International Journal of Electrical Engineering & Emerging Technology, Vol. 07, No. 02, Dec 2024, pp 19-25

Deep Neural Network Based MPPT Modelling and Simulation for Photovoltaic System

[a] Mariam Iqbal, [b] Rabail Memon, [c] Muhammad Anwar, [d] Aaqib Bashir
[a] Department of Electrical Engineering, Mehran University of Engineering and Technology, Jamshoro, Sindh, Pakistan
Corresponding author e-mail: (mariamiqbal.electrical@gmail.com)
[**Received on:** 29-10-2024 **Accepted on**: 13-11-2024 **Published on:** 20-12-2024]

***Abstract*— With the growing demand of electrical power, the deployment of renewable energy resources within the electric power network has become essential. Among these renewable sources, solar is one of the most common renewable resource used nowadays for environment friendly power production. To extract maximum power output from photovoltaic system a techniques known as maximum power point tracking (MPPT) is employed. Perturb and observe (P&O) method is one among the multiple techniques integrated with solar panels for obtaining maximum power output out of them. Besides having simple and practical structure it still lacks in efficiency due to the presence of oscillations near the maximum power point, Slow tracking in changing conditions and performance degradation under varying irradiation. This paper aims to develop a MPPT controller based on deep neural network (DNN) for photovoltaic system. Furthermore, this paper also provide comparison between conventional perturb and observe method and deep neural network based MPPT under standard test condition (STC). The results have showed that the power output of deep neural network based MPPT has reduced oscillations and show better performance. Simulations and deep neural network are developed in SIMULINK and MATLAB environment.**

***Index Terms*— Photovoltaic systems, maximum power point tracking (MPPT), perturb and observe(P&O), deep neural network (DNN).**

I. INTRODUCTION

With the depletion of fossil fuel, the most trending issue of modern day is to find a source that can generate electricity with minimum cost and cause minimum or no damage to the environment. These consideration leads the world to focus on renewable energy resources and among all renewables resources solar and wind are most commonly and practically used. Solar power generation is considered more over other renewable source because they are easy to install, has no fuel cost, does not contain any moving parts and it is clean source of energy. They can be operated alone and connected to the grid, this ability makes solar an ideal match as a power source of generating electricity in rural areas. Generation of electricity from solar is achieved by converting energy contain in electromagnetic radiation of sun into electricity using photovoltaic cells. Sun can provide huge amount of sun light that can be converted into electricity but the amount of energy conversion between sunlight to electricity depends upon the effectiveness of the photovoltaic system. To evacuate maximum power output from the solar panel and to increase the efficiency of the photovoltaic system, maximum power point tracking is usually employed. Maximum power point tracking is a method which ensure that the source will produce maximum output under all circumstances. Broadly Maximum power point tracking (MPPT) techniques are classified into three groups: conventional techniques, advanced techniques and hybrid. Conventional techniques are simple but they have low efficiency due to oscillations, slow tracking response, poor performance under variable irradiation and temperature condition. Advanced techniques are known for their high efficiency and reliability. Hybrid techniques are the combination of both conventional and advanced techniques in order to over the drawbacks of conventional technique through the aid the advanced techniques [1]. The conventional method provides good results under standard irradiation and temperature whereas during changing irradiation and temperature condition will lead inefficiency of the conventional methods [2]. The most commonly used conventional approaches are perturb and observe (P&O) and incremental conductance (INC) [3]. The P&O algorithm incorporated MPPT controller continuously monitor the load requirement and provide the maximum power output according to the loading conditions [4]. Many researches in the literature provide comparison between different classical method and between different classical and advance methods. [5] compares the two conventional method P&O and INC, the results have shown that the INC-based MPPT algorithm contributes improve performance, efficiency and reduce oscillation as compared to P&O. [6] proposed an improvement in traditional incremental conductance method under fast-changing irradiation conditions, the results ensures improved system stability under changing irradiation condition, improve tracking speed and accuracy. [7] provides comparative analysis between two afore mentioned conventional MPPT methods. Results show P&O works fine under constant and slow changing irradiation condition but for fast changing irradiation conditions INC show better results than P&O. Among the advanced techniques, fuzzy logic and ANN based MPPT are most frequently studied. [8] proposed fuzzy logic based MPPT and results show that fuzzy logic based MPPT provide less oscillations, has faster response time, and high efficiency (around 99%) then conventional MPPT methods which has comparatively low efficiency (about 92% to 96%). [9] proposed ANN based MPPT which is rapid and accurate during changing irradiation and temperature conditions, irradiation and temperature are the input on which the ANN is trained and voltage is the output. The deep neural network (DNN) algorithm has the capability to answer the uncertainties of MPPT dynamics with the aim to reduced converter oscillations and identifying converters with optimal efficiency [10]. Feedforward deep neural network (DNN) is a specific example of deep learning algorithm and also known as the most essential building blocks of deep learning in which only unidirectional flow of communications is possible, from input to output [11]. Back propagation neural network (BPNN) is another learning algorithm utilized for the training of deep neural network, MPPT controller that uses back propagation neural network intended to increase the power output from the solar grids under diverse variable load circumstances [12]. The central aim of this research is to design a deep learning based intelligent MPPT controller that can effectively tract the maximum power point (MPP) for photovoltaic systems. This paper consists of five main sections. In the Introduction section, literature reviews on MPPT algorithm in broad-spectrum and the need of DNN based MPPT were analyzed. Section II covers the study of the photovoltaic system and is sub-divided into two sections: the initial section describes the design of photovoltaic panel whereas the subsequent section describes the design of the DC-DC boost converter. Section III covers the study of two different MPPT algorithm namely: P&O and DNN. In section IV, MATLAB simulation results are evaluated. Finally, conclusions are represented in section V.

