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# Design of Improved Incremental Conductance with Fast Intelligent (FI) Based MPPT Technique for Solar PV System

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ABSTRACT

*Currently, the solar PV power extraction technology is undergoing significant improvement. Towards this, the paper proposed the design for a photovoltaic (PV) array and the output performance of a photovoltaic system under the influence of irradiance. To achieve this, the design for improved incremental and conductance fast tracking INC -FI based MPPT technique for solar PV system has been presented. The purpose of employing the improved INC -FI technique is to improve the efficiency of the system. The accuracy and performance of the proposed INC -FI method was increased due to its better tracking capability by utilizing variable ∆D for tracking the MPP in comparison to the conventional INC method at variable temperature while keeping the irradiance constant. Further, the results of the proposed method were compared with the conventional method where the INC -FI based technique outperforms the conventional INC method in terms of better accuracy. For the irradiance with 800w/m2, the achieved MPPT efficiency was 58.21 for conventional method and 80.53 for the improved technique. It was also noted that the tracking efficiency of the conventional method was 84.39 as compared to 99.92 for the proposed INC -FI technique in terms of MPPT efficiency at the irradiance of 1000w/m2. Furthermore, the improved method delivered fast tracking ability of the MPPT system with a time of less than 10 s(approx.). The MATLAB Simulink platform was utilized for designing the proposed technique. In future, the proposed INC based technique would be implemented on hardware for better outcomes and validation*

*Keywords: Maximum power point; photovoltaic module array; renewable energy; matlab/simulink; INC – FI method*

## INTRODUCTION

Presently, renewable energy technologies have gained interest from numerous fields such as social, economic, and governmental players due to various benefits such as zero carbon emission, less maintenance low air pollution and low cost installation (Mohamed et al. 2016). Furthermore, many research is currently undergoing by the scientific community for delivering fruitful results in the field of solar PV based MPPT technology. Currently, solar photovoltaic (PV) energy has been widely explored from the last decade until present date but deal with several challenges regarding its intermittent nature and limited charging hours. Although, several research works are undergoing to transform the extracted energy from solar PV system in a more efficient, accurate, and robust way thereby making the present research more interesting (Najafi et al. 2018). Moreover, the current issue for increasing the efficiency of solar PV systems deals with the installation of MPPT mechanism to effectively increase the accuracy, robustness, and efficiency of the PV system (Moutchou & Jbari 2020).

The proposed MPPT model uses an enhanced boost DC/DC converter to generate voltage to a specific value. Consequently, when solar radiation and temperature changes, the output power of the PV system also changes (Abunima et al. 2019). This makes the output power characteristic of an array becomes nonlinear with time changes due to changes of weather conditions. As a result, the PV cell has nonlinear output behavior, hence there is a need to connect them with DC-DC converter and inverter to stabilize the output system. It is therefore necessary to operate the PV system at the maximum point of power for all radiation and temperature conditions. To get maximum power from the PV range, the PV power system usually requires the MPPT controller to track the MPP (M. T. Makhloufi et al. 2016). Nevertheless, the main disadvantage of a solar PV system is the low efficiency of the solar panel with regards to the total energy conversion. The system's MPPT changes with radiation and temperature due to the nonlinear characteristics of the PV system. In order to increase efficiency, it is important to employ MPPT algorithms for tracking maximum current energy from the solar energy system at various radiations. Various MPPT techniques are available such as perturb and observe (P&O), practical swarm optimization (PSO), incremental conductance (INC), fuzzy logic controller (FLC), neural network (NN), adaptive neuro-fuzzy inference system (ANFIS), genetic algorithm, artificial BEE Colony to track MPPT (Reddy & Natarajan 2018).

Mostly, Perturb and Observe (P&O) technique is the most utilized MPPT control system to increase the power efficiency but suffers from issues related to output oscillations. Further, the tracking observed with P&O may track MPPT in the wrong direction due to frequent changes in irradiation patterns. However, the efficiency, as well as power output of the MPPT system, is increased by the INC method as compared with the P&O method. But the efficiency of the system is reduced in the conventional instrumentation and control (I&C) method due to the fluctuation of output power around MPPT. Ahmed and Salam (Ahmed & Salam 2015) proposed an improved P&O method for estimating the efficiency of the MPPT algorithm. In this method, the steady state oscillations were lowered and achieved higher tracking ability. Even though, the proposed methodology delivered satisfactory results but variable test condition with regards to the temperature should be considered for better validation. Alik and Jusoh (Alik & Jusoh 2018) presented an improved P&O method for tracking MPPT efficiency under partial shading conditions. The proposed method was implemented under MATLAB Simulink environment where the simulation of the solar module was performed under partial shading conditions. Belkaid et al. (Belkaid et al. 2016) developed an improved I&C method for tuning the duty cycle of the implemented converter as well as avoid the divergence under fast varying of luminosity levels. The model was developed and tested under MATLAB/Simulink environment. But the proposed methodology can be extended to other converter topologies as well as considering the shading phenomena for the better validation of the proposed model. Furthermore, Boukenoui et al. (Boukenoui et al. 2017) introduced an experimental analysis of various MPPT technologies such as I&C method for evaluating the performance in terms of efficiency, ripples and convergence time. Although, the experimental analysis consists of several model evaluations but lacks the evaluation of the models under partial shading conditions. In another work, Motahhir et al. (Motahhir, Chalh, et al. 2018) established a INC based MPPT technique for achieving high efficiency with fast computational time and low cost. The obtained efficiency for the model was 98% but suffers from complex programming structure. Simultaneously, Motahhir et al. (Motahhir, El Hammoumi et al. 2018) proposed an improved I&C model for evaluating the MPPT algorithm efficiency under various irradiations data. The model delivered satisfactory results but lacks the information for the validation with temperature profile data. In recent times, Deboucha et al. (Deboucha et al. 2021) proposed particle swarm optimization (PSO) based global MPPT technique for partially shaded PV model. Even though, the tracking time was quite low but the presented model applicability still needs to be further explored. While, Makhloufi and Mekhilef (S. Makhloufi & Mekhilef 2021) developed a Logarithmic PSO Based MPPT technique for partial shading condition of PV system. The results with regards to MPPT efficiency were significant nonetheless, further exploration can be accomplished with other meta heuristic optimization techniques. In another work, Shams et al. (Shams et al. 2020) developed a butterfly optimization technique based MPPT model for various conditions such as partial and unform shading conditions respectively. Although, the above-mentioned literature showed significant advantages but the complexity still remains with regards to easy execution.

