

ISSN: 1813-162X (Print) ; 2312-7589 (Online)

Tikrit Journal of Engineering Sciences

available online at: <http://www.tj-es.com>

TJES
Tikrit Journal of
Engineering Sciences

Mahmmoud ON, Gaeid KS, Nashi AF, Siddiqui KM. Induction Motor Speed Control with Solar Cell Using MPPT Algorithm by Incremental Conductance Method. *Tikrit Journal of Engineering Sciences* 2020; 27(3): 8- 16.

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Keywords:

Induction Motor, PV, Maximum Point
Power Tracking, DC/DC converter, Speed
Controller.

Induction Motor Speed Control with Solar Cell Using MPPT Algorithm by Incremental Conductance Method

A B S T R A C T

In the world, optimizing energy and finding new sources is important because of the increased consumption that occurred in all aspects of life. Nowadays, the world suffers of the reduction in the fossil fuel continuously. One solution to this problem is the sun and the photovoltaic (PV) cell. To get the benefits of PV, the DC/DC and DC/AC converters and inverters are combined in one set to get the better usage of these capabilities. Induction motor (IM) is the horsepower in the industry and will be considered the load in this work. The DC/DC Converter is used for control of IM speed in combination with maximum power point tracking (MPPT). Temperature and radiation change constantly over time, and the maximum energy should be tracked. This follow-up was performed using Incremental Conductance method (INC). INC is control buck-boost duty cycle converter. We get the best performance in INC technology and have less effect on the system. This algorithm uses INC of the MPPT to control half of horse power of IM. The sine pulse width modulation technique (SPWM) is used with three level inverters. Simulation on the Three-phase proves the efficiency of the suggested technique.

ARTICLE INFO

Article history:

Received 07 Dec. 2019
Accepted 10 May 2020
Available online 01 July 2020

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DOI: <http://doi.org/10.25130/tjes.27.3.02>

التحكم في سرعة المحرك الحثي مع الخلايا الشمسية باستخدام خوارزمية تتبع أقصى نقطة للطاقة بواسطة طريقة التوصيل التزايدية

عمر نافع محمود/ قسم الهندسة الكهربائية/كلية الهندسة / جامعة تكريت
خلف سلوم كعيد /قسم الهندسة الكهربائية/كلية الهندسة / جامعة تكريت ، اسعد فنانج ناشي /تكنولوجيا المعلومات والاتصالات / الجامعة التكنولوجية الوسطى،
كاظم معين صادق/ قسم الهندسة الكهربائية/ المعهد القومي للإدارة والتكنولوجيا في بابو بناراسي/ لكانو / الهند
الخلاصة

في العالم، يعد تحسين الطاقة وإيجاد مصادر جديدة أمراً مهماً بسبب الاستهلاك المتزايد الذي حدث في جميع جوانب الحياة. في الوقت الحاضر، يعاني العالم من انخفاض الوقود الأحفوري باستمرار. أحد حلول هذه المشكلة هو الشمس والخلايا الكهروضوئية. للحصول على فوائد الخلايا الكهروضوئية، يتم دمج محولات

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التيار المستمر/التيار المستمر ومحولات التيار المستمر/التيار المتناوب والعاكس في مجموعة واحدة للحصول على الاستخدام الأفضل لهذه القدرات. المحرك الحثي هو القوة الحصانية في الصناعة وسيتم اعتباره الحمل في هذا العمل. يستخدم محول التيار المستمر/التيار المستمر للتحكم في سرعة المحرك الحثي مع الحد الأقصى لتتبع نقطة الطاقة. تتغير درجة الحرارة والإشعاع باستمرار بمرور الوقت، ولهذا يجب تتبع الطاقة القصوى. تم إجراء هذه المتابعة باستخدام طريقة التوصيل التزايد. طريقة التوصيل التزايد تتحكم في قيمة فترة التشغيل للمبدل الخافض الرفع للجهد. نحصل على أفضل أداء في تكنولوجيا التوصيل التزايد ولديه تأثير أقل على النظام. تستخدم خوارزمية التوصيل التزايد لتتبع نقطة الطاقة القصوى للتحكم في المحرك الحثي ذو القوة نصف حصان وتقنية تعديل عرض النبضة الجيبية المستخدمة مع عاكس ذو ثلاث مستويات. تثبت المحاكاة على المحرك الحثي ثلاثي الطور كفاءة التقنية المقترحة.

