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Comparative Analysis of MPPT Techniques for Solar Photovoltaic System

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ABSTRACT: As solar photovoltaic (PV) systems play a crucial role in the global shift towards renewable energy, the optimization of their performance becomes paramount. This study presents a comparative analysis of three prominent Maximum Power Point Tracking (MPPT) techniques: Perturb and Observe (P&O), Incremental Conductance (INC), and Artificial Neural Network (ANN). Parameters such as ripple, accuracy, and response to dynamic environmental conditions are evaluated to assess the overall performance of each MPPT technique. Furthermore, varying irradiance levels on the performance of these algorithms is investigated to optimize the energy conversion efficiency of PV system. Simulation analysis and results of the PV module are made to get its characteristics.

KEYWORDS: PV cell, Maximum power point, DC-DC converter, Renewable Energy.

I.INTRODUCTION

Fossil fuels, such as oil, coal, and natural gas, on the contrary, are available in finite quantities only. This is because, although they are produced through natural processes, they do not replenish as quickly as we humans use them. Not only are fossil fuels bound to run out sooner or later, but what's worse is that their extraction and production is associated with climate-damaging greenhouse gases, as well as health- endangering particles. Contrastingly, Renewable energy sources are known to be much cleaner and produce energy without the harmful effects of pollution unlike their conventional counterparts.

A solar panel can produce electricity from 30–40% of the energy that strikes it. To boost solar panel efficiency, a Maximum Power Point Tracking algorithm is required. Several methods exist for Maximum Power Point Tracking (MPPT), including the hill climbing method known as Perturb and Observe, incremental conductance, fractional short circuit current, fractional open circuit voltage, fuzzy control, and neural network control. It is evident that the converter has an impact on the system's efficiency as well. Generally, it is minimal for a boost topology, maximum for a buck topology, and buck- boost topology after that. The boost converter is a DC-DC converter whose task to perform the step-up conversion of applied DC input. In this converter, the applied constant DC input is gives boost adjustable DC output voltage i.e. input voltage of the boost converter is always less than the Output voltage. So, a Boost converter is also called a step-up converter or step-up chopper.

It is given the name "boost" because the gives output voltage is higher than the applied input voltage. It performs the reverse operation of the buck converter which converts higher DC input into lower DC output. The operation of the boost converter is based on the principle of storing energy in an inductor. The voltage drop across an inductor is proportional to the change in the electric current flowing through the device. The circuit arrangement operates in such a way that it helps in maintaining a regulated and increased dc output at the load.

II.MAXIMUM POWER POINT TRACKING TECHNIQUES

It is very important with photovoltaic generation to operate the system at high power efficiency by ensuring that, the system is always working at the peak power point regardless of changes in load and weather conditions. In other words, transfer the maximum power to the load by matching the source impedance with the load one. To confirm that, an MPPT system has been implemented which enables the maximum power to be delivered during the operation of the solar array and which tracks the variations in maximum power caused by the changes in the atmospheric conditions. The MPPT system is basically an electronic device inserted between the PV array and the load. This device comprises two essential components, as illustrated in Fig. 1. A DC- DC switching power converter along with an MPPT control algorithm to operate the PV system in such way it can transfer the maximum capable power to the load.

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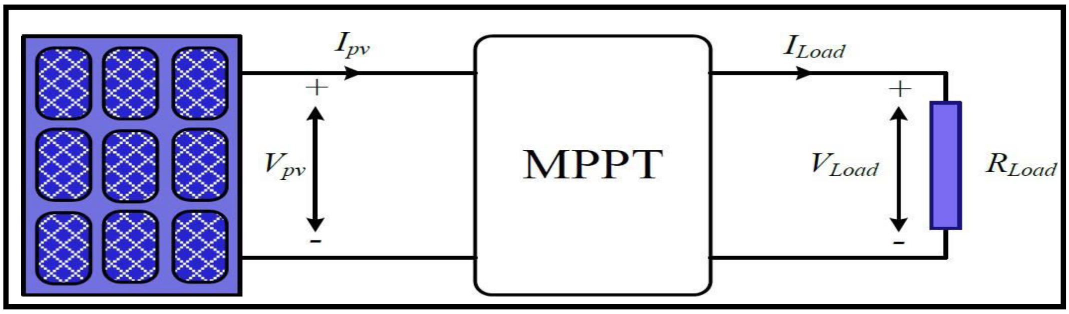

Fig. 1 Converter acting as a Maximum Power Point Tracker

It is crucial to operate the photovoltaic generation system at the MPP or near to it to ensure the optimal use of the available solar energy. The main objective of the MPPT is to match these two parameters by adjusting the duty ratio of the power converter. As the location of the MPP on the I-V curve varies in an unpredictable manner it cannot be defined beforehand due to changes of radiation and PV panel temperature. Accordingly, the use of MPPT algorithm or calculating model is required to locate this point. There are several methods to track the MPP of the photovoltaic system that have been carefully studied, developed, and published over the last decades. In this research paper, the incremental conductance (INC), perturb & observation (P&O) and Artificial Neural Network based MPPT techniques are used to harness the maximum power from PV modules.

