Study on Artificial Neural Network based MPPT Algorithm in PV Application

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***Abstract* – This paper presents a comparative study between the Artificial Neural Network (ANN) and Perturb and Observe (P&O) Maximum Power Point Tracking (MPPT) method for photovoltaic (PV) applications. The study includes a detailed analysis of the fundamental principles and operational aspects of ANN and P&O MPPT methods. The MATLAB Simulink is used to simulate the PV module, DC-DC boost converter, and the ANN and P&O MPPT algorithms of the MPPT control system. The simulation also compares the system's performance under varying solar irradiation rates, both fast and slow. The simulation results demonstrate that ANN-based MPPT outperforms the P&O method in terms of efficiency and accuracy, particularly under dynamic weather and shading conditions. The proposed study provides a comprehensive understanding of the benefits and limitations of ANN and P&O MPPT methods and highlights the potential for future research.**

Keywords—**Maximum power point tracking (MPPT), artificial neural network (ANN), perturbation and observation (P&O), photovoltaic (PV).**

I. INTRODUCTION.

In the modern era, the population is increasing very rapidly and so are their demands. We are heavily dependent on non-renewable sources of energy for most of our needs, and we know non renewables are exhaustible. So, we have to look for alternatives. Out of 20% renewable energy, nearly 3% comes from solar energy. Sun is the supreme inexhaustible source of energy, and we should extract as much as we can. Low efficiency is the major limitation of solar energy generation. The efficiency of solar panels is very low i.e., within 15-21% which is a major concern about this technology. The reason for this low efficiency is the high dependency of solar energy on environmental factors, weather conditions, solar irradiance,etc. Due to these factors, the P-V curve is like an inverted parabola with the maximum power occurring only at one point. So, we want to operate around that point called maximum power point. Various Maximum Power Point Tracking algorithms have been developed and yet many organizations are working on developing more efficient techniques as well, that aim to maximize power efficiency.

Maximum Power Point Tracking (MPPT) is a technique that optimizes the output power of a PV system by continuously tracking the maximum power point (MPP) of the PV module. MPPT is essential for enhancing the efficiency and reliability of PV systems, particularly under varying weather and shading conditions. Several MPPT algorithms have been proposed in the literature. Some of them are Perturb and Observe Method, Incremental Conductance method, Ripple Correlation, Proposed MPPT method, Fractional short circuit current, Fractional open circuit voltage, Neural networks, Fuzzy logic, etc. These approaches differ in numerous ways, including complexity, implementation, tracking algorithm, and so on. Among them, the Perturb and Observe (P&O) method is widely used due to its simplicity and low cost. However, the P&O method has certain limitations, such as oscillations around the MPP, slow response to rapid changes, and sensitivity to noise.

A potent computing tool known as an artificial neural network (ANN) has attracted a lot of attention recently because of its capacity to simulate complex and nonlinear interactions between input and output variables. As an alternative to traditional MPPT techniques, ANN-based MPPT algorithms have been put forth with the promise to get over P&O's restrictions and achieve improved efficiency and accuracy.

In this paper, P&O method and ANN method are explained in detail, after which simulation results of both the methods are analyzed under varying solar irradiation and compared simultaneously.

II. PV MODELLING

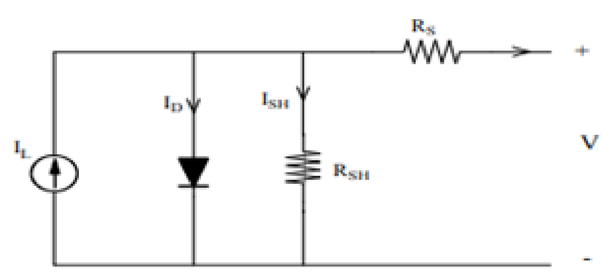


Fig 1: Equivalent PV cell [1]

$$I = IL - Io\left(e^{\frac{q(V+IRs)}{KT}} - 1\right) - \frac{V+IRs}{Rsh} \qquad (1)$$

where,

I - cell current (A).

I_L - light generated current (A).

Io - diode saturation current.

T- Cell Temperature(K)

Rs, Rsh - cell series and shunt resistance(Ω).