1. INTRODUCTION

Life-style development begins with maintaining power generation. One strategy to do that is the sunlight and the semiconductor materials capacities to convert the DC sunlight into useful power used in the industry, domestic and military purpose through Photovoltaic (PV) implementation system [1]. MPPT technologies are categorized according to speed, digital or analog, sensors, simplicity, cost and many other parameters [2]-[3]. Control doubly-fed asynchronous generator electromagnetic torque with different loads with the MPPT [4].

The Benefits of photovoltaic panel are reduction of the pollution, green energy, lower cost and maintenance due to unmovable parts found in PV panel [5]-[6]. MPPT with Split converter for IM is used in [7]. In [8], improved INC technology it is found that it quickly detects increased radiation and makes the right decision, ignores the approximate value of steady-state fluctuation, reduces energy loss and has a high efficiency. INC technology is more efficient and provides fast tracking speed for MPPT for PV [9]. Combining the INC and the PID algorithms in [10]. The algorithm can monitor the MPP point easily, the fluctuation is quite a small combination of switched reluctance four-phase motor drive with split converter for both DC and AC source to charge [11].

As is known, it is affected by the energy extracted from the solar panels strongly on three factors: the radiation levels, ambient temperature, characteristics of the pregnancy [12]. In general, photovoltaic systems were designed to produce maximum available energy

regardless of radiation density and temperature impedance to pregnancy determines the energy produced by solar panels and can be a DC payload with batteries or without it. When we connect solar panel directly to the load, the point will be off the system when the point of intersection of the curve I-V with Load Line, which may not be at the maximum point of energy, leading to energy loss. In order to improve the output power of solar panel and overcome these limitations, DC-DC converter is embedded between the load and solar panel [13].

In order to optimize the use of solar energy, the PV must operate at point power in maximum. There are many techniques for MPPT that have been mentioned in the literature [14], like incremental conductance (INC), perturb and observation (P&O), open-circuit voltage (OCV), short-circuit current (SCC), fuzzy logic and neural network.

When INC is applied with rapid changes in weather conditions, the oscillations across M in INC are much lower compared to P&O [15]. This article discusses the results of the proposed system, which consists of PV modeling, MPPT algorithms and IM speed control.

2. MPPT ALGORITHMS

The MPPT algorithm is used to improve energy efficiency in the PV system [16]. The DC is obtained directly from the PV panel, as mentioned earlier. Using an inverter [17], the power should be converted to AC. The ability of PV to drive the DC or AC loads can be explained in Fig. 1.

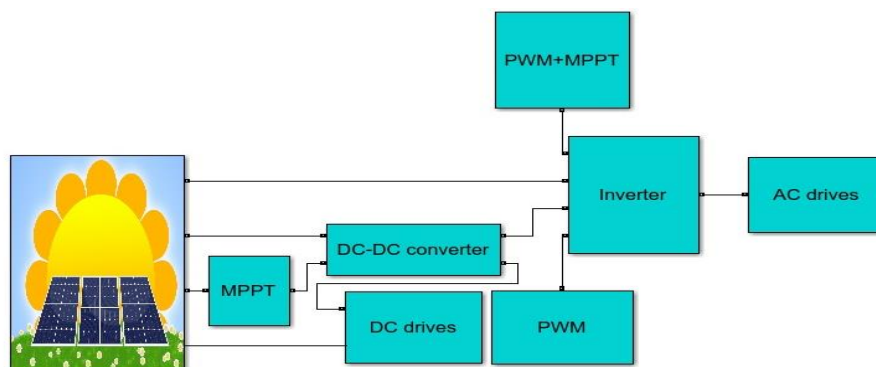


Fig. 1. The grain-size distribution curve.

The on-line, off-line and hybrid techniques are the most main MPPT schemes to ensure better operation of PV

systems. Fig. 2 illustrates the classification of MPPT methods.

