Cascaded Feed Forward Multilayer Neural Network based MPPT Controller for Improving the Performance of Photovoltaic System

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Abstract: This paper deals with the energy production of photovoltaic (PV) cells in different weather conditions. Today, photovoltaic generation plays an important role in generating electricity and satisfies the demand of the island's consumers. The power generation of the PV cell was completely dependent upon sunlight and temperature, but sunlight and temperature changed forever in nature. The many researchers are working on different MPPT technologies for a PV system. Conventional MPPT controllers cannot withstand a sudden change of weather conditions. The main aim of this article is to compare the various conventional and intelligent controller such as the GA, Fuzzy, KGMO, and CNFF for MPPT of the PV system. The proposed intelligent controller was developed and simulated by the MATLAB environment for MPPT in the PV system. In addition, the above results are evaluated and compared. Based on performance, the optimal smart controller has been recommended as MPPT of the PV system.

Keywords: Cascaded Feed Forwarded Neural Network (CFNN), KGMO, Fuzzy, GA, MPPT, PV

I. INTRODUCTION

The quick growth in energy consumption, CO2 emissions and the global inadequacy of demand and supply is due to the increasing rate of population growth and levels of urbanization [1][2]. Under the environmental concern like shortage of energy and pollution, RES such as Solar and Wind are the most suitable replaced energy sources which are presence the foremost energy of recent power systems. Micro grid (MG) integrates flexible DGs, such as wind power, solar power and fuel cells, with manageable storage and loads to form a low-voltage distribution system [3-6]. They improve the reliability of the network and provide durability and quality electrical energy. Managing an MG with an extensive selection of Distributing Generations, fluctuating loads and ESA is a difficult task, particularly below the high level of penetration of renewable energy (RG) generation. The RG is typically organized using maximum power tracking algorithms to emphasize the high use of efficiency energy [7-10]. It is therefore considered a generation that cannot be modulated because of changing and uncontrollable weather conditions [11-15]. Maximum power monitoring technology will play a major role in producing maximum energy from a photovoltaic cell in various weather conditions. A major challenge to regulate the PV generated non-linear current characteristics and voltage during periods of low sunshine or partially shaded situations. Many MPPT algorithms have now been proposed by the researchers to achieve maximum energy production from a photovoltaic system.

Among many little MPPT techniques are very popular like P&O, Incremental Conditions, Feedback voltage and current, voltage and frequency method, feedback power methods. The above conventional methods fail to achieve the speed of operation and maximum power production due to lack of self-regulation capability. In this document proposed various intelligent controller based on MPPT techniques to achieve maximum power output as well as operating speed (auto-adjustment). MPPT techniques based on intelligence are modelled and analyzed in the MATLAB environment. Section 2 provides the mathematical model for the photovoltaic system and design of boost converter. The various Smart Controllers are addressed in Section 3. The proposed intelligent controllers are modelled in Section 4 intelligent Controllers are simulated in MATLAB and analyzed the performances of PV system with various weather conditions. Finally, the hardware and comparative study is presented in section 5. Conclusion of the proposed research is delivered in Section 6.

II. MPPT SYSTEM

RGs plays a vibrant role in reaching consumer's energy requirement because of their ampleness and lower environmental influence. The key obstacle to expanding PV power is the capital cost of implementing the PV system [8]. The production of energy through PV is not constant throughout the day because of climate change. The productivity of electricity production is very low (the productivity is in between 10-17% in low radiation regions).

Consequently, MPPT technologies play a vibrant role in the production of PV energy for best energy production in various environmental circumstances. Various MPPT methodologies are discussed below.

II.I Mathematical Model of Photovoltaic System

The photovoltaic cell is depicted as a Dependent current source parallel to a diode as shown in the Figure 1 including supplementary series and parallel resistors. It should be noted that there will be no power generation in the absence of solar light and that the PV cell will act as a diode. True current from the current source (PV cell) depends on the daylight effectively falling on the PV cell (photo-current) (Figure 1)

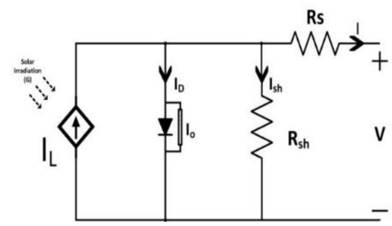


Fig.1. The Equivalent PV cell Circuit

Open Circuit Voltage

The PV cell voltage production be subject to the voltage drop across the diode,

$$V = \left(\frac{NKT}{Q}\right) \ln \frac{I_L - I_o}{I_o} + 1 \quad (1)$$

Where

V = PV Cell OC voltage

N = diode constant 1.50

K = Boltz const (1.381x 10-23 JK-1)

T = temp in Kelvin

Q = elementary charge (1.602 x 10-19 Coulomb)

IL = current generated by the light = Iph (A)

Io = diode current capacity (A)

Current Generated by the Light (Radiation)

$$I_L = \left(\frac{G}{G_{ref}}\right) * (I_{L\,ref} + \propto_{Isc} \, (T_C - T_{C\,ref})) \quad (2)$$

Where

G = instant irradiation (W/m2)

Gref = reference irradiation under standard condition 1000 W/m2

ILref = reference Photoelectric current under standard condition 0.15 A

Tc = Instant temp.