II. METHODLOGY

Our photovoltaic system comprises of solar panels, a constant DC load, and a DC-DC boost converter as shown in Fig. 1. First we select photovoltaic panel and then design the DC-DC boost converter. An MPPT technique is needed for the purpose of getting maximum power from the photovoltaic panels. Two MPPT techniques (P&O and DNN) are analyzed in order to fulfill afore mention requirement of MPPT. All the coding and simulations are done in MATLAB workspace and Simulink

A. Photovoltaic Panel

Photovoltaic panels are DC device that can convert energy contain in the electromagnetic wave of sun into electricity. The term "photovoltaic" describes a phenomenon in which light is directly converted into electrical energy. A solar panel comprise of several individual cells that are linked together to generate electricity. These cells are connected together to form a string and when number of strings combines it make a module. A PV field are constructed by connecting number of series and parallel PV panel in order to meet the required power output. Single diode model is most commonly used so as to evaluate the characteristics of PV panel because of its simplicity. This model includes a current source, series and shunt resistances, and a diode as shown in Fig. 2.

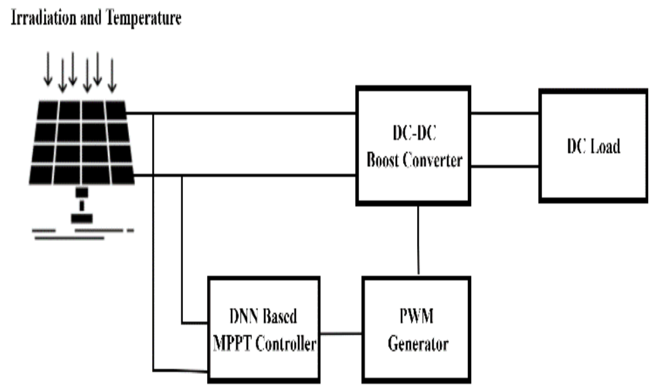

Fig. 1. Block Diagram proposed system

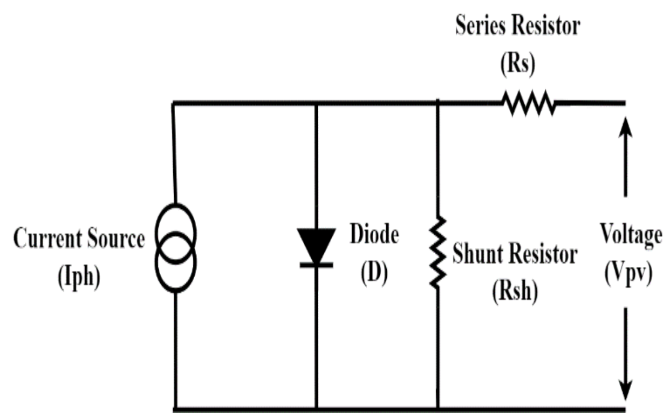

Fig.2. Single Diode Model of a Solar Cell

and can be describe by the following mathematical equations

$$Id = Iph - Io\left(\exp\frac{Vpv + RI}{Vt}\right) - \frac{Vpv + RI}{Rsh} \quad (1)$$

$$Vt = \frac{nNskT}{q} \quad (2)$$

Where:
Id: Current of the pv cell
Vt: Thermal Voltage
Iph: Photo current
Io: Reverse saturation currents of the diode.
Rsh: Shunt Resistance
n: diode ideality constant
Ns: Number of cells connected in series
R: Series Resistance
k: Boltzmann Constant
T: Temperature of the diode p-n junction
q: Charge of Electron

The PV array model used is Kyocera Solar KD200GX-LPU modules. The PV module was modeled with 1 parallel and 10 series arrays. For our proposed model the main design specifications of Photovoltaic array are presented in Table 1.