V - cell output voltage (V).

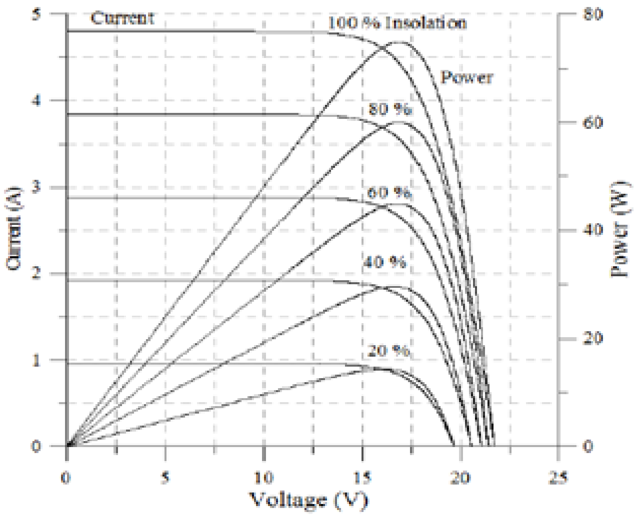


Fig 2: I-V & P-V characteristics of PV panel [4]

We can see nonlinear relationship in the current equations in equation no 1. Because of these non-linearities in current characteristics of PV, we can achieve maximum power only at one point called Maximum power point (MPP). So, we aim to keep our operating point in that region.

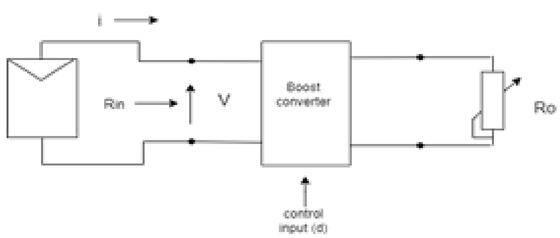


Fig 3: Input Resistance control by duty Control

Boost converters basic equations are

$Vout = Vin * (1 - d)$

$Iout = Iin * (1 - d)$

Also, $Ro = \frac{Vo}{Io} = \frac{Vin}{Iin*(1-d)^2} = \frac{Rin}{(1-d)^2}$

So, $Rin = Ro * (1 - d)^2 \qquad (2)$

Fig 3 represents the idea of controlling the operating point of the load line. As we know, load R_o is not in our control. It will vary from time to time. As the load varies our characteristics will vary and we will not be able to operate at maximum power point. We want the load seen from the PV cell to be constant, so we control our load line with the help of duty ratio governed by equation no 2. Duty cycle pulse is generated by ePWM after processing the respective MPPT algorithm. A controller is used to process the algorithm, after which it signals the ePWM to change the duty ratio. That duty ratio is feed to the switch of boost converter. So, basically by controlling the duty ratio, we can able to control our input resistance.

III. PERTURB & OBSERVE MPPT

In this method, as the name suggests, we first disturb our operating point and then observe the change in output power. The change is calculated by subtracting newly calculated power from the previous one. If ΔP_{pv} is positive, it means operating point is on the left side of MPP and the perturbation that means change in voltage should be same in the direction of increment. If ΔP_{pv} is negative, operating point is on right side of MPP and voltage perturbation should be in opposite direction of increment. The process will continue till $\frac{\Delta Ppv}{\Delta Vpv}$=0.

An adaptive P&O technique and a predictive and adaptive MPPT P&O technique have also been introduced in a related setting. Instead, the focus has been placed on the voltage perturbation in the Adaptive P&O approach. The Predictive and Adaptive MPPT P&O approach uses a constant duty cycle perturbation that linearly decreases as more power is extracted from the PV panel.