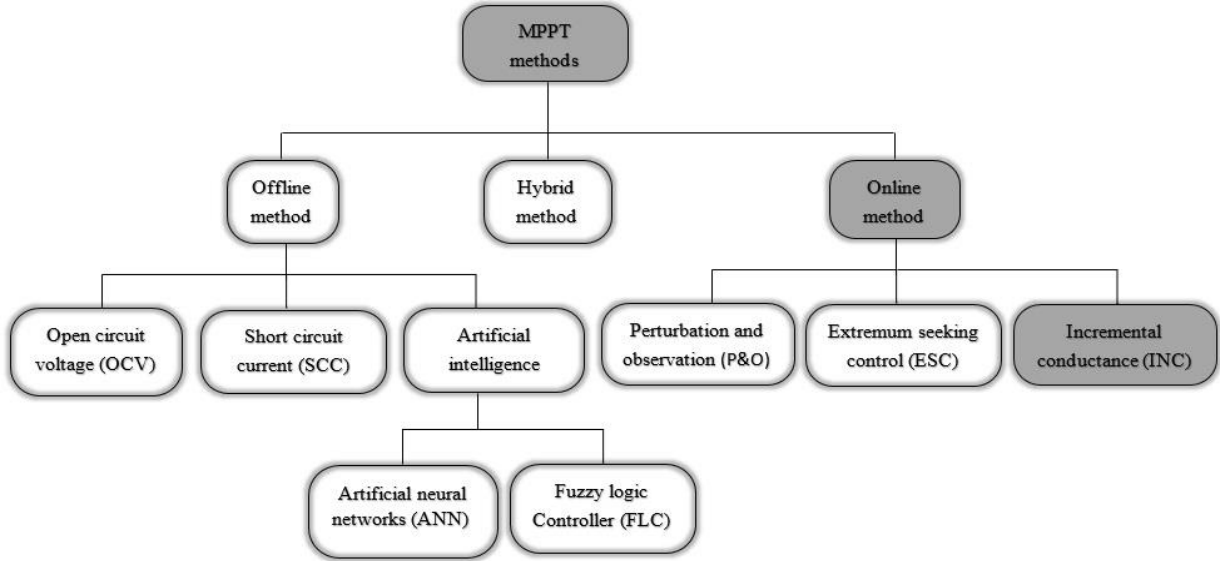


Fig. 2. Classification of MPPT methods

There are two main MPPT online methods [18], the methods are incremental conductance (INC) [19], and

Perturbation and Observation [20]. This work used INC method it's shown in Fig. 3.

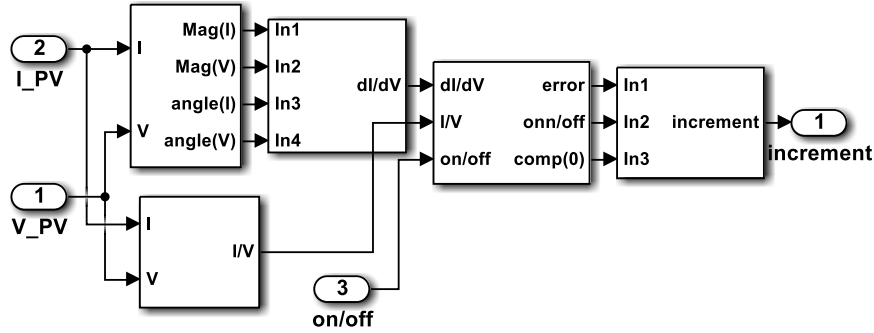


Fig. 3. PWM generation technique

The INC principle is based on the premise that the power derivative on voltage derivative of PV output equals zero. The output of this algorithm is almost efficient under rapid switching conditions, MPP approaches to the left when PV radiation is reduced. In terms of performance, this technology is known to be one of the better innovations, but its cost is high and its control circuit is complex. Normally, MPPT failed to track sunlight for many reasons. The best performance specifications of the MPPT system are to obtain sufficient tracking of accuracy, speed, low steady state error and high efficiency [21]. DC-DC converters are classifying as a Luo converter, SEPIC buck, boost, buck-boost, Cuk, Zeta, Forward, push-pull, full bridge, and fly back converter [22]. Two MPPT algorithms with recent cuckoo search and particle swarm optimization used in [23]. The operation of PV panels in the shaded environments can lead to reduction in the power generation output and hence the MPPT will not lead to efficient results [24]. In [25], the advanced techniques with control systems, books, Simulink implementation of PV systems is given and the classical techniques as well.

A simple comparison of the MPPT techniques may be made in Table 1.