Hence, there is a need for the development of an improved MPPT technique. In this work, an improved I&C method is implemented to provide more stability in terms of output power fluctuation and less oscillatory behavior (Anowar & Roy 2019). In this study, our main goals are to achieve lower response time and higher efficiency in the MPPT stage. The paper proposed INC method to achieve the output under two conditions related with change in temperature and irradiance. Further, the results related with voltage, current and power and efficiency was extracted in MATLAB Simulink environment.

The article contains four sections. Section 1 provides an insight into the phenomenon of the PV system. Section 2 is dedicated mathematical modelling Photovoltaic module, boost converter model and Modified and Proposed Incremental Conductance Algorithm. Then, the simulation results are presented and discussed in Section 3. Finally, section 4 presents the conclusion.

## PHENOMENON OF PV SYSTEM

The solar PV system delivers several benefits such as clean energy, reduced carbon emission, low cost, and long life but suffers from its unpredictable nature and its limited working hours related to maximum sunshine hours (Hanif et al. 2018). Hence, it becomes necessary to find a suitable way to transform the solar PV energy in a beneficial way resulting in higher output with more efficiency and accuracy (Doshi & Vyas 2018). Due to its intermittent nature and dependency on temperature and irradiance, the output power from the solar PV system is variable, unlike the battery system. The PV output is only a maximum of STP condition, i.e., at 25 ° C and 1000W / m2 irradiation. Therefore, under different environmental conditions, the PV energy fluctuates during the day. PV is not a stable source of static output power other than the battery, i.e., it is the resulting energy depending on the amount of radiation and the sun's temperature.

The performance of the PV cells depends on the temperature of the units. The connection of solar cells is applied both in parallel as well as series to obtain necessary electrical parameters in terms of current and voltage (Suria 2019). The adoption of crystalline silicon units is linear to strong illumination. The climatic condition significantly affects the solar PV system yield which can reduce it by 0.5% per degree. Further, the yield is affected by 10 to 30% while considering sstandard test condition (STC) and actual yield in illumination (Alias & Yaacob 2016). A hotspot in the local ohmic shunt connected with the solar cell is created due to reverse current through shunt under shading conditions resulting in damaged solar modules. The higher temperature of the PV modules is proportional to the reverse current. These phenomena become important when some cells operate under the reverse bias mode, in turn, destroy specific cells, thus disrupting the entire PV system (Aminou Moussavou et al. 2019).

## MATHEMATICAL MODELLING

### PHOTOVOLTAIC MODULE

The composition of solar cells is essentially a p-n junction constructed from a thin semiconductor plate. The energy from solar radiation can be directly transformed into electricity due to the PV effect (Pandiarajan & Muthu 2011).

For Figure 1, the characteristic current output voltage of solar PV cell is provided by the expressions 1. Further, in equation (1) the current generated by the ideal current source due to solar radiation. The PV panel can be modelled as given in expression (1)-(8).

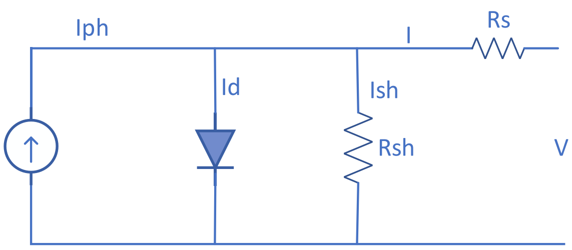



FIGURE 1. Circuit Diagram of PV Array in Simulink

In this model, the photovoltaic current $I_{Ph}$, diode current $I_d$ the output and short circuit current $I_{sh}$ can be expressed as follows:

$$I_{Ph} = [\, I_{sc} + K_i(\mathrm{T} - 298)] \left(\frac{G}{1000}\right) \quad (1)$$

$$I_d = I_{scr}\left[\exp\left(\left(\frac{q}{aKT}\right)\right)(V + IR_s)\right) - 1] \quad (2)$$

$$I_{sh} = \left(\frac{V+IR_s}{R_{sh}}\right) \quad (3)$$

Where, $V = k\frac{T_c}{q}$

The total current I can be expressed as

$$\mathrm{I} = I_{Ph} - I_d - I_{sh} \quad (4)$$

$$I = [\, I_{sc} + K_i(\mathrm{T} - 298)] \left(\frac{G}{100}\right) - I_o\left[\exp\left(\left(\frac{q}{aKT}\right)\right)(V + IR_s)\right) - 1] - \left(\frac{V+IR_s}{R_{sh}}\right) \quad (5)$$

The module saturation current $I_d$ is given as

$$I_o = I_{rs} * [\frac{T}{Tr}]^3 * \exp\left[\left(\frac{q*E_{go}}{a*k}\right)\left(\frac{1}{Tr} - \frac{1}{T}\right)\right] \quad (6)$$

The expression for $I_{rs}$ is given as

$$I_{rs} = {I_{scn}}\Big/\left(exp\frac{V_{ocn}}{aN_sV_{tn}} - 1\right) \quad (7)$$

where, $v$ represents the output voltage of the PV cell (V), $I_{sc}$ constitute short-circuit current of the PV cell (A) at ambient temperature, $I_{scr}$ expresses saturation current at reference condition ($A$), $K_i$ refers to short-circuit temperature coefficient, represents the reference temperature ($K$), $G$ denotes solar irradiance(W/m2), $I_{rs}$ refers to saturation current at reference temperature ($A$), $q$ is the electron charge (1.6e-19), $K$ is the Boltzmann constant (1.38e-23), a is the diode Idealist factor, $T$ is the temperature ($k$), $R_s$ is the series resistance of the PV cell (Ω), and $R_{sh}$ is the parallel resistance of the PV cell (Ω), $V_{ocn}$ is the open circuit voltage (Yatimi & Aroudam 2018). The equivalent model of the PV unit is expressed by equations (3) where $N_s$ represents series solar cells per unit, and $N$ denotes parallel solar cells per unit.