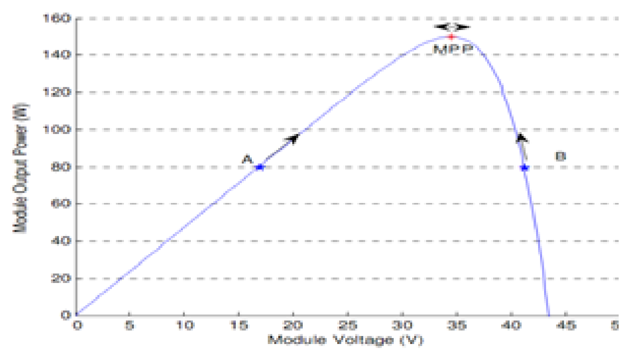


Fig 4: Perturb and Observe Algorithm [5]

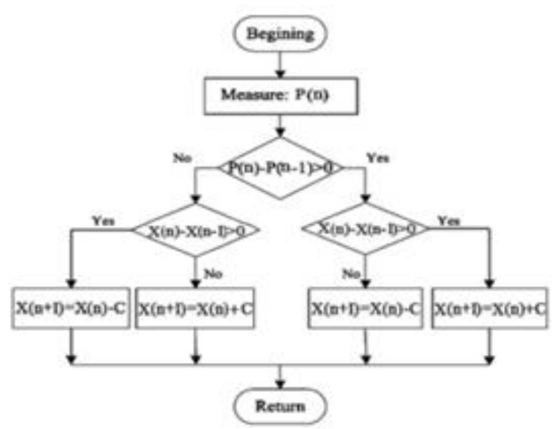


Fig 5: Flow Chart of P&O Algorithm [6]

Even though several modified adaptive P&O algorithms have been put forth to enhance the performance of the conventional P&O method, oscillation around MPP under slowly changing irradiation and miss-tracking of accurate MPP under rapidly changing irradiation remain problems for these techniques. So, to overcome these drawbacks, we look forward to artificial neural networks algorithms.

IV. ARTIFICIAL NEURAL NETWORK MPPT

Artificial Neural Network (ANN) is a machine learning technique inspired by the structure and function of biological neurons. ANN consists of interconnected processing units, called neurons, that are organized into layers. Each neuron takes in information from other neurons or from the outside world, processes those signals using a nonlinear activation function, and then sends out a signal to other neurons or outside targets. To reduce the difference between the projected and actual outputs, learning involves adjusting the strength of the connections between neurons, or weights.

ANN-based MPPT algorithms use a neural network model to predict the MPP of the PV module based on the input parameters, such as voltage, current, and temperature. A dataset of input and output pairs obtained from the PV system under various operating conditions is used to train the neural network model. After it has been trained, the MPP can be predicted in real-time.

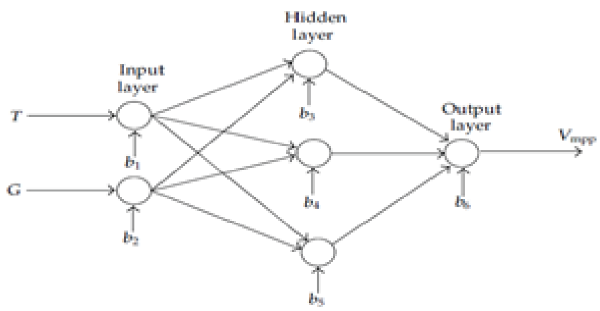


Fig 6: - Three-layer Neural Network Structure [6]

In this paper, error back propagation method is used to train the data. Temperature (T) and irradiance (G) are fed to the input layers as shown in figure 6. Voltage at maximum power point is the output. With changing V_{mpp} and I_{mpp}, duty cycle of boost converter is governed by following equation:

$$D = 1 - \sqrt{\frac{Vmpp*Iout}{Impp*Vout}} \quad (3)$$

A. Training the model

TABLE 1: Test Case Parameters

Name of parameter	**Value**
Short Circuit current	8.66 A
Open circuit Voltage	37.30V
Current at max power point	8.15 A
Voltage at max power point	30.7 V
Current temperature coefficient	0.086998
Voltage temperature coefficient	-0.36901
Irradiance	1000
Temperature	25

Using input output and curve fitting feature of Neural Network Start toolbox, model is trained.