MPPT by INC technique the ratio of the derived PV power in relation to the derived voltage is zero which is given in (1) [26].

$$dP/dV = 1 \quad (1)$$

Where:

$$P = V \cdot I \quad (2)$$

$$d(V \cdot I)/dV = I + V \cdot dI/dV = 0 \quad (3)$$

$$dI/dV = -I/V \quad (4)$$

$$dI/dV = -I/V$$

Where:

dI , dV is the harmonic components of current (I) and voltage (V) ripples of MPPT

I , V is the average voltage (V) and current (I) values for MPPT

The error is measured as in (5)

$$dI/dV + I/V \approx 0 \quad (5)$$

Then, the regulator output is the duty cycle correction to control the system.

Table 1

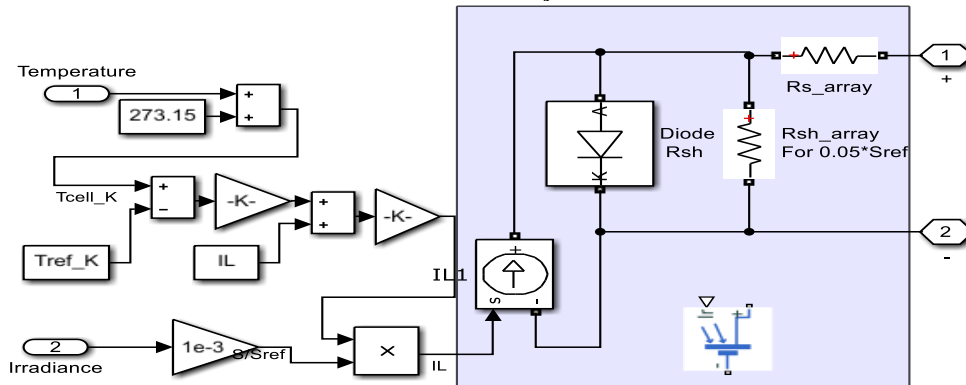
Comparison of MPPT technologies

MPPT method	Sensed parameters	Kit (Analog or Digital)	Cost	Convergence speed	Complexity	Efficiency
P&O/Hill Climbing	Voltage or Current	Both	Expensive	Fast	Medium	moderate
FLC	Depends	Digital	Expensive	Fast	High	High
INC	Depends	Digital	Expensive	High	High	High
ANN	Depends	Digital	Expensive	Fast	High	High
OVC	Voltage	Both	Inexpensive	Medium	Low	Low
SCC	Current	both	Inexpensive	Medium	Low	Low
Hybrid	Voltage or Current	Digital	Expensive	Fast	High	Hight
ESC	Voltage or Current	Both	Expensive	Fast	Medium	High

3. PV MODELING

PV panel modeling can be shown as in Fig. 4. This circuit composed of current source to represent the solar

irradiation (IL). P-N junction diode is connected with the current source. The shunt resistance array represents the leakage current while the series resistance represents the PN junction surface resistance..

**Fig. 4.** PV panel modeling.

The series PV panels are connected to obtain high voltage and the panels are connected in parallel when high current is needed to produce the required power output.

The series array resistance is calculated as follows:

$$R_{S-array} = R_S * N_{series} / N_{parallel} \quad (6)$$

The series resistance comes from the following

- 1.The metal contacts resistance
- 2.Ohmic losses in the front surface of the cell
- 3.Impurity concentrations

4.Junction depth

The parallel array resistance is calculated with 0.05 compensation as:

$$R_{p-array} = 0.05 * S_{ref} \quad (7)$$

Moreover, it's approximately equal to changing in reverse bias voltage to changing in reverse bias current of diode characteristic.

Where:

S_{ref} is the irradiance

The diode voltage is calculated as follows:

$$V_{diode} = V_{pv} + R_s I_{pv} \quad (8)$$

The diode characteristic, which depends on various variables give it the nonlinearity characteristic is given in (9)

$$I_{diode} = I_{out} * [Exp(V_{diode}/V_T) - 1] \quad (9)$$

Where:

I_{out} is the current which flows on reverse direction when the diode is reverse biased. It's called the saturation current or leakage current.

V_T is the temperature voltage and it is can be illustrated as in (10)

$$V_T = K * T_{pv_cell} / q * N_{ident} * N_{cells} * N_{series} \quad (10)$$

Where:

N_{ident} is the ideality factor for a diode and it is an indicator of the behavioral proximity of the device under test, to an ideal diode.

$q=1.6e^{-19}C$ is the electron charge,

$K=1.38e^{-23} j/k$ is the Boltzmann's constant.