TCref = temp of the model at 298.0 K

αISC = short circuit current temp co-effi (A/K)=0.0065 AK-1

IL is Current Generated by the Light (Radiation)

Reverse Current Capacity

$$Io = I_{or} \left(\frac{T_c}{T_{ref}}\right)^3 e^{\overline{(K*N)*\left[\left(\frac{1}{Tcref}\right)-\left(\frac{1}{Tc}\right)\right]}^{\,(Q*Eg)}} \quad (3)$$

$$\mathbf{I_{or}} = \frac{\mathbf{I_{scn}}}{\mathbf{e}^{\left(\frac{\mathbf{V_{ocn}}}{\mathbf{N*V_{tn}}}\right)}} \quad (4)$$

Where

Io = Reverse current Capacity

Ior = current Capacity

Eg = silicon diode band gap 1.10 eV

S C Current (Ish = Il)

This is the utmost value of the current produced by a cell under SC conditions: Volt = 0.00 V

$$\mathbf{I_{sh}} = (\mathbf{I_L} - \mathbf{I_o}) * \left(\mathbf{e}^{\frac{\mathbf{eV}}{\mathbf{KT}}} - \mathbf{1}\right) \mathbf{A} \quad (5)$$

II.II. Boost Converter Design.

Boost Converter is working as a DC-DC step up converter, which is used to convert fluctuating DC voltage with respect to change in weather conditions to constant stepped up voltage to connect to the inverter for grid integration and domestic applications, here the boost converter is designed with diode, MOSFET as switch and load element to capture the output voltage. The output voltage is varied according to triggering duty cycle. Fig.2 shows the basic structure of boost converter.

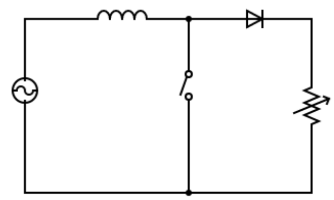


Fig.2. Basic Structure of Boost Converter

Duty cycle of MOSFET or switch is given as

$$\boldsymbol{D} = [\boldsymbol{1} - \frac{\boldsymbol{V_{in(\min)} * \eta}}{\boldsymbol{V_{out}}}] \quad (6)$$

Change in ripple current

$$\boldsymbol{di} = \boldsymbol{i_{ripple}} * \boldsymbol{i_{out}} * \frac{\boldsymbol{v_{out}}}{\boldsymbol{v_{in}}} \quad (7)$$

The output current of converter

$$\boldsymbol{I_{out}} = \frac{\textbf{Converter Power Rating}}{\textbf{Converter output voltage}} \quad 8)$$

Inductance of boost converter

$$\boldsymbol{L} = \frac{[\boldsymbol{v_{in}}(\boldsymbol{v_{out}} - \boldsymbol{v_{in}})]}{\boldsymbol{di} * \boldsymbol{f_s} * \boldsymbol{v_{out}}} \quad (9)$$

Acceptable change in voltage

$$\boldsymbol{Dv} = \frac{\boldsymbol{v_{out}}}{\boldsymbol{dv\ percent/100}} \quad (10)$$

Output capacitor to reduce the ripples

$$\boldsymbol{C} = \frac{\boldsymbol{I_{out}} * \boldsymbol{D}}{\boldsymbol{f_s} * \boldsymbol{dv}} \quad (11)$$

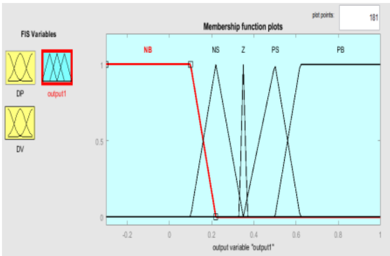
Output Resistor

$$R = \frac{V_{out}}{I_{out}} \quad (12)$$

III. MPPT ALGORITHMS

III.I. Fuzzy Logic (FL) Controller Algorithm

The FL controller is the most popular expert systems and proven intelligent algorithm. The basic fuzzy control block diagram is shown in fig.3.a the fuzzy logic supervisor has two inputs such as a modification in voltage and modification in power as shown in fig 3.b. The output of fuzzy logic supervisor is the duty cycle of semiconductor switch (MOSFET). The input membership function of FL controller has 5 major subdivision, such as NB, NS, Z, PS and PB as shown in fig 3.c & fig 3.d. In this input membership function trapezoidal function has been used for negative big and positive big for smoothing the operation. Other membership functions are a triangular function has been used for other membership functions such as negative small, zero and positive small [8]. Based on input and output membership function the fuzzy rules-based inference system has been developed 25 rules presented in fig 3.e.