Training algorithm : Lavenberg-Marquardt
Performance : Mean squared error
Layer size : 10

TABLE 2: Training results

	Observation	**MSE**	**R**
Training	700	1.9478e-9	1.0000
Validation	150	2.1024e-9	1.0000
Test	150	2.1340e-9	1.0000

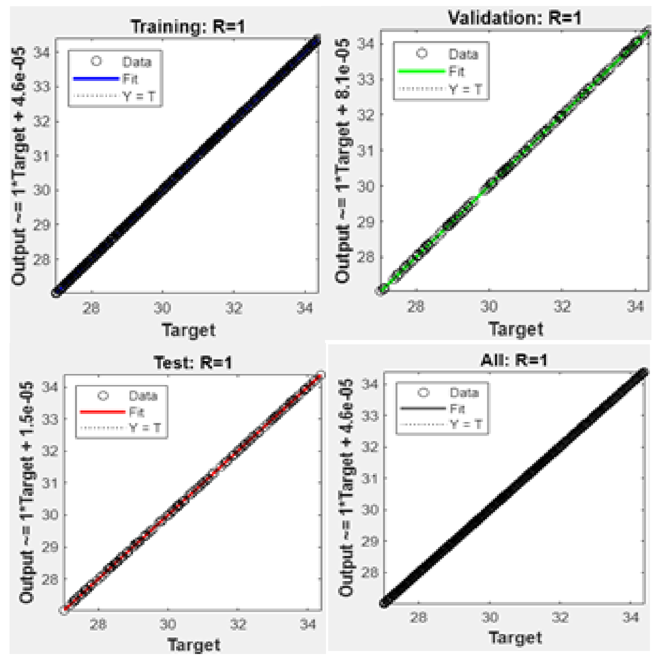


Fig 7: Regression plot after training the model.

In all regression plots R=1 is observed, that means our results satisfy our training data. Corresponding Simulink model is generated.

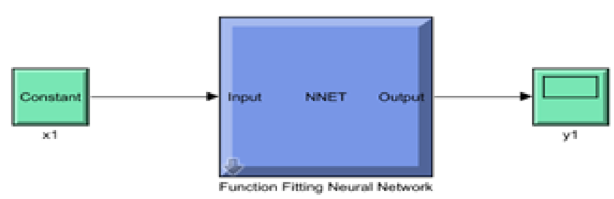


Fig 8: Simulink Generated ANN model.

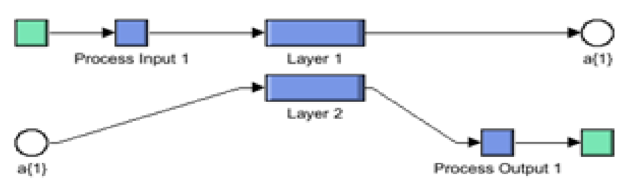


Fig 9: Inside view of the ANN block

B. Testing the Model

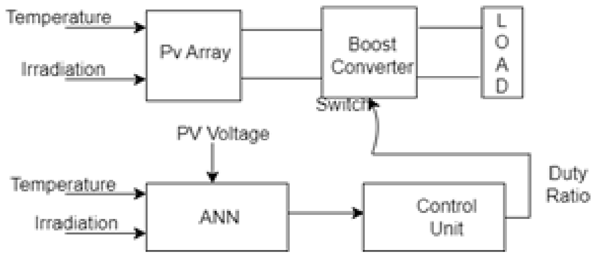


Fig 10: Block Diagram of ANN MPPT Method

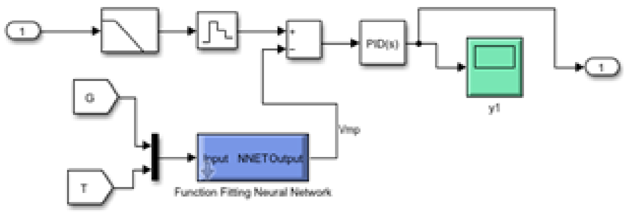


Fig 11: Internal schematic of ANN Block

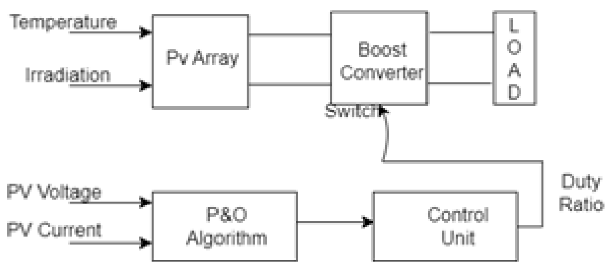


Fig 12: Block Diagram of P&O MPPT Method

The setup was built in MATLAB Simulink. Keeping all the parameters constant, ANN and P&O both are methods are performed. For ANN MPPT, Parameters are connected according to the block diagram Fig 10 and for P&O MPPT, parameters are connected according to Fig 12. The internal diagram of ANN block is shown in Fig 11. For ANN algorithm, temperature, irradiation and PV voltage are the inputs whereas for P&O, PV voltage and PV Current are required inputs.