The load current expressed in the (11)

$$I_L = \frac{S}{S_{ref}} * (I_{L_Ref} + \alpha * (T_{pv} - T_{ref}), \alpha = 0.001 \quad (11)$$

The voltage generated by PV cells and the current are expressed in (12):

$$V_g = I_g R_s (N_s / N_p) \ln(1 + \frac{N_p I_{ph} - I_g}{N_p I_o}) \quad (12)$$

$$I_g = I_{ph} - I_o (Exp(q V_g / kT) - 1) \quad (13)$$

From (13), set $V_g = 0$ in the exponential expression, hence the short circuit current can be obtained as:

$$I_{sc} = I_{ph} \quad (14)$$

The voltage of the open circuit is obtained by equating the cell current to zero, expressed in (15).

$$V_{oc} = (kT/q) \ln(\frac{I_{ph} + I_o}{I_o}) \cong (kT/q) \ln(\frac{I_{ph}}{I_o}) \quad (15)$$

In this equation the value of $I_{ph} > I_o$

The PV cell's MPP, expressed in (16):

$$P_m = I_m V_m = FF * I_{sc} V_{sc} \quad (16)$$

where:

FF, I_m, V_m is the fill factor which is the reliability indicator, maximum current and maximum voltage respectively.

$$FF = P_{max} / P_{theoretical} \quad (17)$$

The PV panels can efficiently be determined as in (18):

$$\eta = P_{out} / P_{in} \quad (18)$$

Where:

P_{out}, P_{in} is the input and output power respectively

$$P_{out} = P_{max} (W / m^2) \quad (19)$$

At 1.5 am, $P_{in} = 1000 (W / m^2)$.

4. SPEED CONTROLLERS IM

The IM motor drives received great attention in the various applications [27]. One stage PV system with five phase IM drive is proposed [28]. The system of PV used makes conversion of sunlight energy into useful power through semiconductor materials, known as PV cells [29]. In the discrete system, a dead-beat control is use with PWM control method to MPPT of the sunlight. Fig. 5 shows the MATLAB/Simulink implementation of the PWM used in this work.

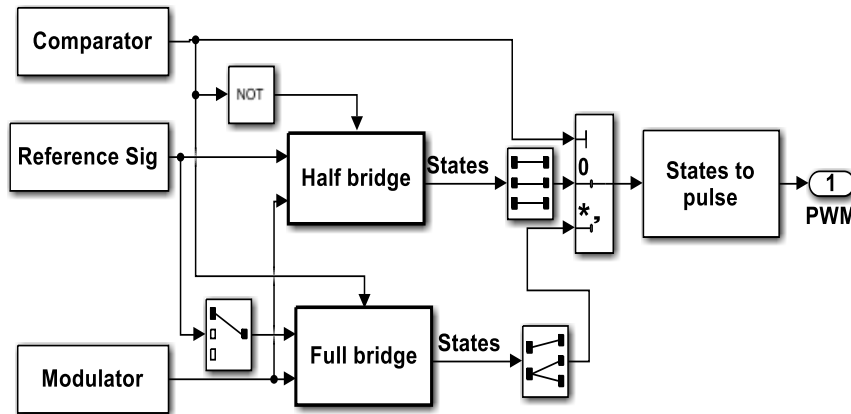


Fig. 5. PWM generation technique

The dead-beat modeling of state space of the inverter system to estimation of the PWM duty cycle studied in [30]-[31]. The MPPT technique with a three-phase IM used Dc-to-Dc boost converter to control angular speed studied in [32]. PV panel with artificial intelligence using fuzzy logic with estimators in the pumping system utilizing IM studied in [33]. The PV with pumping system using MPPT with monitoring use inverter PS1200 complete set in [34].

The inverter is executed by MOSFET switches. The inverter is controlled by PWM signal, which is generated according to the sensor signal of the inverter. Fig. 6 shows the implementation of two control loops of inverter its voltage control and the current control.