$$\mathrm{I} = N_p I_{ph} - N_p I_o * I_s\left(exp\frac{(V+IR_s * N_{sp}/N_{ps})}{aN_sV_t} - 1\right) - \frac{(V+IR_s * N_{sp}/N_{ps})}{R_p * {N_{sp}}/{N_{ps}}} \quad (8)$$

The PV cell array simulation in MATLAB /Simulink will be modelled according to the parameters in Table 1.

By using the PV cell array simulation data in MATLAB/ Simulink, the characteristics for various curve such as I-V, P-V for constant irradiation i.e., G=1000W/m$^2$ at different temperatures can been presented in Figure 2. It is observed that when the value of irradiation is varied from 50W/m$^2$ to 1000W/m$^2$, the open circuit voltage i.e., $V_{oc}$ is increased but with the same conditions, the linear increase in the short circuit current i.e., $I_{sc}$ is observed. Additionally, the power output of the selected PV module is increased due to the increase in the product of $V_{oc}$ and $I_{sc}$.

Moreover, when the temperature is varied from 0ºC to 65 ºC, it is observed that the component of $I_{sc}$ is marginally increased but results in the decrease in the $V_{oc}$ in a linear manner as displayed in the figure 3. Therefore, the obtained output power from the selected PV module is lower with higher temperature as compared to operate the PV module with a low value of temperature.

TABLE 1. The parameter of PV array cells simulation

| Parameter | Value |
|---|---|
| maximum power (Pmax) | 200.143W |
| maximum Voltage (Vmax) | 26.3V |
| maximum Current (Imax) | 7.61A |
| open circuit Voltage (VOC) | 32.9V |
| short circuit Current (ISC) | 8.21A |
| irradiation (G) | 50-1000W/m2 |
| temperature (T) | 25 C |

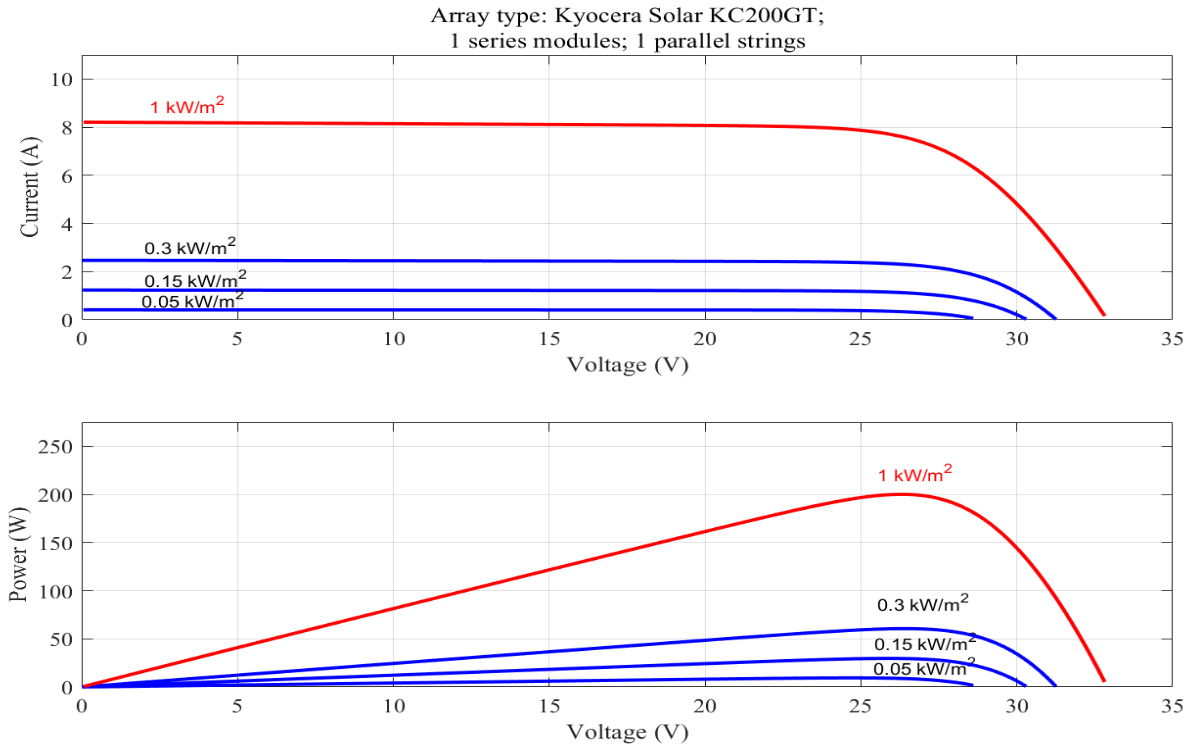



FIGURE 2. Output curve for I-V and P-V characteristics of PV cell at varying irradiance