Solar Irradiation and temperature are the major parameters that affect PV power generation. These two inputs are fed to the PV array. The PV current and voltage are taken as controller parameters. More ever Boost converter input voltage is the PV panel output voltage. According to the given MPPT algorithm, duty cycle is changed of which is taken care by control unit. The duty cycle is fed to the switch of boost converter. So, according to equation 2, by controlling duty cycle, input resistance is tried to kept constant.

V. SIMULATION RESULTs

Simulation was performed under rapidly varying solar irradiation and 25 °C temperature. It was modelled using a stair generator whose waveforms are as shown in Fig. 13.

The output waveforms of ANN MPPT and P&O MPPT were plotted in Fig 14 and Fig 15, respectively. From simulation results, it can be viewed that whereas P&O fails to achieve the MPP when the irradiation varies extremely quickly, the ANN technique can track the MPP quickly under rapidly changing irradiation. In addition, whereas P&O technique oscillation is very high and causes power loss in steady state, ANN oscillation is very low around MPP once it reaches.

When the solar irradiation is changing slowly, the ANN approach oscillates very little, whereas the P&O method oscillates much more, which results in significant power loss.

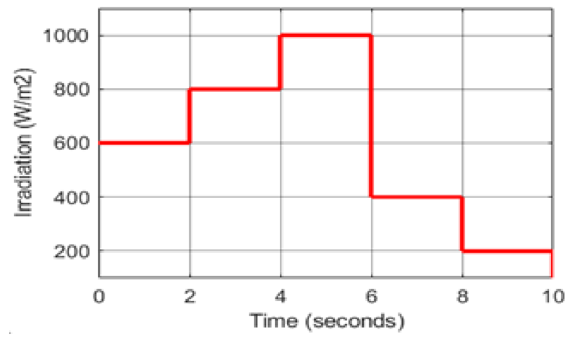
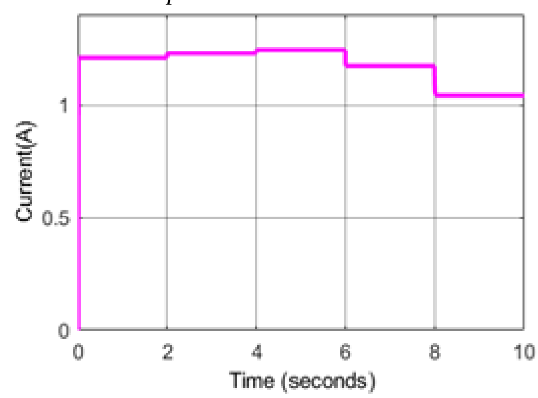
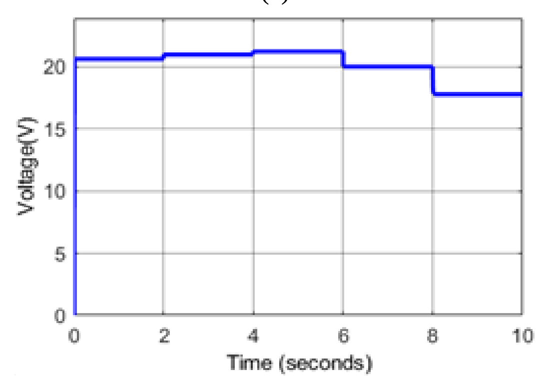