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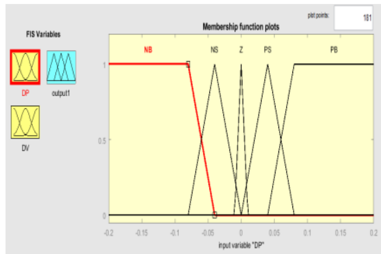

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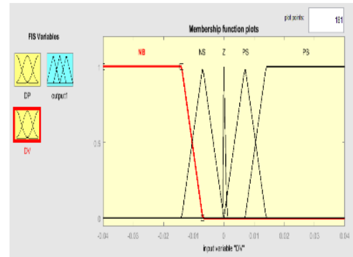

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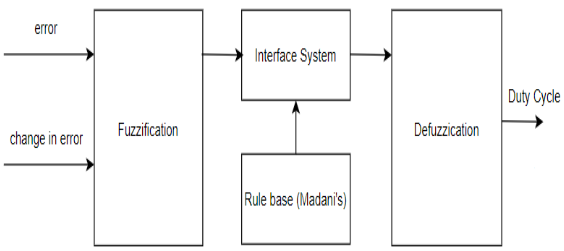
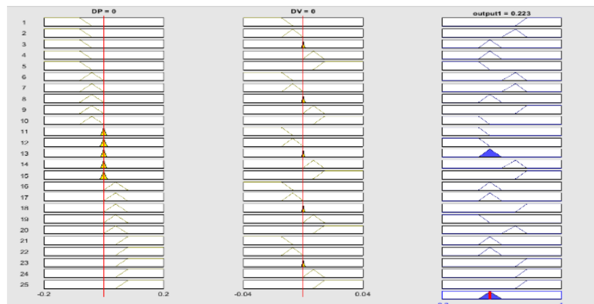


(a)



(e)

Fig.3. Fuzzy Logic Controller design parameters
(a). Basic block diagram of Fuzzy Controller (b). Fuzzy input membership function of change in power to change in voltage (c). Fuzzy input membership function of rate of change in power to rate of change in voltage (d). Fuzzy output membership function of duty cycle. (e). Fuzzy rules-based inference system

Table 1. Fuzzy Rules

DP/DV/ Change in DP/DV	**NB**	**NS**	**Z**	**PS**	**PB**
NB	PB	PS	NB	NS	NS
NS	PS	PS	NB	NS	NS
Z	NS	NS	NS	PB	PB
PS	NS	PB	PS	NB	PB
PB	NB	NB	PB	PS	PB

III.II. Genetic Algorithm

GA is an algorithm for stochastic optimization through natural genetic selection. The process takes OC Voltage and Isaac as contributions and it results the best maximum power current (Imp) using the modelling of the cell, without knowledge of the ordinance and temperature [16-18]. The process is developed using MATLAB Code in the embedded Simulink block by the essential functions, with the Genetic Algorithm constraints and PV constraints are respectively the parameters Genetic Algorithm and PV panel. The fig.4 shows the flowchart of Genetic algorithm.

III.III. KGMO Algorithm

The basic principle of gas molecules optimization algorithm (KGMO) was suggested with the concept of laws of gas molecules. It develops laws based on experiential explanations to convey the macroscopic performance of gas particles. The nuclear theory of gases tells that all materials consist of a great number of molecules or atoms. The properties of gases like pressure, volume and temperature are the outcomes of the achievement of the particles that comprise the gas. There are five theories that define how molecules perform in a gas. The molecular kinetic concept of idyllic gases is described as follows:

1. A gas consists of a group of particles that transportable in a conventional, Motion of gas particles based upon the Newton's law.
2. Particles within a gas are sockets and do not inhabit any volume.
3. The Bump of particles are totally flexible hence no energy is increased nor vanished over the course of the Bump.
4. There are no alluring or repulsive forces exist among the particles.
5. The avg KE of a particle is 3, it is=2, when T is the out-and-out temp, and k is Boltz const.