Voltage control is used to control and maintain the DC constant voltage link. Current control is used to synchronize PV with the network. It is achieved by aid of Phase-locked loop to control parameter of the current and voltage for synchronization and also to keep a DC voltage fixed with the assistance the frame of reference (d-q) along with a controller PI, which has been tuned by using method of Ziegler Nicholas [35]. The harmonic sources like the renewable sources of energy produce electric power to a load that is directly attached to the cells [36]-[37]. The IM mathematical model in the direct-quadrature reference frame is:

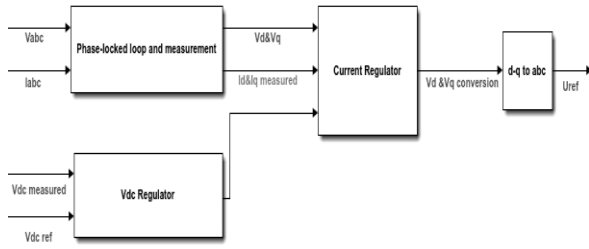


Fig. 6. Current and voltage control loop

$$\begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \end{bmatrix} = \frac{1}{L_m^2 - L_s L_r} \left(A \begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \end{bmatrix} + \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_r & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix} \right) \quad (20)$$

$$A = \begin{bmatrix} \frac{-(R_s + R_r(L_m / \tau_r)^2)}{\sigma L_s} & 0 & \frac{L_m}{\sigma L_s L_r \tau_r} & \frac{\omega_r L_m}{\sigma L_s L_r} \\ 0 & \frac{-(R_s + R_r(L_m / \tau_r)^2)}{\sigma L_s} & \frac{-\omega_r L_m}{\sigma L_s L_r} & \frac{L_m}{\sigma L_s L_r \tau_r} \\ L_m / \tau_r & 0 & -1 / \tau_r & -\omega_r \\ 0 & L_m / \tau_r & \omega_r & -1 / \tau_r \end{bmatrix} \quad (21)$$

Where:

ω_r , τ_r , L_s , L_r , L_m , σ , and are IM angular velocity (rad/s), rotor time constant, the stator inductance, rotor inductance, mutual inductance, leakage coefficient respectively [38].

5. RESULTS

Fig. 7 shows a complete control system block diagram for IM speed control with solar cell Using MPP. This figure contains three main parts: input part, MPPT with the smoothing filter and the motor drive parts. The input part was constructed with the PV array, the irradiance and temperature reference inputs. The second part is consisting of the DC/DC converter and the last part is PWM generation signal for the IM through the inverter and the LC filter. There are measurement tools to record the parameters such as speed, torque, currents and voltages.

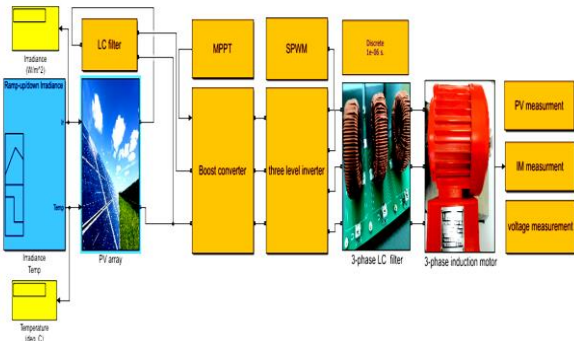


Fig. 7. Simulink implementation of algorithm proposed

The output waveform of the three-level inverter without MPPT (purple) and with proposed MPPT (red) is shown

in Fig. 8. The output from the three-level inverter provides 3 voltage levels +210 V, +105 V, 0 V, -105 V and -210 V. The torque output of IM without MPPT (purple) and with proposed MPPT (red) is shown in Fig. 9. In this figure, high torque ripples under transient response. The torque output due to a reference of 2.5 N-m is 2.5 ± 5 N-m during first second. The torque of the proposed system decreases significantly by 50 percent between (0.25-0.75) sec to ensure improved functioning of the IM in the steady-state region. The motor stator current, without MPPT (purple) and with proposed MPPT (red) is shown in Fig. 10. In this figure, the starting current of the IM, is very large, 7 Amp for the MPPT and 9 Amp without MPPT. The transient response reaches its reference of 1.5 Amp within 0.75 sec for the proposed algorithm and 1.25 sec without MPPT