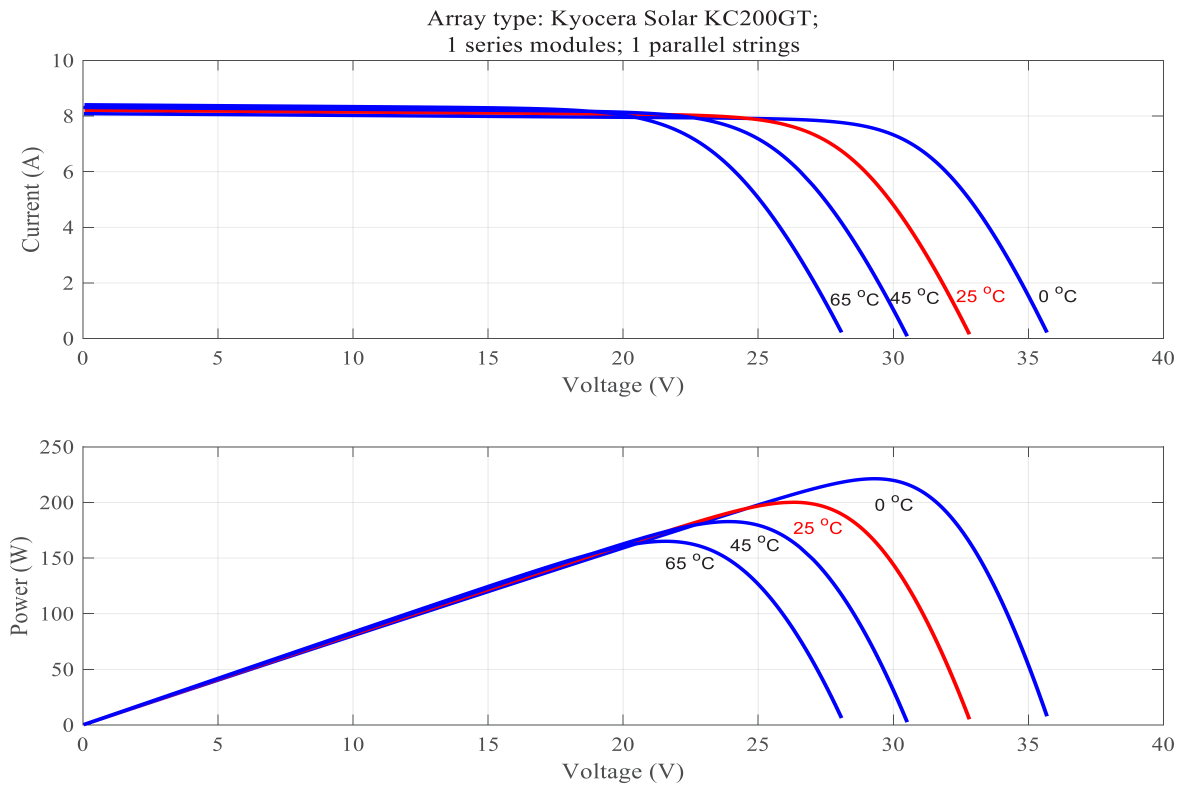



FIGURE 3. Output curve for I-V and P-V characteristics of PV cell at varying temperature

BOOST CONVERTER MODEL

The generation of high DC voltage output from low DC voltage input is performed with a boost converter circuit as shown in Figure 4. The energy is stored with a circuit consisting of L-C with necessary diode circuitry and additional switch while keep the magnitude of output current lower to input current (Kumar et al. 2016).

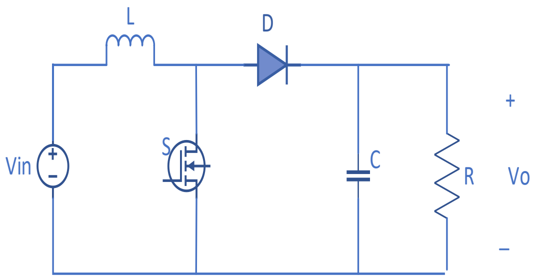



FIGURE 4. Circuit of boost converter

The expression for the obtained output voltage is expressed by the following expression as presented in Eq.9.

$$V_{OUT} = \frac{V_{IN}}{(1-D)} \quad (9)$$

Where, $D$ is the duty cycle and $V_{IN}$ is input voltage, respectively.

INCREMENTAL CONDUCTANCE BASED MPPT TECHNIQUE

P-V characteristic of photovoltaic cell is a single peak curve under constant illumination intensity. The INC method achieves MPPT by comparing with instantaneous conductance of PV cells. According to the characteristic curve of the PV array in Figure 2 and Figure 3(Qin & Che 2019). The presented expression illustrates the methodology for the INC algorithm for MPPT based solar tracking system. Further, the slope obtained for MPPT is zero for presented Figures 2 and Figure 3 (Xuesong et al. 2010).

$$P_{max} = U * I \quad (10)$$

$$\frac{dP}{dU} = 1 + U * \frac{dI}{dU} = 0 \quad (11)$$

$$\frac{dI}{dU} = -\frac{I}{U} \quad (12)$$

Figure 5 represents the conventional INC method based MPPT work with the help of a flow chart (Xuesong et al. 2010).

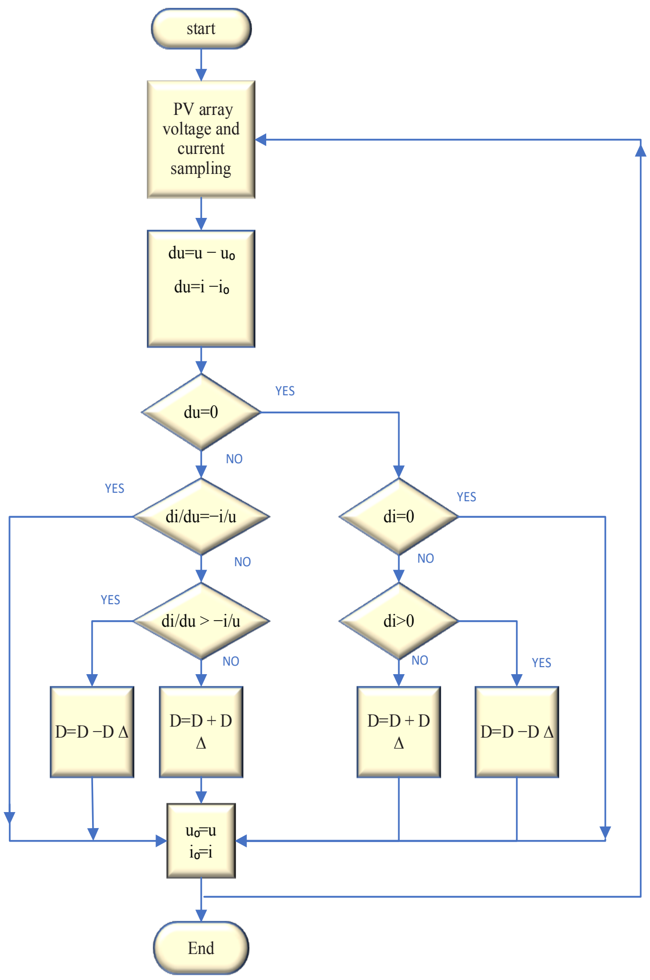



FIGURE 5. Flowchart of the conventional Incremental Conductance algorithm technique