TABLE I: Parameters of KD200GX-LPU

Parameter	Value
Maximum Power	*200.032 W*
Cells per module (Ncell)	54
Open Circuit Voltage Voc	*33.2 V*
Short Circuit Current Isc	8.16 A
Voltage at Maximum Power Point Vmp	26.6 V
Current at Maximum Power Point Imp	7.52 A
Temperature Coefficient of Voc	*-0.33* % / deg.C
Temperature Coefficient of Isc	*0.02* % / deg.C
Series Resistance	0.35681Ω
Shunt Resistance	110.6743Ω
Ideality Factor	0.94833

B. DC-DC Boost Converter

A device that converts particular DC voltage to another desirable DC voltage level is known as a DC-DC converter. A DC-DC boost converter is also a type of DC-DC converters that increase the voltage. The input is mostly solar pv or any other DC supply and output is the DC load. DC-DC boost converters often used with the PV system because of its voltage regulation properties. Depending on the environmental conditions (temperature and irradiation), the output of solar panel often has produce varying terminal voltage and for the purpose of getting a constant voltage at the load terminals, a DC-DC boost converter is employed. Fig. 3 shows the construction of DC-DC boost converter.

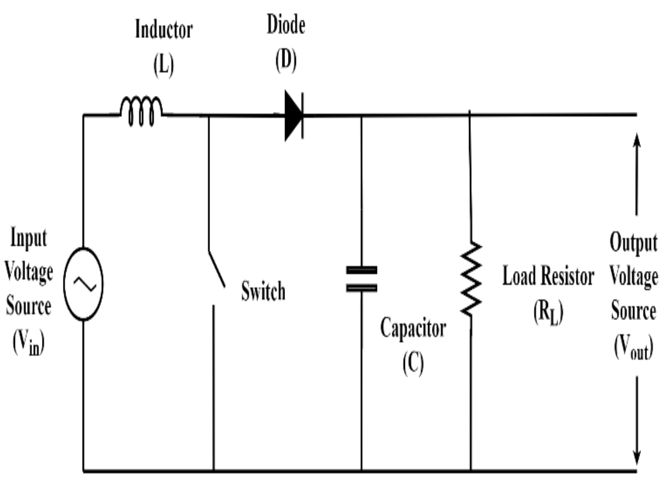

Fig.3. DC-DC Boost Converter

The behavior of the DC-DC boost converter and the calculations of the parameters are governed by the following equations

$$D = 1 - \frac{Vin}{Vout} \quad (3)$$

$$L = \frac{D(1-D)^2 R}{2f} \quad (4)$$

$$C = \frac{DVout}{VrRf} \quad (5)$$

$$R = \frac{Vout}{Iout} \quad (6)$$

Where:
D: Duty Cycle
Vin: Input Voltage
L: Inductance
C: Capacitor
R: Load Resistance
F: Switching frequency
Vr: Ripple voltage
Iout: Output Current
Vout: Output Voltage

III. MPPT ALGORITHM

It is the switching frequency that decide how fast boost converter will react when the input power changes. By adjusting the duty cycle we can control the switching frequency. Now in order to control the duty cycle is it essential to combine DC-DC boost converter in association with an MPPT controller. The two MPPT approaches under consideration of this article are P&O and DNN.

A. Perturb and Observe (P&O) Based Algorithm

It is one the most frequently practiced algorithm because it is simple to implement. The core working principle of this method is to generate a duty cycle on which the boost converter extract maximum power output from the photovoltaic panel. It does it by measuring the power at an instant k, and then compare this power with the pervious power output say (k-1). Then according to the results it adds and subtract a small perturbation and observes the corresponding influence on the output power. The maximum power point (MPP) is approached if the duty cycle is maintained in the same direction and the power increases. On the other hand, MPPT moves away, if the power decreases. Then, the duty cycle must reverse its direction. The core principle of P&O is shown in fig. 4. Fig. 5 represents the flow chart of the algorithm. The simulation is created in MATLAB Simulink.

