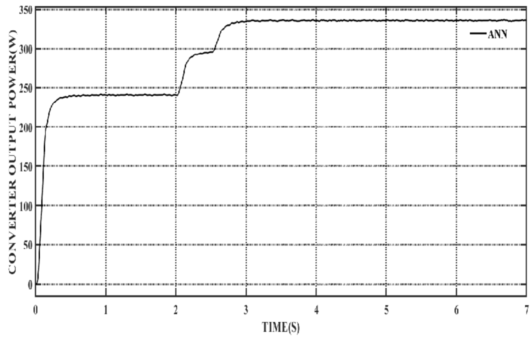

Fig. 13(b). Converter output power

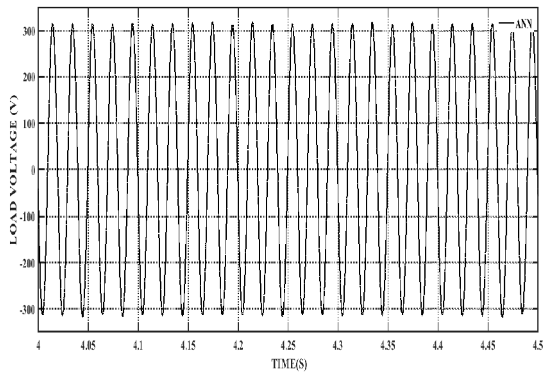

Fig. 13(c). Inverter output voltage

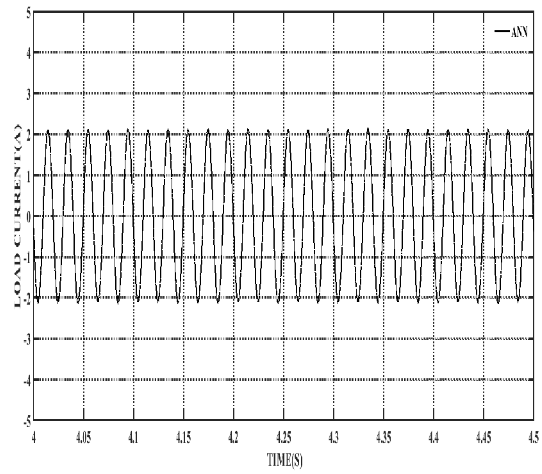

Fig. 13(d). Inverter output current

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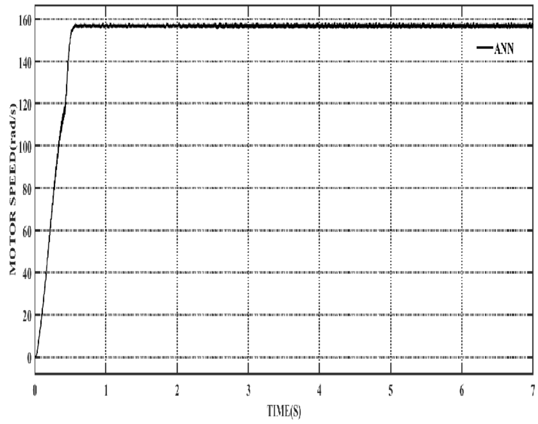

Fig. 13 (e). Motor speed

Fig. 13 Performance of PV system using ANN based MPPT

From the Figure 13 stage by stage output of ANN MPPT based PV power system analysed is noted. From the Figure it is observed that with the help of ANN MPPT buck boost converter produces 241V DC output. It is converted into pure sine wave 222V AC by inverter with filter unit and supplies motor. The motor speed is shown in Figure 13(e).