MODIFIED AND PROPOSED INCREMENTAL CONDUCTANCE ALGORITHM

The proposed fast intelligent (FI) MPPT technique for solar PV model successfully utilize the variable ΔD for tracking the MPP to obtain high performance and efficiency at various environmental conditions such as temperature and irradiation. Further, an error is defined for minimizing the oscillations occurring around the MPP which detects when the system obtains the MPP. Additionally, due to the inclusion of the tracking mechanism, the tracking speed for the proposed method is faster with regards to the conventional INC technique. Moreover, the power losses is minimized at various temperature in the proposed MPPT algorithm. The flowchart for the proposed algorithm has been presented in figure 6.

The conventional INC technique is utilized to deviate the power away from the MPP under variable irradiance. Due to this, the algorithm demonstrates inappropriate outcomes and furthermore requires more time for the operation to find a new MPP. Additionally, the occurrence of the oscillations is frequent after the MPP has reached a steady state. On the contrary, the proposed INC- FI technique detects the fast irradiance variation and deliver the accurate results. Henceforth, the power starts to converge to new MPP from the start and retains the position. Subsequently, the modified INC technique converge the power faster as compared to the conventional method.

DISCUSSION OF SIMULATION RESULTS

Figure 7 shows results based on conventional Incremental Conductance technique which then later improved with improved Incremental Conductance algorithms as shown in Figure 8. Both are implemented using the PV system in order to acquire for the maximum power. The performance of MPPT algorithms is analyzed at irradiation and temperature in different conditions. The PV models and the proposed method fast intelligent (FI) MPPT technique employed in which the system is developed in MATLAB/ Simulink environment. The platform utilizes an inbuilt solar PV array in connection with a DC-DC boost converter, and PWM generator.

The main specifications for the boost converter include Cin = 10μF, Cout = 3500μF, L = 8mH, and switching frequency = 25 kHz. The load resistance was set at 10 Ω the results output of the simulation is presented in Figures 10.

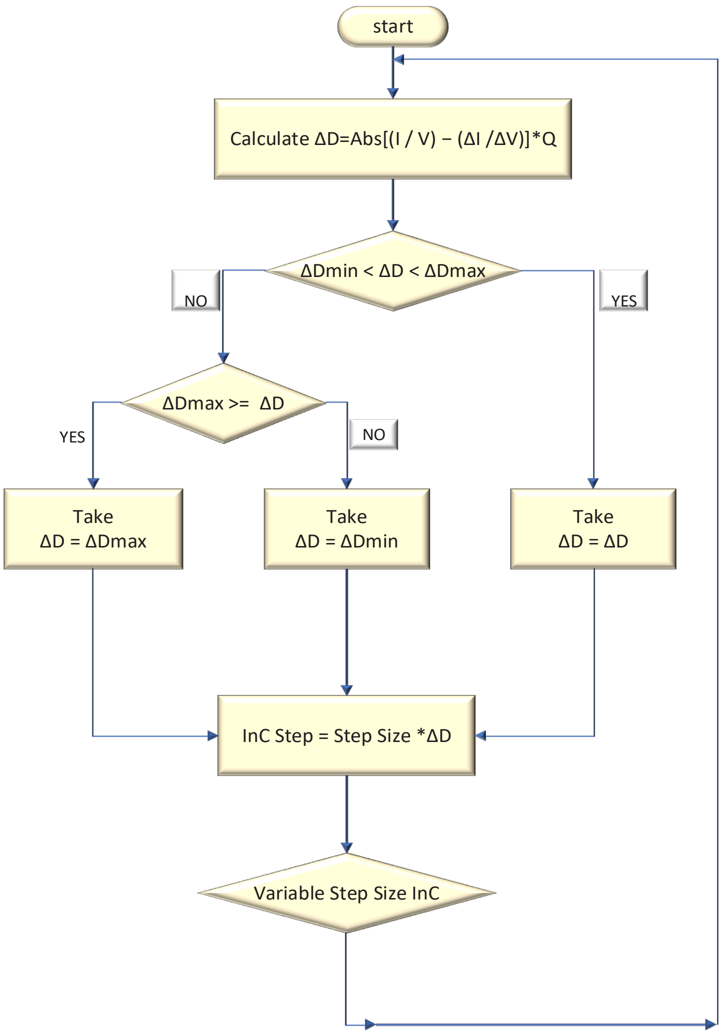



FIGURE 6. Flowchart of the improved Incremental Conductance Algorithm Technique based on the fast intelligent (FI) MPPT method