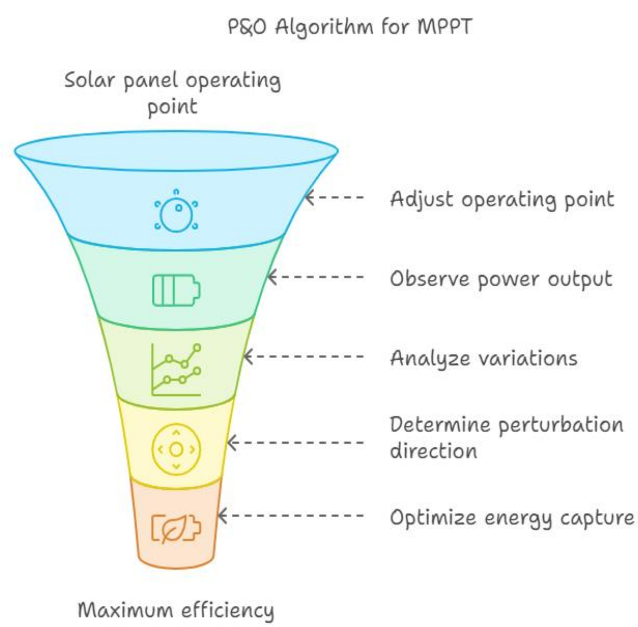

Fig.4. Basic Principle of P&O

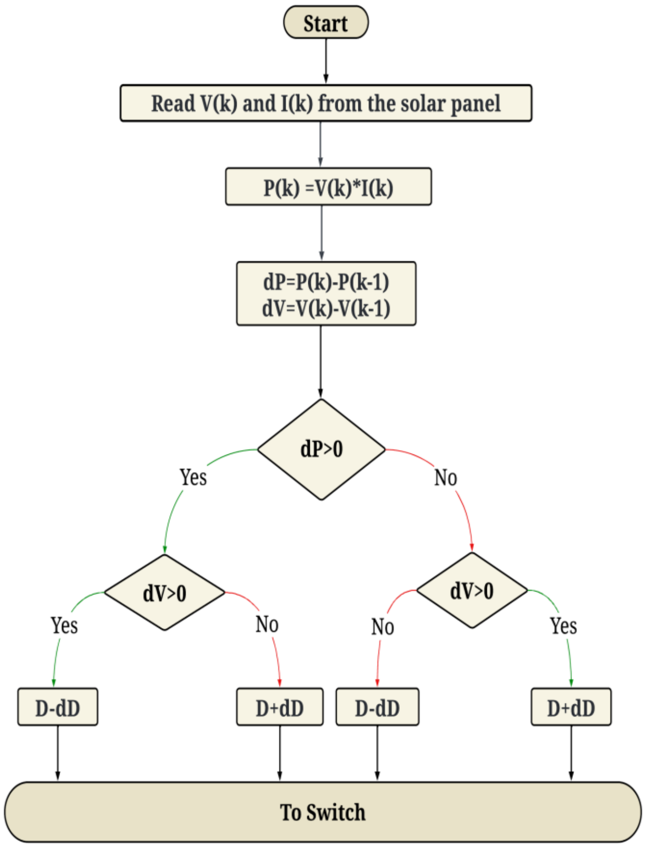

Fig.5. Perturb and Observe Algorithm

B. Deep Neural Network (DNN) Based MPPT

The concept of deep learning is driven by the functioning and structure of human brain. A deep neural network consists of number of layer which are mainly categorized as input, hidden and output layers. As in human brain neuron cells process and convey information in the form of chemical and electrical signals, an artificial neuron are the mathematical functions that process the input and pass information to the next neuron. In a deep neural network, neurons are connected through weights. These weights determine the effect of input data on the next layer and eventually on output. The learning of deep neural network is aided by fine-tuning the weights of the connections between neurons. This process is directed by a loss function. The amount of complex information that a deep neural network can handle effectively depend on the number of hidden layers. Deep neural network (DNN) architecture is shown in Fig. 6. An activation function is a mathematical function that is implemented on each neuron in the network in order to introduce non-linearity in the network. For a deep neural network to learn complex model a non-linearity pattern is essential otherwise the input and output is related by linear relationship. Common activation functions are: ReLU, sigmoid and tanh. Another important parameter of deep neural network is the learning algorithm. In order to minimize the difference among the actual output value and the predicted output value, a Learning algorithm is applied. This refer to the methods used to fine-tune the network's parameters mainly the weights and biases. This process is called training. The frequently employed learning algorithms are Levenberg-Marquardt (LM), Bayesian Regularization (BR) and Scaled Conjugate Gradient (SCG). The entire data given to the network divides into three groups (data sets), the group that contain large data is called training data set and two smaller portion of remaining data is called testing data set and validation data set used for testing and validation of results. For the implementation of DNN there are total three phases: training, testing, and validation.