$$X_{i=x_i^1,..,x_i^d,...,x_i^n} \qquad i\in N_p \tag{13}$$

$$V_{i=v_i^1,..,v_i^d,...,v_i^n} \qquad i\in N_p \tag{14}$$

$$K_i^d(t) = \frac{3}{2}\, NbT_i^d(t), \;\; K_{i=k_i^1,..,k_i^d,...,k_i^n} \qquad i\in N_p \tag{15}$$

$$V_i^d(t+1) = T_i^d(t)wv_i^d(t) + C_1 rand_i(t)\left(gbest^d - x_i^d(t)\right) + C_2 rand_i(t)(pbest_i^d(t) - x_i^d(t)) \tag{16}$$

$$T_i^d(t) = 0.95 \times T_i^d(t-1) \tag{17}$$

$$X_i^d(t+1) = \frac{1}{2}a_i^d(t+1) \times t^2 + V_i^d(t+1) \times t + x_i^d(t) \tag{18}$$

This segment outlines the kinetic optimization development with gas molecules. The gas particles moves with in the vessel till they meet into the part of vessel which has the least temp and KE. Gas particles interest each other on the basis of low intermolecular electric forces, where the electric force is the outcome of progressive and adverse loads in the particles. In this method, each gas particle and the agent, has four features: position, KE, speed & mass. The kinetics of every gas particle determine the speed and location of the gas molecule. In this method, the gas particles discover the whole research space and achieve the lowest temp. The fig.5. Shows the flow chart of KGMO algorithm

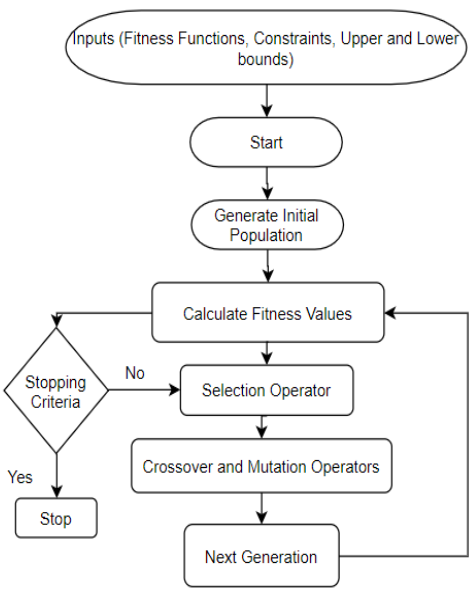


Fig.4. Flowchart for Genetic Algorithm

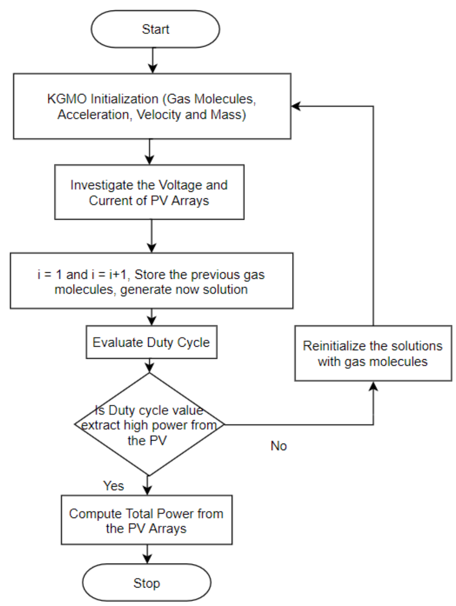


Fig.5. Flowchart for KGMO Algorithm

III.IV. Cascaded Feed Forward Neural Network (CFNN) (Machine Learning based) MPPT Algorithm

The CFNN is a feed-forward (FF) neural network, s but it includes a link from the contribution layer and each prior layer to the following layers. In a three-layer network, the production layer is also associated openly to the contribution layer adjacent to the concealed layer. As with FF networks, a cascading network with 2 or more layers may learn any arbitrarily finite I-O relationship with enough hidden neurons [19-22]. The CFNN can be used for any type of contribution to the production cartography.

The benefit of this technique is that it takes into account the non-linear association among entry and exit without eradicating the linear affiliation between the two.

In the perceptron assembly which is designed among the contribution and the production is a form of undeviating association, whereas on FFNN the assembly formed among the contribution and the production is a secondary association. The linking is non-linear by an activating function in the concealed layer. If the linking form on perceptron and multilayer grid is combined, then the grid with a direct linking among the contribution layer and the production layer is molded, moreover the linking incidentally. The network formed from this connecting model is known as the CFNN.