III.SIMULATION AND RESULTS

The system has been modelled and simulated in MATLAB/SIMULINK. The modelled system consists mainly of PV array model, DC/DC buck converter model used to interface PV output to the resistive load to track the maximum power of the PV array. To perform the tracking of maximum power, P&O, INC and ANN based MPPT techniques are used. In this work, the PV module JKM540M-72HL4-BDVP 540Wp connected in 6×24 matrix, is used for simulation work. This module has maximum efficiency of 21.7% and power tolerance of 0-3% and its power degradation for 2-30 year is 0.45% as mentioned in its datasheet. To validate the model, usually standard conditions specified at irradiation of (G = 1000 W/m2) and temperature of (T = 25°C). The parameters of PV panel used in this work are listed in the Table 1.

TABLE 1: Electrical Characteristics of JKM540M-72HL4-BDVP 540Wp

Rated Power (Pmax)	540 Wp
Maximum Power Voltage (Vmp)	40.76 V
Maximum Power Current (Ipm)	13.25 A
Open-Circuit Voltage (Voc)	49.26 V
Short-Circuit Current (Isc)	13.93
Temperature Coefficient (Pmax)	-0.35%/oC
Temperature Coefficient (Voc)	-0.28%/ oC
Temperature Coefficient (Isc)	0.048%/ oC
Total series connected PV Cells	144
Module Efficiency	21.7%
Power Tolerance	0 ~ + 3%
Series Resistance (RS)	0.21992 Ω
Shunt Resistance (RSh)	450.4275 Ω

The simulations offer a valuable opportunity to verify the feasibility and the performance of the proposed P&O, INC and ANN based MPPT algorithm. For evaluation and comparison analysis, the simulation studies were carried out under steady-state and dynamic conditions for the proposed MPPT techniques, by configuring the simulations under exactly the same conditions. The main focus is how fast the MPP is being tracked during the dynamic state and the power ripple caused by oscillations around the MPP in the steady-state condition. For P&O and INC the value of duty ratio step-change (ΔD) will determine the convergence speed (time to reach steady-state) and the oscillation during

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steady- state operation. For ANN MPPT the fine tuning of PI controller (Value of P and I) will determine the convergence speed and oscillation during steady-state condition. For good comparisons amongst the proposed MPPT techniques, the behaviour of all three methods will be presented by the simulation results.

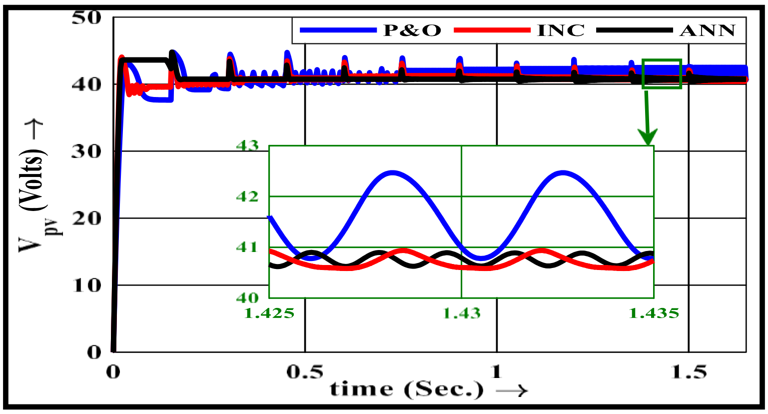

Fig. 2 PV terminal voltages with varying insolation levels at 25°C temperature

The voltage at PV terminal can be seen in Fig. 2 and Table 2 shows the ripple voltage (ΔVpv) at PV terminal with proposed different MPPT techniques when module insolation is 1000 W/m^2 and Temperature of 25°C.

TABLE 2: PV terminal voltage and Ripple voltage at G=1000W/m^2 & T=25°C

MPPT Technique	AverageVpv (Volt)	Ripple Voltage ΔVpv (Volt)
ANN	40.76	0.27
INC	40.69	0.35
P&O	41.83	1.69

The lowest ripple voltage is found in ANN-guided MPPT technique as shown in Table 2.