C. Data Collection and Processing

For the training of deep neural network, a huge amount of data is required. The data collected from photovoltaic system includes voltage, current and duty cycle. The voltage and currents are the two inputs of DNN and duty cycle is the output. The data has been taken from the simulation of P&O algorithm based MPPT for photovoltaic system which is developed in Simulink. These collect data are then stored in excel file for data processing. After collection and processing of 1048576 data points, 70% of the entire data are used for training ,15% for testing and 15% for validation.

D. Design of deep Neural Network

The architecture of deep neural network in this research comprises of total seven layers, one input layer, five hidden layers containing ten neurons each and one output layer as shown in Fig. 6.

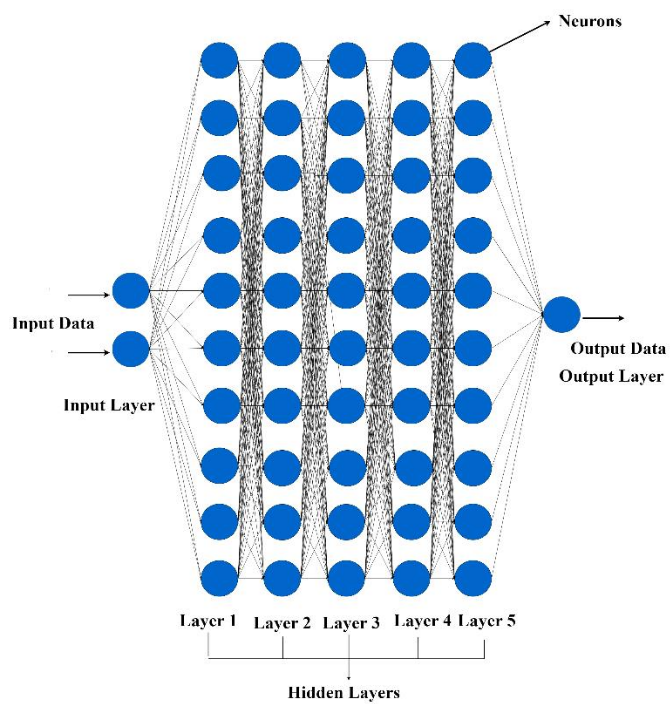

Fig.6. Architecture of Deep Neural Network

A type of sigmoid activation function called as logistic sigmoid (logsig) is used as the activation function and can be expressed by the help of mathematical equation:

$$f(x) = \frac{1}{(1+e^{-x})} \quad (6)$$

For the training process Levenberg-Marquardt algorithm is used. This algorithm makes its core principle by combining two optimization methods namely Gauss-Newton method and the Gradient Descent method. The combination of these two make this a dynamic algorithm. Step by step process of this algorithm are as follow:

In order to minimize the error function, the algorithm begins with initial set of parameters weights and biases and iteratively upgrade them. The algorithm then computes Jacobean matrix for every single iteration which symbolize the sensitivity of the error function to changes in the parameters. After this a combination of the Gradient Descent method and the Gauss-Newton method is used to update the parameters. The algorithm provides a smooth transition between the two approaches based on the current state of the optimization process. Fig. 7 represent the regression plot of the DNN where R= 0.99905 represents the highly accurate prediction of output based on the input and correlation between the target-generated duty ratio of the chosen solar panel and the output-generated duty ratio. The value of regression also demonstrate that the collected data is precisely trained by incorporating the Levenberg-Marquardt(LM) algorithm with negligible error and the output approaches the desired value. Fig. 8 shows the error histogram. Fig. 9 shows the trained dataset's gradient, momentum parameter (Mu), and validation check at 1000 epochs. The applicability of the Levenberg Marquardt(LM) algorithm for MPPT is supported by the diminutive value (around zero) of the gradient, Mu, and the validation tests of the trained dataset. At 1000 epochs, the trained data set's samples converge to the best training outcome and is known as mean squared error and is represented in fig. 10.