The network molded by this linking model is named a cascading neural network (CFNN). The equations can be as follows:

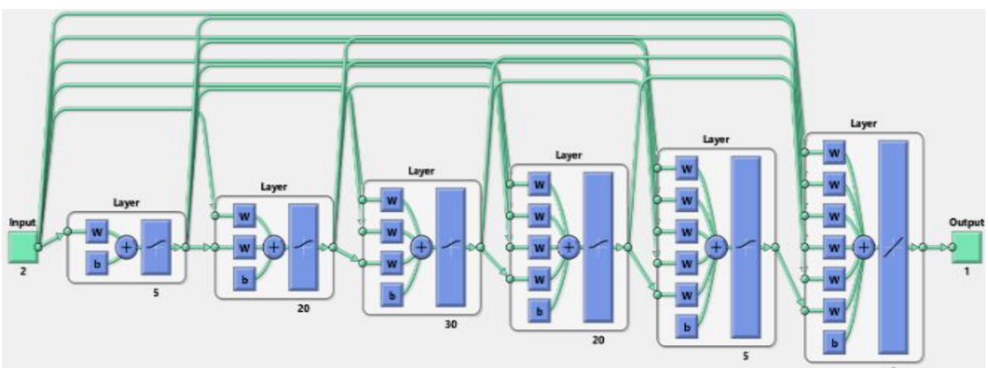
$$y = \sum_{i=1}^{n} f^i w_i^i x_i + f^o(\sum_{j=1}^{k} w_j^o f_j^h(\sum_{i=1}^{n} w_{ji}^h x_i)) \qquad (19)$$

Where fi is the activation function and wii is weight from the contribution layer to the production layer. If a bias is introduced to the contribution layer and the activation function of each neuron in the concealed layer is fh then equation becomes

$$y = \sum_{i=1}^{n} f^i w_i^i x_i + f^o(w^b + \sum_{j=1}^{k} w_j^o f_j^h(w^b + \sum_{i=1}^{n} w_{ji}^h x_i)) \qquad (20)$$

In this investigation, the CFNN model is applied in time series data. Thus, the neurons in the contribution layer are the lags of time series data Xt-1, Xt-2, ..., Xt-p, whereas the production is the current data Xt.

The proposed multi-layered cascade neural network model has been developed for an algorithm to trace maximum power points for the PV system as shown in fig 6.a.. This network is equipped with two contributions such as PV voltage and PV current. The production of this network is the duty cycle of DC-DC converter. There are 4 concealed layers used from the contribution layer to the production layer. Each concealed layer has a different number of neural are used such as 20 neurons are used in layer 1, 30 neurons are used in layer 2, 20 neurons are used in layer 3 and 5 neurons are used in layer as shown in fig. The proposed network has been trained on more than 10000 data such as PV voltage, PV current and duty cycle. The more than 1000 epochs have been done to generate the MPPT algorithm and this network has been well trained. Thus, the best driving performance of the proposed CNFF is 9.2922 x 16-17, as shown in the fig 6.b.. Gradient analysis, Mu and validation check for the proposed CNFF as shown in fig 6.c. Finally, the suggested network regression value is presented in the fig 6.d.



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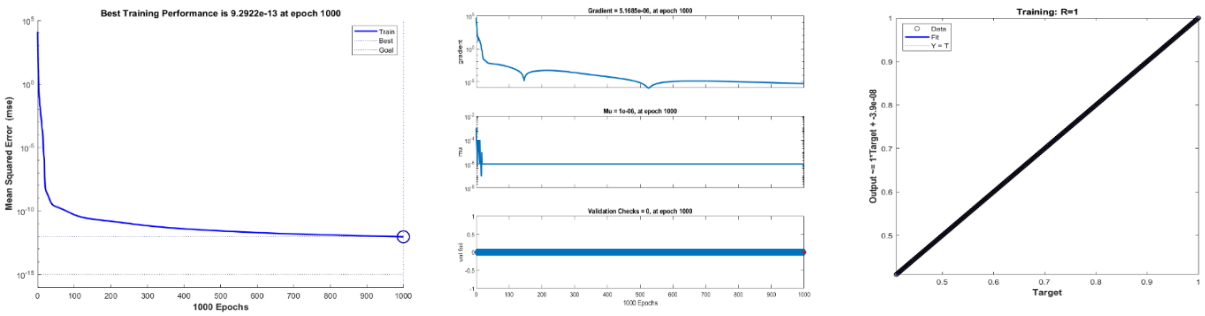


(b)

(c) (d)

Fig.6. CFNN Control Design Parameters

(a). Cascade Feedforward multilayer Neural Network for MPPT Algorithm (b). Analysis of best training performance of proposed CNFF (c). Analysis of gradient, Mu and Validation check for proposed CNFF (d). Analysis of regression for proposed CNFF

IV. SIMULATION RESULTS

In this paper that the finding Maximum Power Point using different algorithms has been implemented and the simulation results are as shown below.