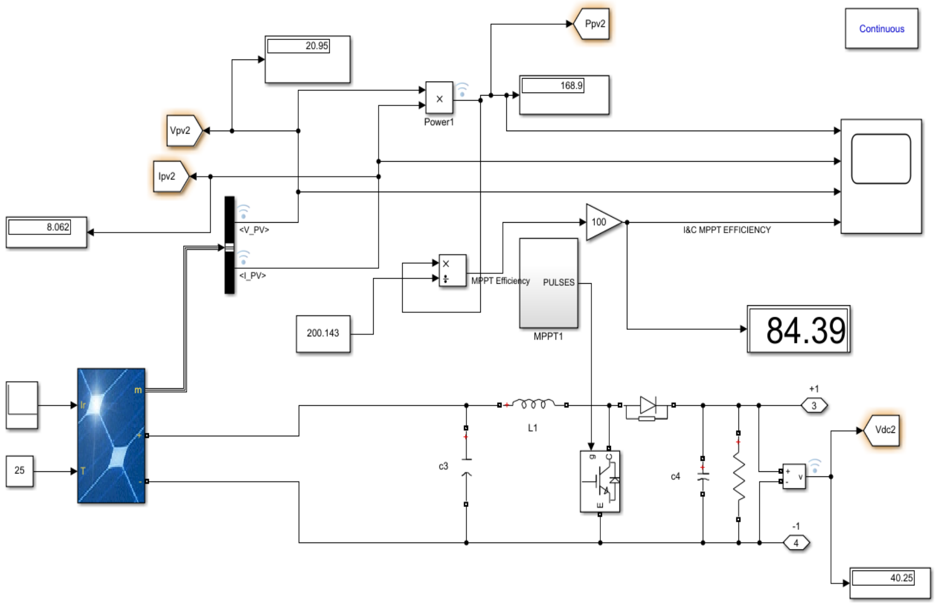



FIGURE 7. The Simulation model of PV array in Simulink with the conventional Incremental Conductance Algorithm Technique

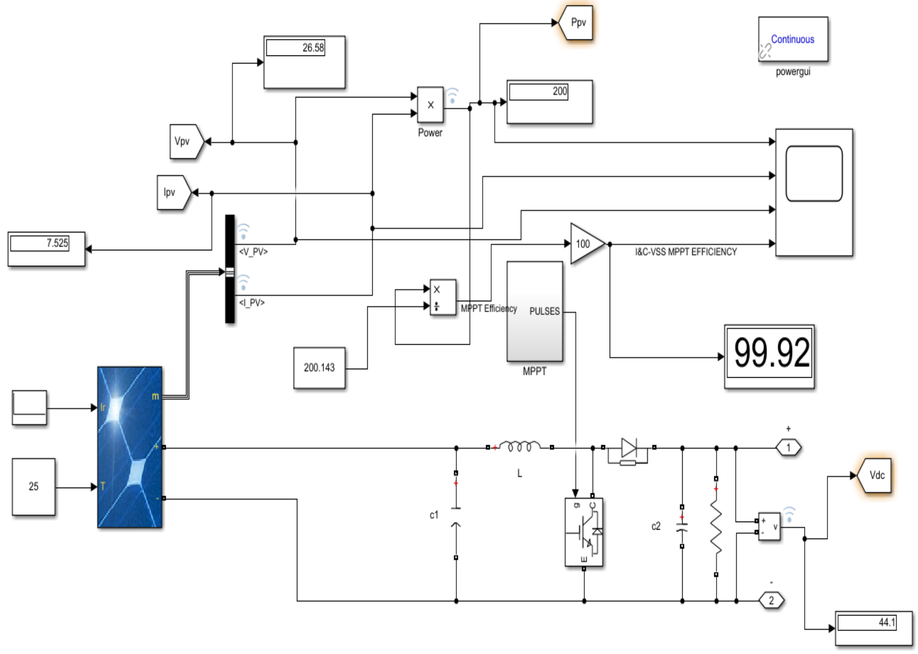



FIGURE 8. The Simulation model of PV array in Simulink with the Improved Incremental Conductance Algorithm Technique

In Figure 9, *u* and *I* refer to the voltage and current sampling value; *u0* and *i0* denote the voltage and current sampling value in the preceding cycle; *D* refers to the initial duty ratio of the boost converter.

The simulation results for the proposed INC-FI technique and conventional INC method has been presented in Figure 9. The outcomes for both the technique have been compared under variable irradiance condition and constant solar temperature at 1000W/m$^2$ and 800W/m$^2$. It is seen that improved INC-FI technique delivers more accurate results and limits the power losses within the desired range at constant temperature. Further, the improved INC-FI method deliver better tracking capability for MPP during simulation.