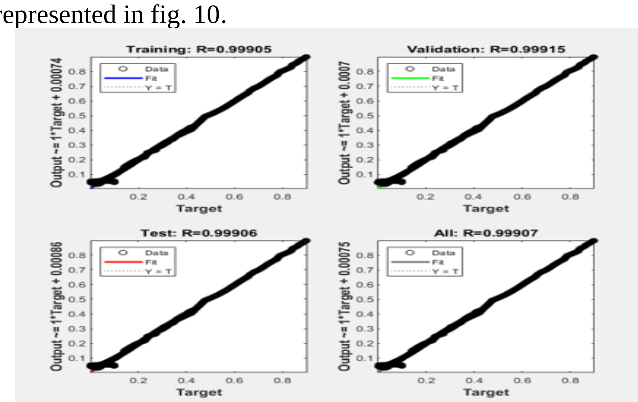

Fig.7. Regression plot of the proposed DNN model.

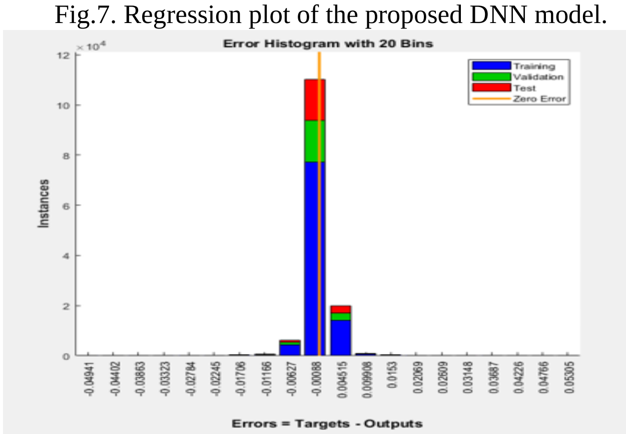

Fig.8. Error Histogram

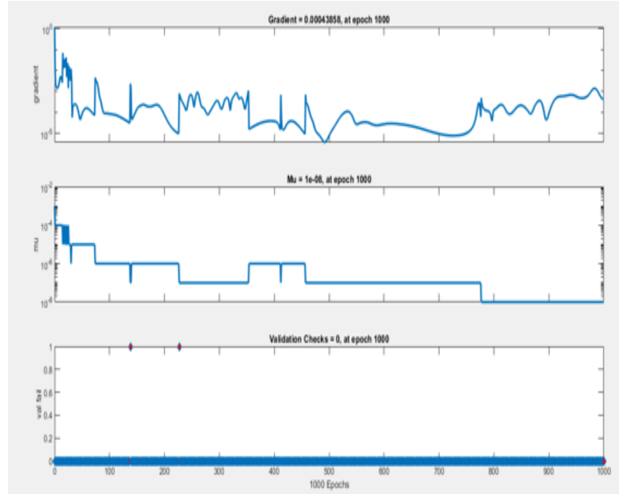

Fig.9. Training state plot of the DNN based MPPT.