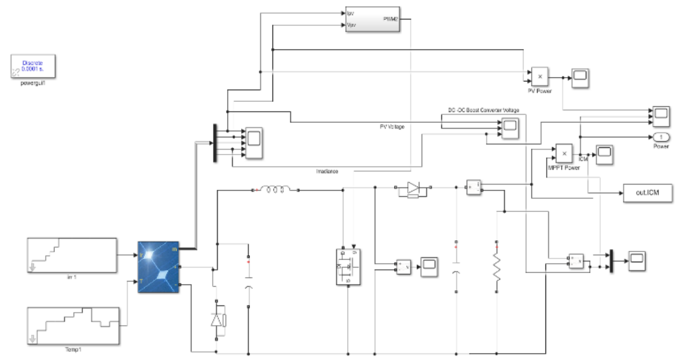
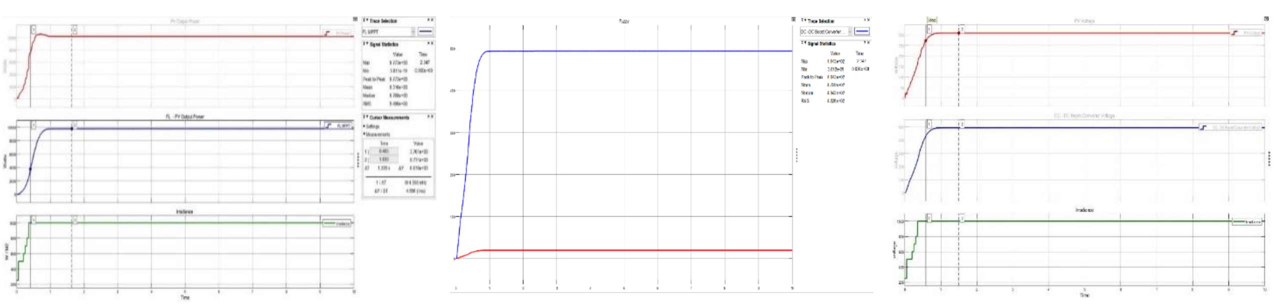


Fig.7. Simulation model 10 kW PV system for Various MPPT Algorithms

IV.I. Fuzzy Logic (FL) Controllers Results



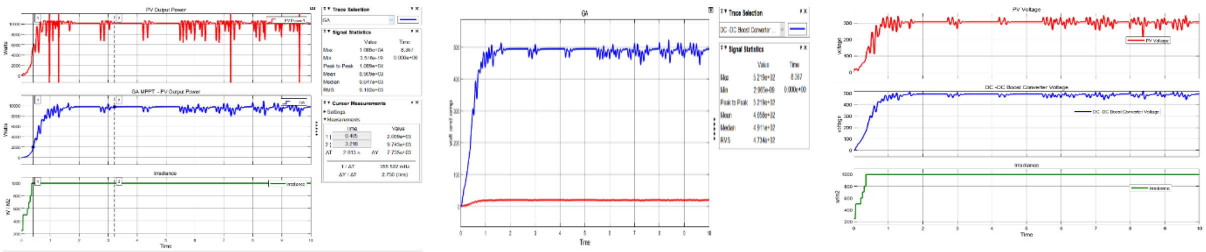
(a) (b) (c)

Fig. 8 Fuzzy Logic Controller Results

(a). PV output power vs MPPT PV power under various integration (b) Boost converter output voltage and current (c) PV output Voltage vs Boost converter output Voltage under various irradiance

The designed fuzzy logic Controller had implemented in MATLAB/Simulink model of 10 kW PV system. This simulation model has been analyzed under standard operating conditions. The simulation results are evaluated. The same simulation model the variable irradiance has been applied input of PV system and analyses system performance. Under various weather conditions the PV output power and MPPT output power has been recorded and plotted in fig 8.a. The boost converter voltage and current waveform are plotted under various weather conditions 493.4 V and 19.8 respectively in fig 8.b. Compare PV output Voltage 310 V and Boost converter output voltage 493.4 V under various irradiance as shown in fig 8.c.

IV. II Genetic Algorithm Results



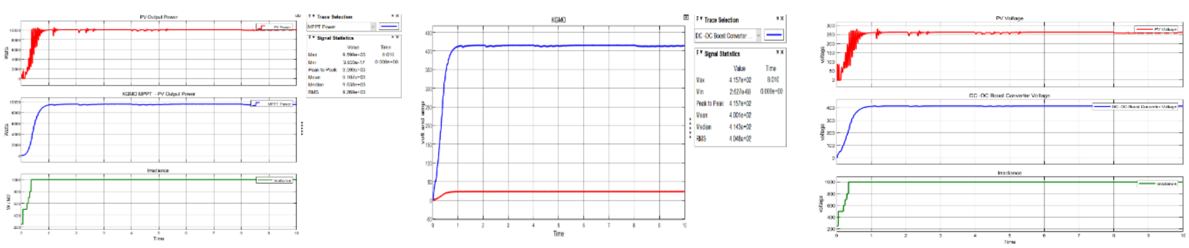
(a) (b) (c)

Fig.9. Genetic Algorithm Results

(a). PV output power vs MPPT PV power under various integration (b). Fig 19. Boost converter output voltage and current (c). PV output Voltage vs Boost converter output voltage under various irradiance

The designed GA Controller had implemented in MATLAB/Simulink model of 10 kW PV system as shown in fig 7. This simulation model has been analyzed under standard operating conditions. The simulation results are evaluated. The same simulation model the variable irradiance has been applied input of PV system and analyses system performance. Under various weather conditions the PV output power and MPPT output power 9743 W has been recorded and plotted in fig 9.a.. The boost converter voltage and current waveform are plotted under various weather conditions 491 V and 19.8 respectively in fig 9.b.. Compare PV output Voltage 310 V and Boost converter output voltage 491 V under various irradiance as shown in fig. 9.c.