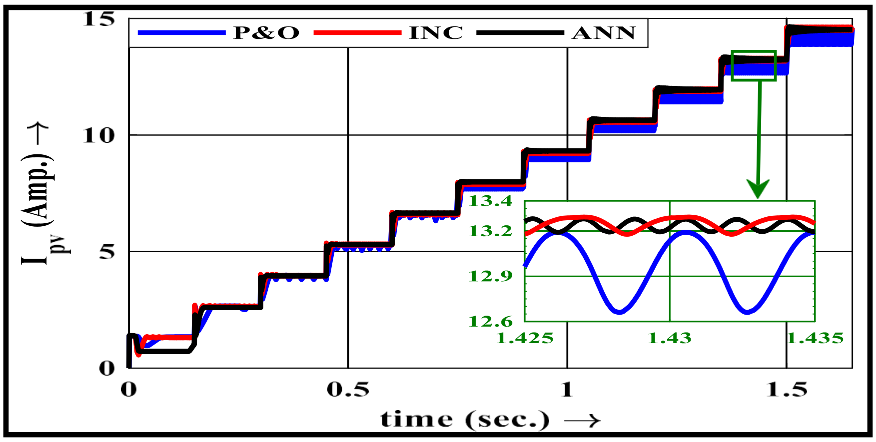

Fig. 3 PV terminal currents Ipv with varying insolation levels at 25°C temperature

The PV terminal current can be seen in Fig.3 and Table 3 shows the ripple current (ΔIpv) at PV terminal with proposed different MPPT techniques when module insolation is 1000 W/m^2 and Temperature of 25°C. From Table 3, it is found that the lowest ripple current is found in ANN-guided MPPT technique.

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Table 3: PV terminal current and Ripple current at G=1000W/m^2 & T=25^{o}C

MPPT Technique	AverageIpv (Amp.)	Ripple Voltage ΔIpv (Amp.)
ANN	13.5176	0.09
INC	13.2557	0.12
P&O	12.8925	0.53

The PV power at PV terminal can be seen in Fig.4 and Table 4 shows the ripple power (ΔPpv) at PV terminal with proposed different MPPT techniques when module insolation is 1000 W/m2 and Temperature of 25^{o}C.

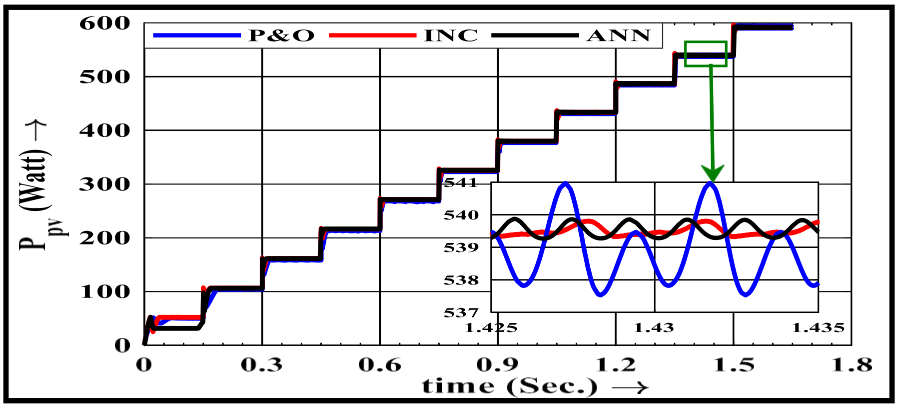

Fig.4 PV terminal power Ppv with varying insolation levels at 25oC temperature

TABLE 4: PV terminal power and change in power at G=1000W/m^2 & T=25^{o}C

MPPT Technique	AveragePpv (Watt)	Ripple Power Δppv (Watt)
ANN	539.5680	0.6
INC	538.3889	0.8
P&O	537.3400	3.5

From Table 4, it is found that the lowest ripple power is found in ANN-guided MPPT technique and INC is closer to the ANN in power tracking. Fig. 5 and Fig.6 shows efficiency and duty ratio of boost converters.