Fig 13: Rapidly changing irradiation signal for comparison

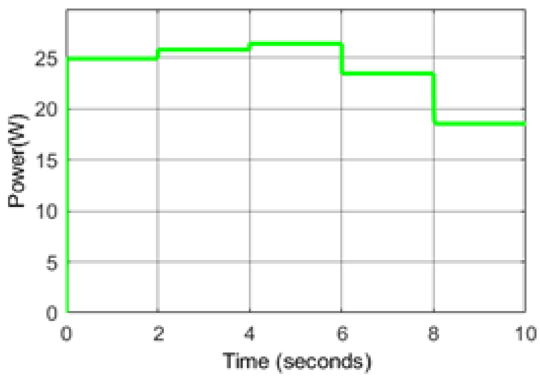
A. ANN MPPT output P&O MPPT OUTPUT



(a)



(b)



(c)

Fig 14: Current, Voltage and Power outputs of ANN MPPT

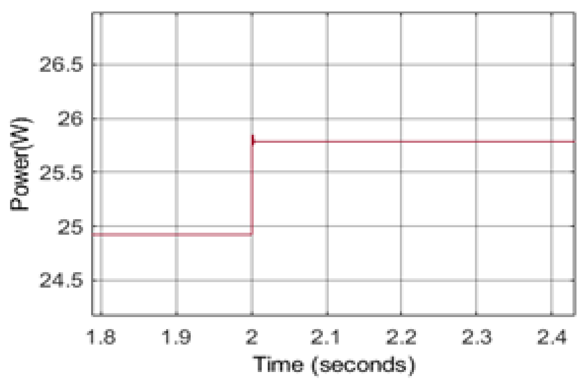
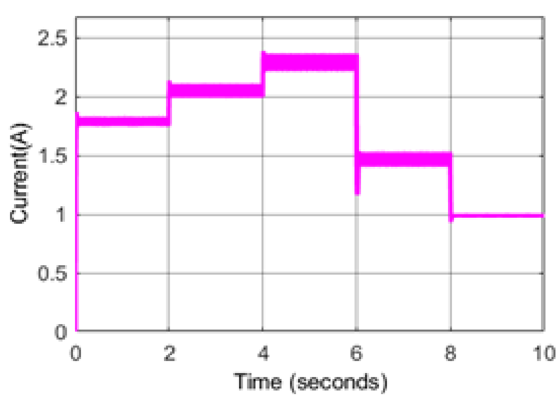
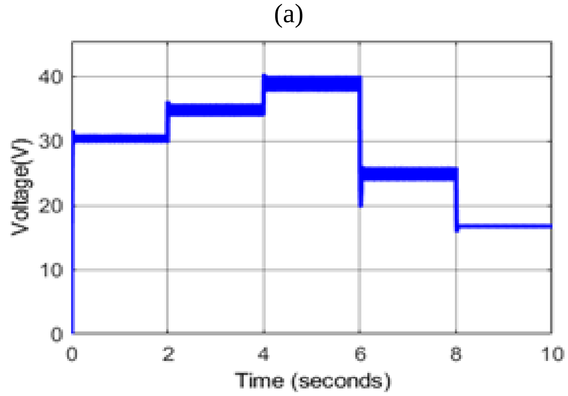


Fig 16: Zoomed in view of Power outputs of ANN MPPT

B. *P&O MPPT OUTPUT*



(a)



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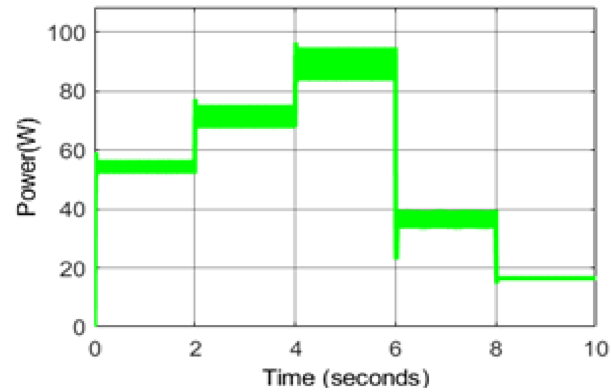

(c)