IV.III KGMO Algorithm Results



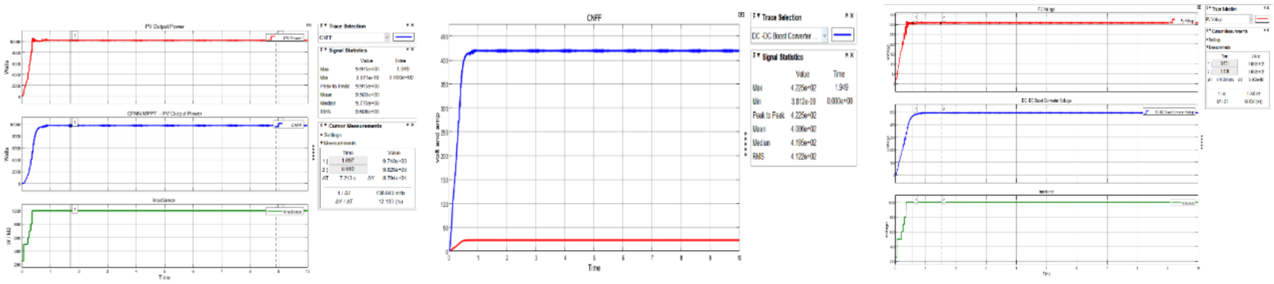
(a) (b) (c)

Fig.10. KGMO Algorithm Results

PV output power vs MPPT PV power under various integration (b). Boost converter output voltage and current (c). PV output Voltage vs Boost converter output voltage under various irradiance

The designed KGMO Controller had implemented in MATLAB/Simulink model of 10 kW PV system as shown in fig 7. This simulation model has been analyzed under standard operating conditions. The simulation results are evaluated. The same simulation model the variable irradiance has been applied input of PV system and analyses system performance. Under various weather conditions the PV output power and MPPT output power 9599 W has been recorded and plotted in fig 10.a. The boost converter voltage and current waveform are plotted under various weather conditions 415 V and 19.8 respectively in fig 10.b. Compare PV output Voltage 310 V and Boost converter output voltage 415 V under various irradiance as shown in fig 10.c.

IV.IV Cascaded Feed Forforded Neural Network Algorithm Results



(a) (b) (c)

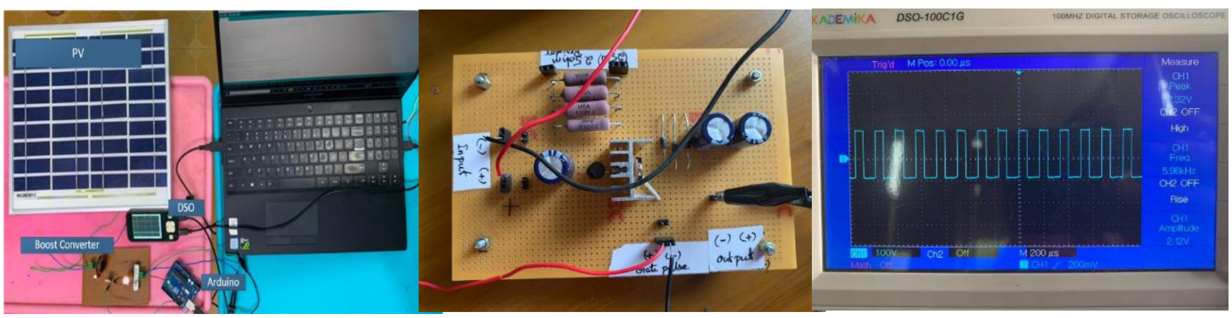
Fig.11. CFNN Algorithm Results

(a) PV output power vs MPPT PV power under various integration (b). Boost converter output voltage and current (c). PV output Voltage vs Boost converter output voltage under various irradiance