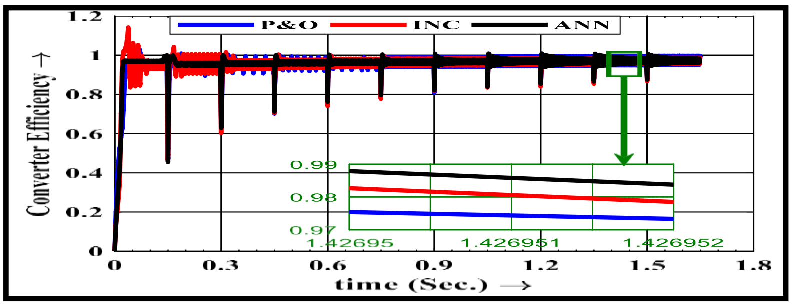

Fig.5 Efficiency of Boost converter with varying insolation levels at 25oC temperature

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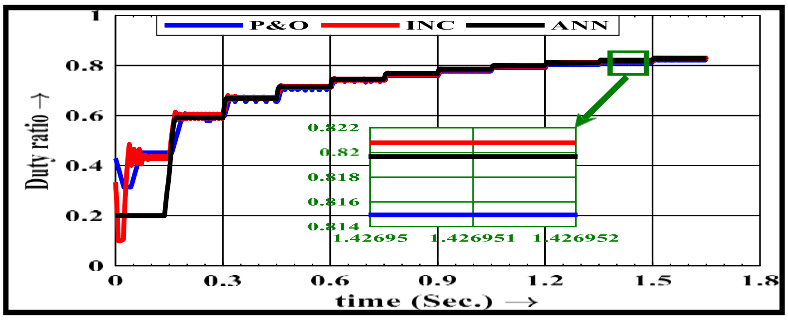
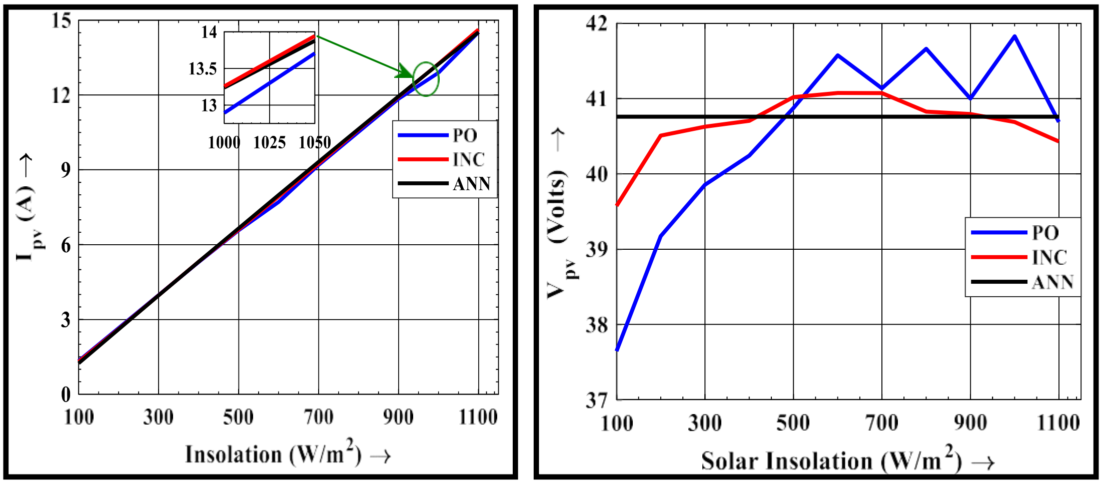


Fig.6 Duty ratio of Boost converter with varying insolation levels at 25°C temperature

The comparative study considers two important features: the maximum power and steady- state oscillation. To show the performance of the proposed MPPT algorithms in the steady-state and dynamic condition, the proposed MPPT algorithms were tested with different increasing insolation level as shown in Fig. 7. The solar insolation was changed from 100 to 1100 W/m^2.



(a) (b)

Fig.7 Steady-state PV terminal Current and Voltage for proposed MPPT techniques

IV.CONCLUSION

The three more efficient MPPT controllers proposed were analysed and developed in more depth using new system simulations to clearly show improvements. The first proposed technique is perturb and observe P&O technique. The P&O MPPT method is very simple in comparison with other techniques, which makes it the easiest to design and implement. However, a P&O method with fixed perturbation step makes it difficult to achieve both a fast response and optimal steady-state operating conditions when atmospheric conditions are changeable. The design and results of the developed P&O MPPT technique were presented and explained. The training of ANN based MPPT algorithm and PI controller tuning have been described for better & stable operation of dc-dc converter and power tracking. The MATLAB based Simulink model for different proposed MMPT techniques have been presented and the detail view, parameter setting for them have also been highlighted. The study-state performance parameter for different MPPT techniques have been presented and also tabulated. The change in various parameters is determined for critical analysis of various proposed MPPT techniques is also discussed.

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