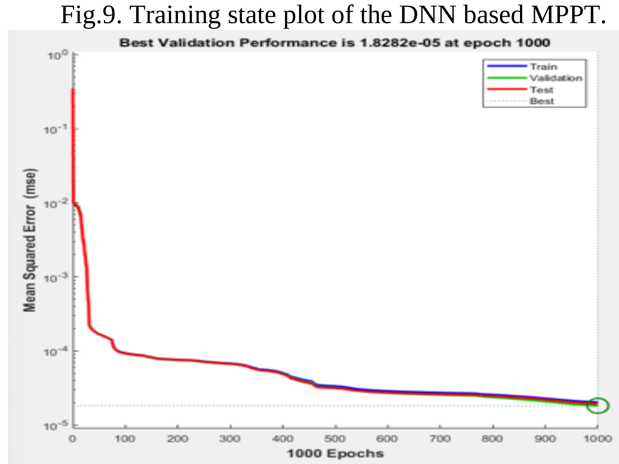

Fig.10. Performance test of DNN algorithm

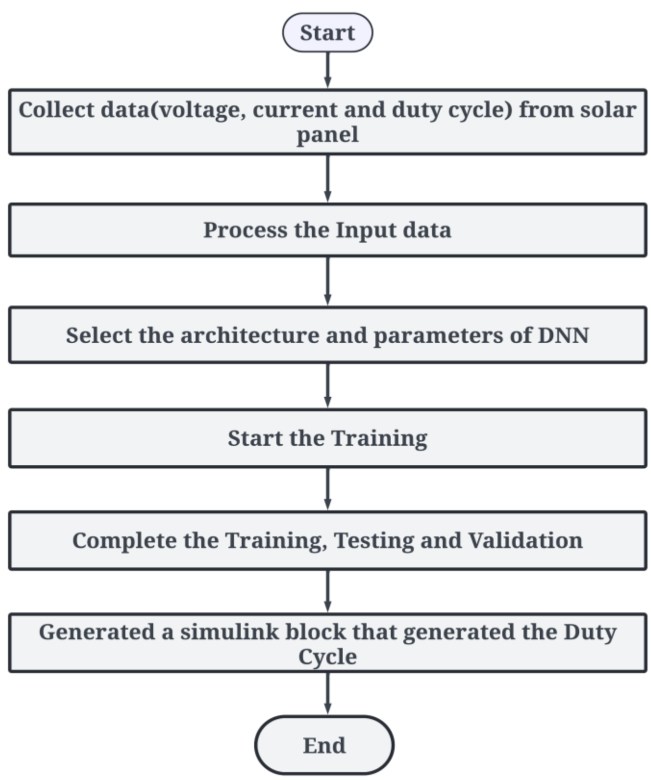

Fig.11 Working Flow of DNN

The fig. 11 defines the general DNN-based MPPT operating principle. Initially, data extraction from the solar panel is accomplished by the implementation of a perturb and observe (P&O) based MPPT. After preprocessing, the data is saved in an Excel file. Following data collection, a MATLAB workspace code is generated that defines the entire architecture, activation function, and learning process. The training then begins after the excel file is added to the code. The DNN uses the remaining data to test and validate its learnings from the patterns in the training set. A Simulink window with the DNN-based MPPT block opens once training is complete. This block is now placed in the same simulation in the place of P&O based MPPT so as to evaluate the results.

IV. RESULTS

To validate the effectiveness and efficacy of the suggested deep neural network(DNN) based MPPT for photovoltaic system, it was tested and compare with MPPT utilizing perturb and observe technique. The MATLAB Simulink model of the recommended system is shown in the Fig. 12. Fig. 13 shows the waveforms of voltage, current and power of DNN based MPPT. A comparison between DNN and P&O based MPPT is shown in fig. 14. From the results it is found out that P&O takes approximate 1 sec to track the maximum power and has slow tracking response whereas DNN tracks the maximum power point much faster and take approximate 0.4 sec to track maximum power point. DNN based MPPT also has reduce oscillations then P&O.