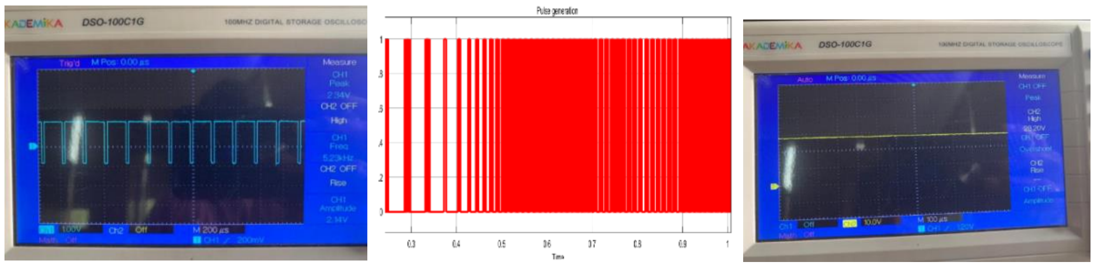
The designed proposed CNFF Controller had implemented in MATLAB/Simulink model of 10 kW PV system as shown in fig 7. This simulation model has been analyzed under standard operating conditions. The simulation results are evaluated. The same simulation model the variable irradiance has been applied input of PV system and analyses system performance. Under various weather conditions the PV output power and MPPT output power 9915 W has been recorded and plotted in fig 11.a. The boost converter voltage and current waveform are plotted under various weather conditions 422 V and 19.8 respectively in fig 11.b.

V. HARDWARE RESULTS

The proposed system was developed as a functional model of 10W PV system and power converter as shown in Figure 12.a. The proposed CNFF algorithm has been interfaced with Arduino mega 2560 controller, which is helpful to develop duty cycle based on input changes. Arduino's Mega 2560 interfaces directly with MATLAB using a MATLAB simulation library. Design data can be found in Table 2. The switching pulses are generated by the proposed algorithm and its run cycle will change with respect to climate change. Figure 12.b accounts for 50% of the utilization cycle generated by the proposed algorithm. Figure 12.c represents a 90% operating cycle created by the proposed algorithm. The proposed algorithm for the duty cycle of switching pulses under different weather conditions in MATLAB is shown in Figure 12.e. The 28.20 V DC-DC converter output voltage prototype model (12 V input) as shown in Figure 12.f.



(a) (b



(d) (e) (f)

Fig. 12 Hardware Results

(a) Working model of PV MPPT system (b). DC-DC Converter Model (c). Switching signal with 50 % duty cycle (d). Switching signal with 90 % duty (e). Pulse generation by proposed CNFF algorithm (f). DC-DC Converter output Voltage 28.2 V (Input 12 V)

Table 2: PV and Boost converter parameter

S.No	Parameter	Value
1	Power	10 W
2	Voc	21.20 V
3	Isc	0.66 A
4	Vmax	17.40 V
5	Imax	0.58 A
6	Capacitor c1	100 µf
7	Capacitor c2	4700 µf
8	Inductor	0.05 H
9	MOSFET	IRF540 N
10	Resistance	33 Ω

Table 3 Comparison

S. No.	Name of algorithm	MPPT Power	Conversion Percentage
1	INC	8405	84.05%
2	PSO	9312	93.12%
3	Fuzzy	9773	97.73%
4	GA	9192	91.92%
5	KGMO	9599	95.99%
6	CNFF	9915	99.15%

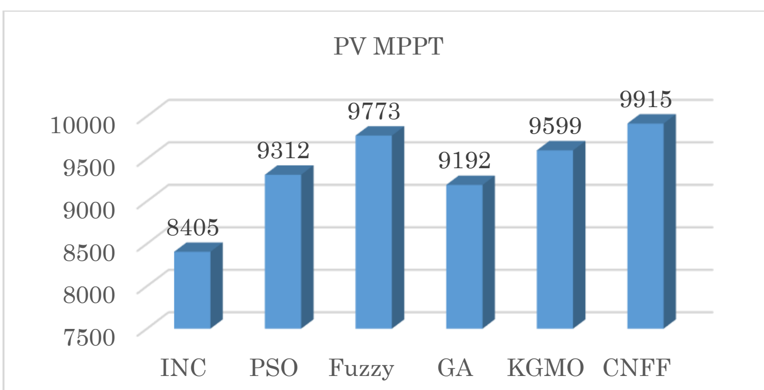


Fig 13. Comparative analysis of various MPPT techniques.

VI. CONCLUSION

This research has focused on the maximum energy production of photovoltaic systems in a variety of meteorological conditions. The mathematical model of the photovoltaic cell has been developed and analyses its performance in different weather conditions. According to the simulation results, the MPPT algorithm was inevitable to generate the maximum power of the PV system. In this study, a number of MPPT algorithms were tested in a variety of meteorological conditions. The following algorithms were analyzed, namely

Fuzzy, GA, KGMO and CNFF. Based on simulation results and comparative analyses, the CNFF produces better results relative to other MPPT algorithms. Comparative analyses can be found in Table 3 and Figure 13. Finally, the prototype work model was developed and checked by the proposed MPPT algorithm.

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