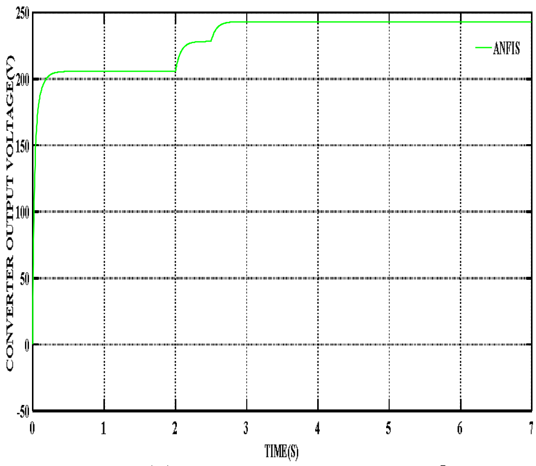

Fig. 14(a). Converter output Voltage

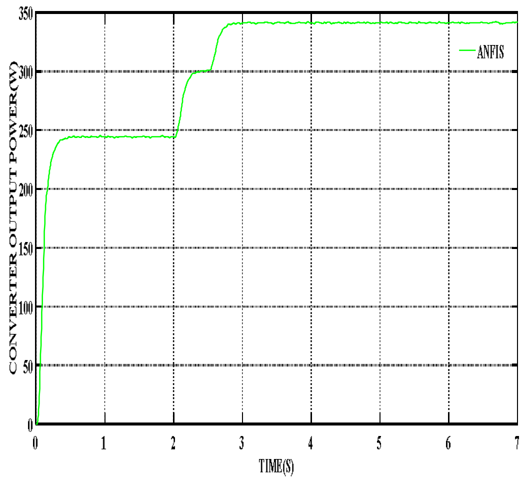

Fig. 14(b). Converter output power

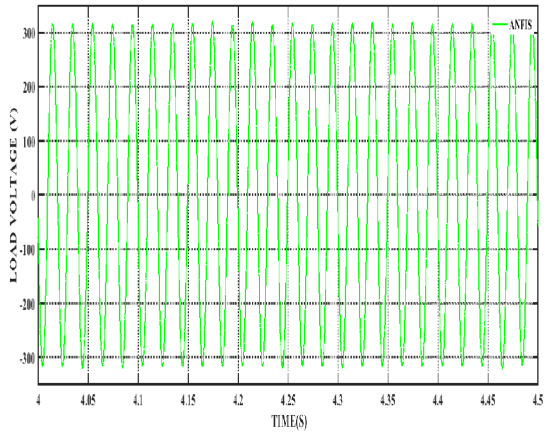

Fig. 14(c). Inverter output voltage

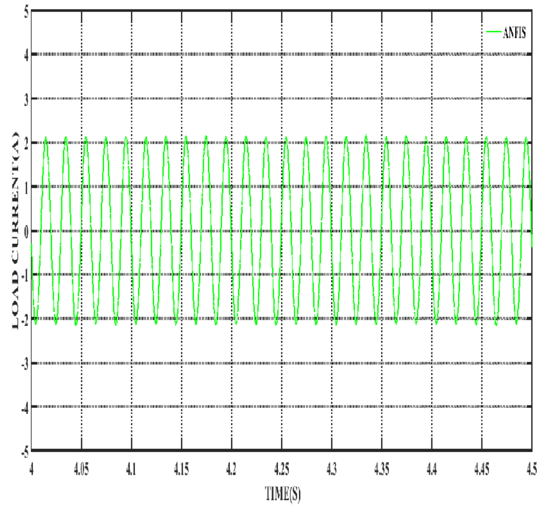

Fig. 14(d). Inverter output current

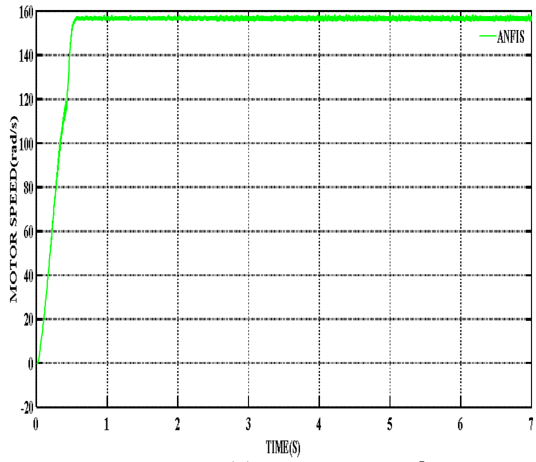

Fig. 14 (e). Motor speed

Fig. 14Performance of PV system using ANFIS based MPPT

Stage by stage output of ANFIS MPPT based PV power system analysed is observed from the Figure 14. From the Figure 14 it is noted ANFIS MPPT boosts the converter voltage to 243V, which is greater than ANN MPPT based converter.