Fig 15: Current, Voltage and Power outputs of P&O MPPT

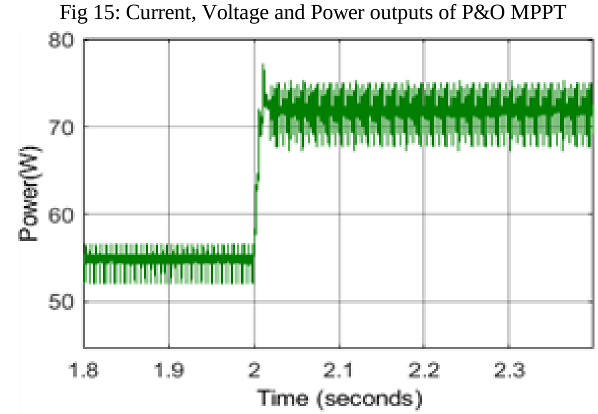

Fig. 17: Zoomed in view of Power outputs of P&O MPPT

VI. Conclusions

This paper's simulation finding for the ANN and P&O approaches demonstrate that, in the event of rapidly changing solar irradiation, the ANN method is particularly quick and accurate in locating and tracking the MPP. Furthermore, despite gradually changing sun irradiation, this approach can consistently extract the maximum power point. On the other hand, the P&O approach fails to follow the MPP when irradiation changes quickly over a short period of time. The approach also exhibits considerable oscillation around MPP when used slowly.

Reference

[1] Nedumgatt, Jacob James, et al. "Perturb and observe MPPT algorithm for solar PV systems-modeling and simulation." *2011 Annual IEEE India Conference*. IEEE, 2011.

[2] Subudhi, Bidyadhar, and Raseswari Pradhan. "A comparative study on maximum power point tracking techniques for photovoltaic power systems." *IEEE transactions on Sustainable Energy* 4.1 (2012): 89-98

[3] Huang, Chao, et al. "A prediction model-guided Jaya algorithm for the PV system maximum power point tracking." *IEEE Transactions on sustainable energy* 9.1 (2017): 45-55.

[4] Atia, Yousry. (2009). PHOTOVOLTAIC MAXIMUM POWER POINT TRACKING USING SEPIC CONVERTER. ERJ Engineering Research Journal Faculty of Engineering Minoufiya University. 32. 10.21608/erjm.2009.69528.

[5] Design and simulation of Photovoltaic water pumping system - Akihiro Oi.

[6] Khanaki, Razieh & Mohd Radzi, Mohd Amran & Marhaban, Mohammad Hamiruce. (2013). Comparison of ANN and P&O MPPT

methods for PV applications under changing solar irradiation. CEAT 2013 - 2013 IEEE Conference on Clean Energy and Technology. 287-292. 10.1109/CEAT.2013.6775642.

[7] Farzad Sedaghati, Ali Nahavandi, Mohammad Ali Badamchizadeh, Sehraneh Ghaemi, Mehdi Abedinpour Fallah, "PV Maximum Power-Point Tracking by Using Artificial Neural Network", *Mathematical Problems in Engineering*, vol. 2012, Article ID 506709, 10 pages, 2012. https://doi.org/10.1155/2012/506709

[8] Y. Yongchang and Y. Chuanan, "Implementation of a MPPT controller based on AVR Mega16 for photovoltaic systems," in *International Conference on Future Electrical Power and Energy Systems*, 2012, vol. 17, pp. 241–248.

[9] M. S. Ngan and C. W. Tan, "A study of maximum power point tracking algorithms for stand-alone photovoltaic Systems," in *IEEE Applied Power Electronics Colloquium (IAPEC)*, 2011, pp. 22–27.

[10] P. Q. Dzung, "The new MPPT algorithm using ANN based PV," in *International Forum on Strategic Technology*, 2010, pp. 402–407

[11] S. Premrudeepreechacharn and N. Patanapirom, "Solar-array modelling and maximum power point tracking using neural networks," in *IEEE Bologna Power Tech Conference Proceedings*,, 2003, vol. 2, no. 3, pp. 419–423.

[12] S. E. K. T. Hiyama, "Artificial neural network-polar coordinated fuzzy controller based maximum power point tracking control under partially shaded conditions," *Renewable Power Generation*, vol. 3, no. 2, pp. 239–253, 2009.

[13] M. Z. Alabedin, E. F. El-Saadany, and M. M. a. Salama, "Maximum power point tracking for photovoltaic systems using fuzzy logic and artificial neural networks," in *IEEE Power and Energy Society General Meeting*, 2011, pp. 1–9.