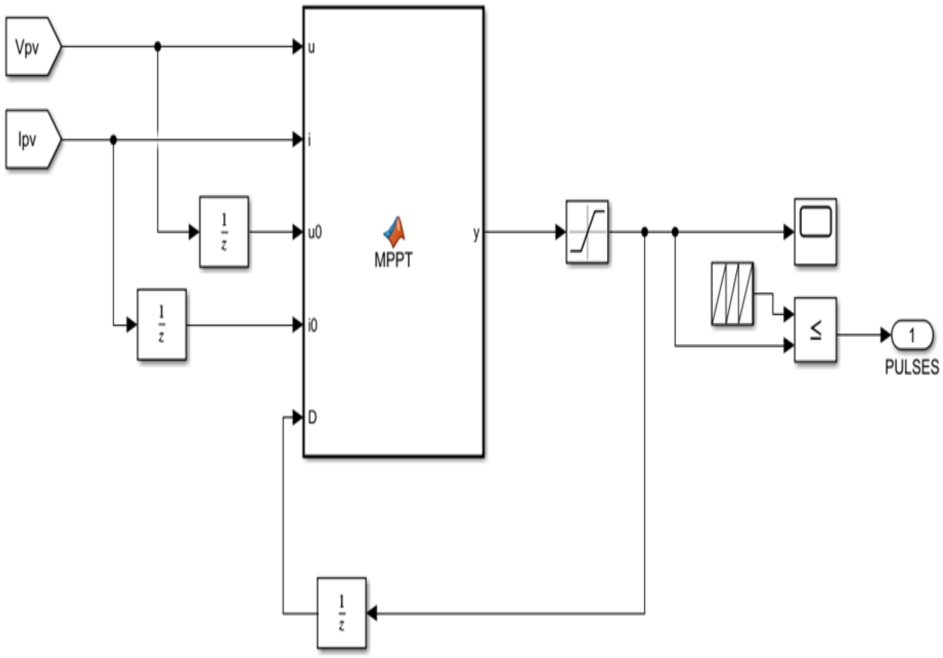
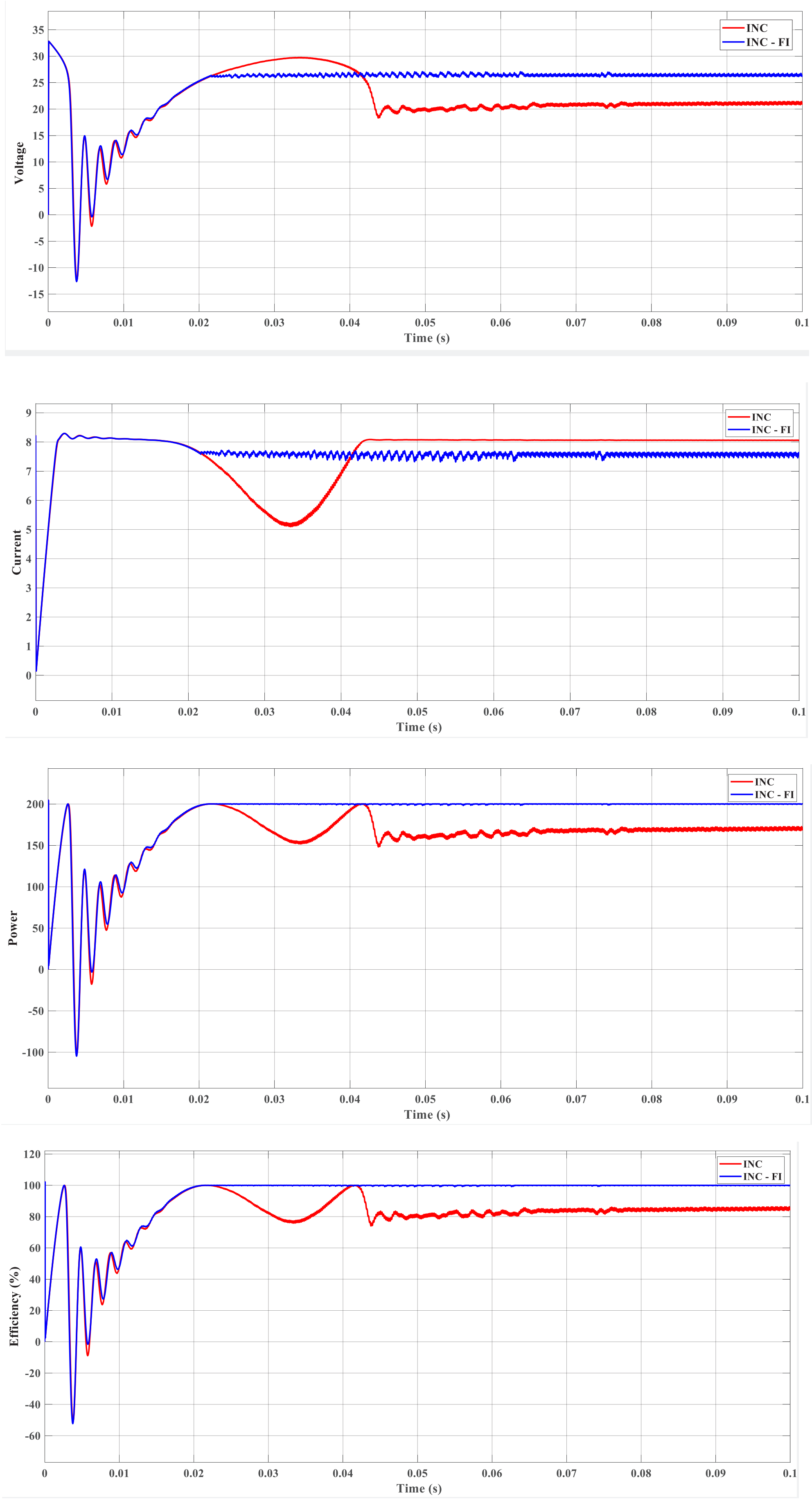