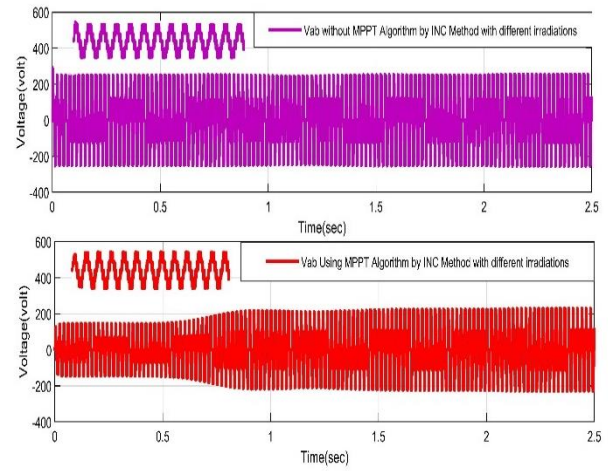


Fig. 8. Inverter voltage with three levels

The motor stator current, without MPPT (purple) and with proposed MPPT (red) is shown in Fig. 10. In this figure, the starting current of the IM, is very large, 7 Amp for the MPPT and 9 Amp without MPPT. The transient response reaches its reference of 1.5 Amp within 0.75 sec for the proposed algorithm and 1.25 sec without MPPT. The rotor current for both cases is shown in Fig. 11. The IM rotor current during operation to reach the rated current of the motor 1.5 Amp within 0.75 sec for the proposed algorithm and 1.25 sec for the system without MPPT.

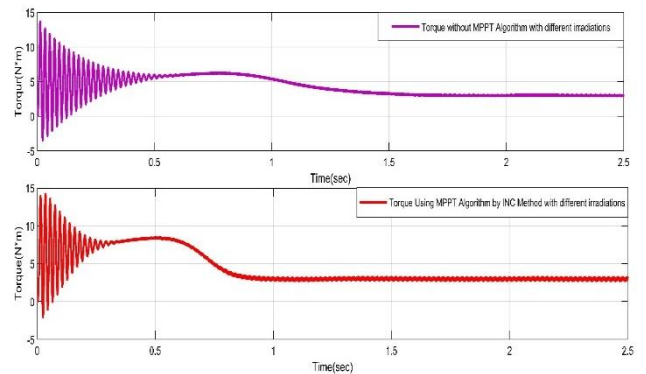


Fig. 9. The induction motor torque

Fig. 12 shows the output speed of the IM to follow its reference speed of 1440 RPM for the system without MPPT (purple) and with the proposed MPPT (red). When the IM is started the speed increases gradually and this gradient remains at time 0.75 sec and at time 0.75 to 2.5 sec the IM speed is fixed at 1440 RPM for the proposed algorithm. At 1.25 sec IM is fixed without MPPT.