BUPT

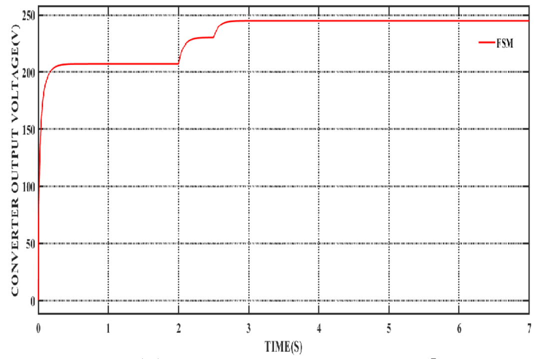

Fig. 15(a). Converter output Voltage

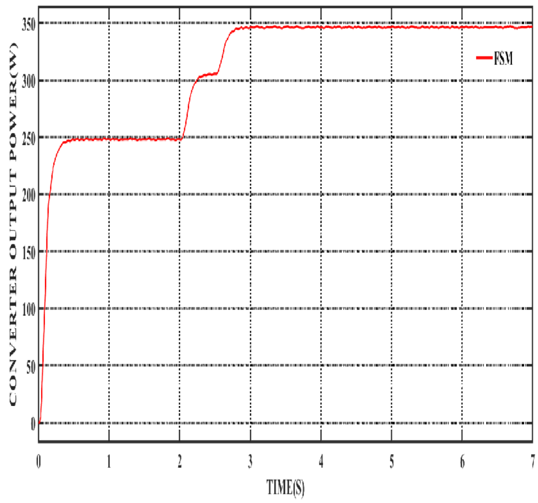

Fig. 15(b). Converter output power

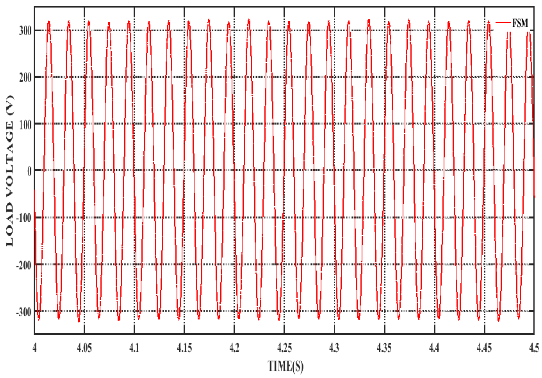

Fig. 15(c). Inverter output voltage

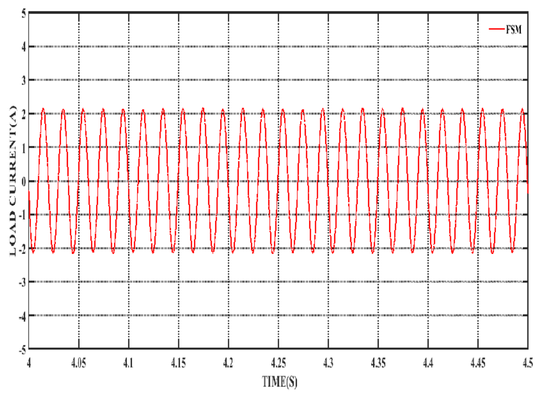

Fig. 15(d). Inverter output current

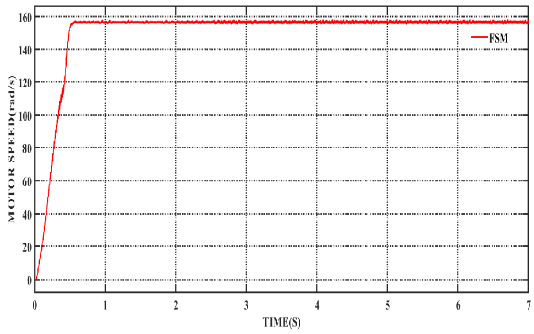

Fig. 15 (e). Motor speed

Fig. 15Performance of PV system using FSM based MPPT

From the Figure 15 it is noted that FSM based MPPT results 245V in buck boost converter, which is higher than all other MPPT methods discussed above from Figures 12 to 14. FSM tracks and settles in maximum power of 347 W and runs the pump at maximum speed of 1480 rpm.

Comparative performance various MPPT under dynamic partial shading condition is shown in Figure 16 and 17.

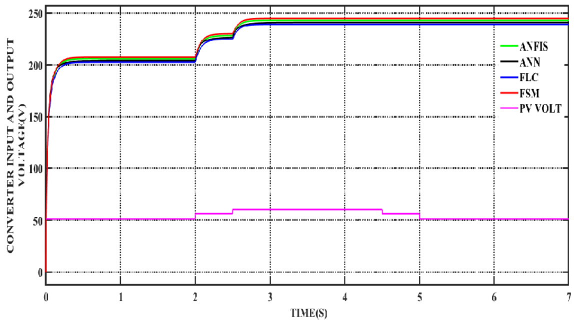

Fig. 16. Comparative DC voltage performance various MPPT under PSC

From the Figure 16 it is noted that the FSM produces highest voltage compare to all the controllers.