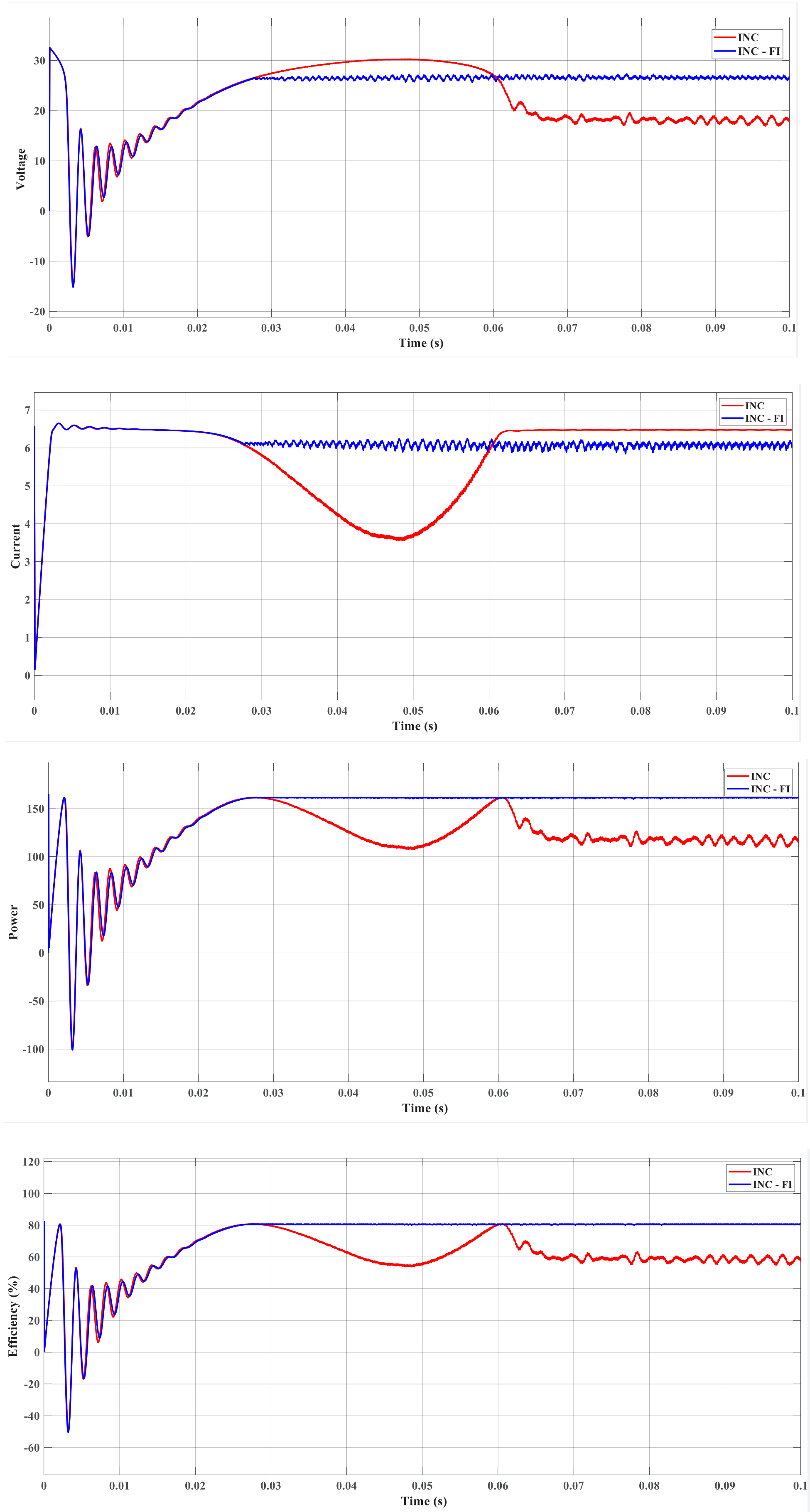

FIGURE 9. Block module chart of MPPT in INC MPPT method

The power loss can be minimized significantly by utilizing the proposed method during variable irradiance conditions. On the other hand, it is observed that better stability at steady state for various outcomes of PV array such as power, current, voltage and efficiency has been achieved by INC-FI technique. Nevertheless, the stability as well as transient state condition for the conventional model was not appropriate. With regards to the power efficiency of the PV array, the improved INC-FI technique depicts better outcomes for tracking efficiency under variable irradiance condition and solar temperature as shown in figure 9. It is observed that the MPPT efficiency of the conventional method was 85.39 as compared to 99.97 for the proposed INC-FI technique. The fast tracking was achieved with the proposed method with a time of 0.02 s (approx) compared to the conventioanl method i.e 0.1 s (approx). Further, when the value of the solar irradiance is decreased from 1000W/$m^2$ to 800W/m2, the MPPT efficiency also decreased to 80.54% as compared to the 99.92% at 1000W/$m^2$ for INC-FI technique. In both the cases, the proposed INC-FI method forecasted better accuracy to estimate the MPPT efficiency. The decrease in the power efficiency for the conventional method was due to the inability to track the power at variable irradiance whereas, the drawback was minimized in the proposed method which displayed better outcomes. Also, high fluctuation were comman during the operation for the conventional method which were reduced with the proposed technique. The tracking speed for the proposed method was significantly increased as the steady state condition in the simulation results was achieved in less time as compared to the conventional method.



INC
INC - FI
Voltage
35
30
25
20
15
10
5
0
-5
-10
-15
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
Time (s)
INC
INC - FI
Current
9
8
7
6
5
4
3
2
1
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
Time (s)
INC
INC - FI
Power
200
150
100
50
0
-50
-100
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
Time (s)
INC
INC - FI
Efficiency (%)
120
100
80
60
40
20
0
-20
-40
-60
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
Time (s)


(a)




(b)

FIGURE 10. Simulation result comparison between the INC and INC-FI method under the scenario of temperature variation with constant solar irradiance: (a) 1000 W/m2; (b) 800 W/m2

TABLE 2. Comparitive analysis for various MPPT tecnhiques based on critical factors

| Method | Tracking time | Efficiency(%) | Tracking accuracy | Transient oscillations | sensor | Reference |
|---|---|---|---|---|---|---|
| Proposed algorithm | 10s | 99.9 | high | high | Voltage, current | --- |
| Modified GA and FA | 30 s | 95 | high | --- | Voltage, current | (Y.-P. Huang et al. 2018) |
| Spline Model Guided | 20 s | 98.5 | high | high | Voltage, current | (C. Huang et al. 2019) |
| FFA With SPP MPPT | 15 s | 80 | low | high | Voltage, current | (Y.-P. Huang et al. 2020) |
| Global/Local MPPT | 20 s | 99 | high | high | Voltage, current | (S. Makhloufi & Mekhilef 2021) |

A comparison analysis for various MPPT technologies has been analyzed as depicted in table 2. It is observed that different technology possesses different strength and weaknesses. However, the proposed improved INC based MPPT technology displayed better performance regarding high performance and fast-tracking application.

## CONCLUSION

This paper has presented a successful simulation of PV array with proposed INC -FI which is utilized for displaying better tracking efficiency for variable temperature condition. The simulated results are by taking into consideration of the effects of temperature variance. Further, a comparative study with conventional method as well as proposed method has been performed at variable temperature on MATLAB Simulink platform. The proposed INC -FI technique for MPPT algorithm demonstrated better tracking capabilities and delivered the power efficiency of 99.92% as compared to the 84.39% for the conventional method. The significant improvement of the results in the proposed INC -FI technique was due to its better tracking capability at variable temperature condition. Additionally, this resulted in the minimization of the power loss. The proposed system can adapt to the change in the environmental conditions and delivers efficient results.

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## DECLARATION OF COMPETING INTEREST

None

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