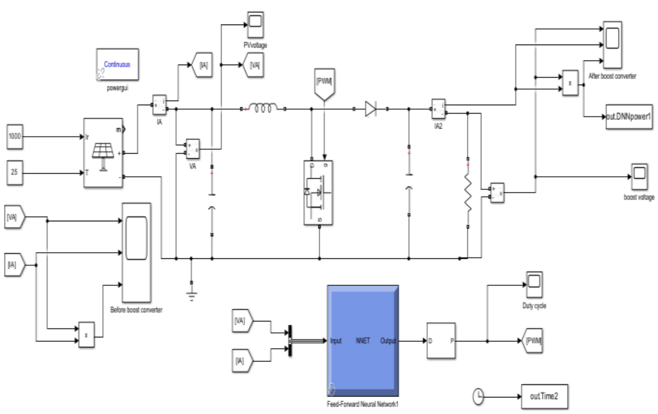

Fig.12. MATLAB Simulink model for DNN based MPPT for Photovoltaic System

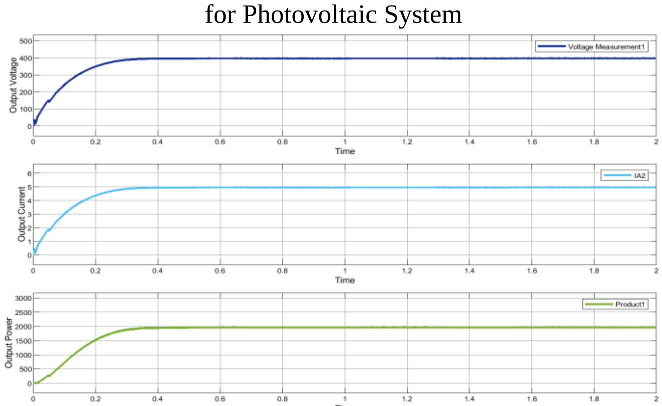

Fig.13. Waveform of Voltage, Current and Power from boost converter

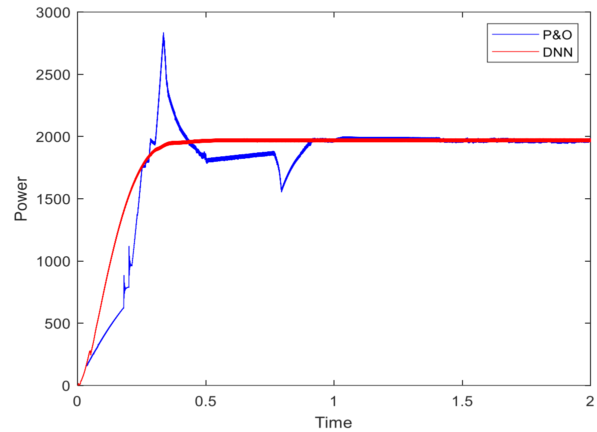

Fig.14. Comparison of DNN and P&O based MPPT Controllers

V. CONCLUSION

The MPPT is used with boost converter to take out maximum power output from photovoltaic system. In this research a deep neural network (DNN) based maximum power point tracking (MPPT) controller for photovoltaic system is presented. The voltage and current are the input data whereas the duty which controls the output of the DC-DC boost converter in the output data of our proposed system. Conventional method such as P&O is used to collect the data in order to train the deep neural network. The system was tested under standard test conditions and based on the results it is concluded that the proposed DNN based MPPT provides better results and efficiency, has fast tracking time and less oscillations then P&O.

REFERENCES

[1] A. O. Baba, G. Liu, and X. Chen, "Classification and evaluation review of maximum power point tracking methods," *Sustainable Futures,* vol. 2, p. 100020, 2020.

[2] M. Kumar, K. P. Panda, J. C. Rosas-Caro, A. Valderrabano-Gonzalez, and G. Panda, "Comprehensive review of conventional and emerging maximum power point tracking algorithms for uniformly and partially shaded solar photovoltaic systems," *Ieee Access,* vol. 11, pp. 31778-31812, 2023.

[3] S. A. Sarang, M. A. Raza, M. Panhwar, M. Khan, G. Abbas, E. Touti, *et al.*, "Maximizing solar power generation through conventional and digital MPPT techniques: a comparative analysis," *Scientific Reports,* vol. 14, p. 8944, 2024/04/18 2024.

[4] A. A. AlZubaidi, L. A. Khaliq, H. S. Hamad, W. K. Al-Azzawi, M. S. Jabbar, and T. A. Shihab, "MPPT implementation and simulation using developed P&O algorithm for photovoltaic system concerning efficiency," *Bulletin of Electrical*

Engineering and Informatics, vol. 11, pp. 2460-2470, 2022.

[5] R. Dutta and R. P. Gupta, "Performance analysis of MPPT based PV system: A case study," in *2022 2nd International Conference on Emerging Frontiers in Electrical and Electronic Technologies (ICEFEET)*, 2022, pp. 1-6.

[6] L. Shang, H. Guo, and W. Zhu, "An improved MPPT control strategy based on incremental conductance algorithm," *Protection and Control of Modern Power Systems,* vol. 5, pp. 1-8, 2020.

[7] L. Assiya, D. Aziz, and H. Ahmed, "Comparative study of P&O and INC MPPT algorithms for DC-DC converter based PV system on MATLAB/SIMULINK," in *2020 IEEE 2nd international conference on electronics, control, optimization and computer science (ICECOCS)*, 2020, pp. 1-5.

[8] R. Rai and O. Rahi, "Fuzzy logic based control technique using MPPT for solar PV system," in *2022 First international conference on electrical, electronics, information and communication technologies (ICEEICT)*, 2022, pp. 01-05.

[9] Y. E. A. Idrissi, K. Assalaou, L. Elmahni, and E. Aitiaz, "New improved MPPT based on artificial neural network and PI controller for photovoltaic applications," *International Journal of Power Electronics and Drive Systems,* vol. 13, pp. 1791-1801, 2022.

[10] E. Leksono, R. Sobirin, R. F. Iskandar, P. H. K. Utama, M. I. Bayeqi, M. F. Hasan*, et al.*, "MPPT Modeling and Simulation in PV Systems Using the DNN Method."

[11] M. Abulaila, I. M. Alsudi, and K. M. Al-Aubidy, "A Deep Learning Approach for MPPT of PV System: Design and Comparison," in *2024 21st International Multi-Conference on Systems, Signals & Devices (SSD)*, 2024, pp. 87-91.

[12] K. Rafeeq Ahmed, F. Sayeed, K. Logavani, T. Catherine, S. Ralhan, M. Singh*, et al.*, "Maximum power point tracking of PV grids using deep learning," *International Journal of Photoenergy,* vol. 2022, p. 1123251, 2022.