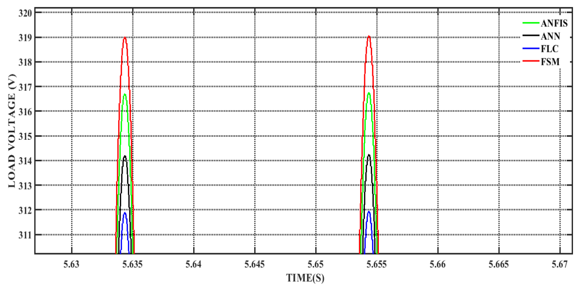

Fig. 17. Comparative AC voltage performance various MPPT under PSC

The effect of MPPT on DC-DC buck boost converter decides the input to the inverter. From the Figure 17 it is noted that the efficient FSM produces nearly required 230V AC (rms) voltage to the load.

Comparative performance of all MPPTs under PSC is shown in table 5.

Table 5
Comparative performance of allMPPTs under PSC

Controllers	Parameters			
	Converter Output Voltage (V)	Converter Output Power (W)	Inverter Output Voltage (V)	Motor speed (rpm)
FLC	239.2	330.5	220.5	1477
ANN	241.2	336	222	1478
ANFIS	243	341	224	1479
FSM	245	347	225.6	1480

From the table 5 it is clear that in all aspects FSM offers better performance than ANFIS, ANN and FLC based MPPT

Case 2: all modules with constant irradiance

Figure 18 shows the performance of PV system using various MPPT with constant irradiance

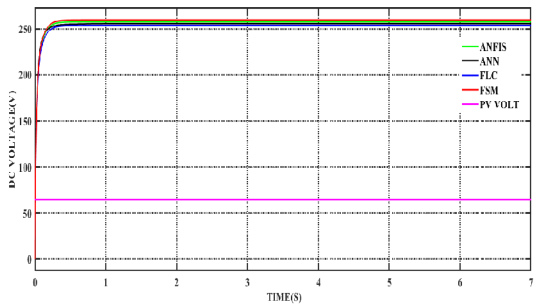

Fig. 18. Comparative DC voltage performance using various MPPT under constant irradiance

From the Figure 18 it is noted that under constant irradiance Except FSM all other MPPT produces almost equal voltage. Rise in FSM voltage compare to all other controllers is also not noticeable. The effect this control in a motor speed is shown in Figure 19.

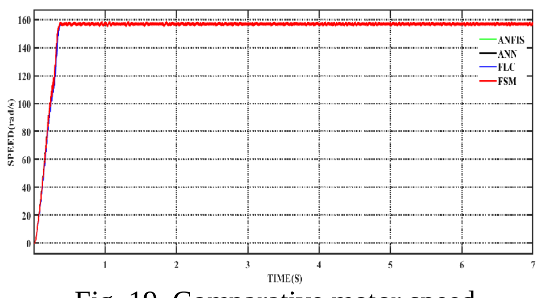

Fig. 19. Comparative motor speed performances using various MPPTs under constant irradiance

From the Figure 19 it is observed that under constant irradiance performance of all MPPTs are almost same. From the analysis FSM MPPT improves not only DC voltage and DC power as output of converter, it results improved performance of water pump. The maximum voltage produced by the FSM reduces more current by the pump to meet the load, which reduces losses and improves efficiency of pump.

4. Conclusion:

PV powered pump for application of agriculture is analysed under partial sahding condition. Initially to meet PSC, various configurations of PV panels such as SS,SP,BL and TCT are analysed. From the analysis it is proven that TCT provides best performance in case of PSC. Effective MPPT is required to track Maximum power when multiple peaks occur due to PSC. In this paper novel FSM is proposed and analysed as MPPT in TCT conFigured system under PSC as well as with the constant irradiation. Effectiveness of the proposed system is compared with the other intelligent FLC, ANN and ANFIS controllers. Effectiveness of the proposed system is analysed in the aspects of converter output voltage, power, inverter voltage and motor speed. Effective tracking of maximum power by FSM results improved DC voltage, results required AC voltage to run the pump and reduces losses in a pump which enhances its efficiency. From the analysis it is proven that FSM MPPT produces best performance under any circumstance such as constant irradiation or PSC.

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