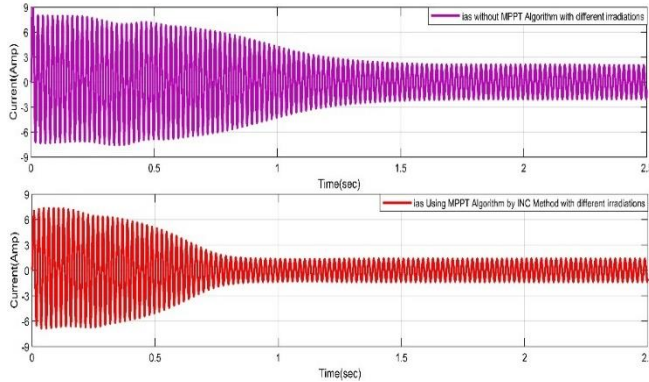


Fig. 10. Induction motor stator current

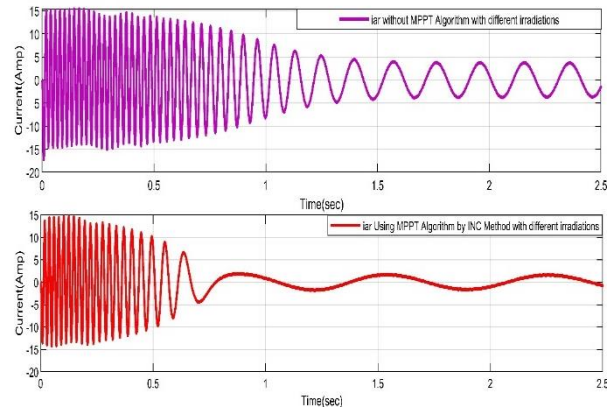


Fig. 11. Induction motor rotor current

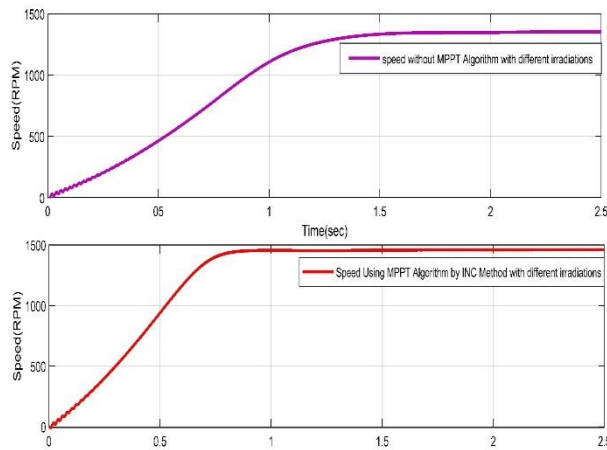


Fig. 12. Induction motor speed

Fig. 13 shows the reference irradiance values. The reference value starts from the value 1000 W/m^2 for 0.6 sec, then decreased to 400 W/m^2 between 1.1-1.2 sec, and settled with 1000 W/m^2 at 1.7 sec.

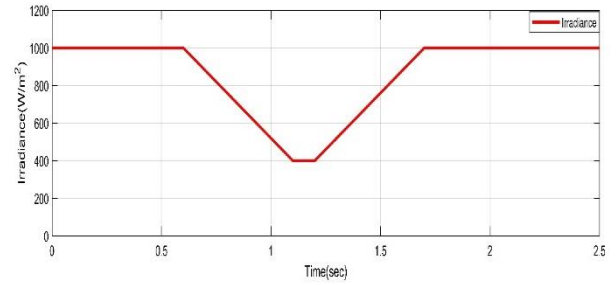


Fig. 13. Different irradiance values

Fig. 14, illustrates the different temperature values starting from 30°C and it continues to 2 sec, then changed 25°C to check the proposed algorithm against the temperature variation. Fig. 15 shows the power and current curve versus the voltage for the PV panel while applying the MPPT algorithm for different radiation values of 200, 400, 600, 800, 1000 W/m^2 . MPPT varies with the difference of radiation. The PV current corresponds to the ratio of immediate radiation to radiation in standard test conditions. The lower the solar radiation gradually, the lower the energy of the PV output due to the direct correlation between PV power and radiation

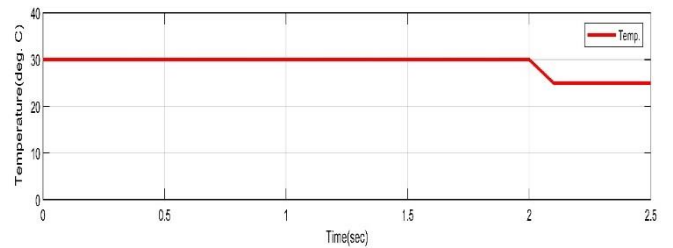


Fig. 14. Different temperature values

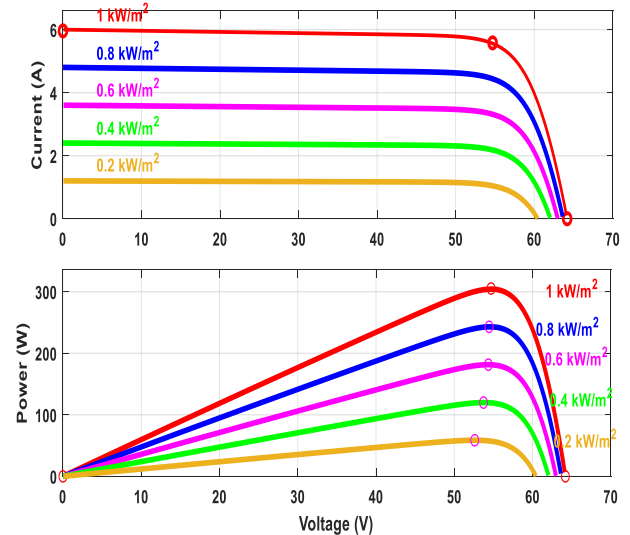


Fig. 15. Current and power vs voltage

6. CONCLUSION

Simulations were performed at MATLAB and the findings were analyzed. The proposed system is controlled using a control strategy using the MPPT INC algorithm to extract the maximum power from the PV panel and SPWM technology and to control the three-phase IM speed using the voltage/frequency approach. As a result, the voltage source inverter adjusted the

terminal voltage such that the voltage / frequency ratio remained the same. The maximum torque was observed to remain constant across the range of speeds. INC have a good capability to track MPPT, Also, less transient response time, that is, the IM stability was faster. And the ripple in speed is lower. The design proposed therefore increases both the efficiency of the PV source and the IM by using inverter on three levels.

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