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Speed Control of Induction Motor Based on Multilevel Inverter with Boost Converter Using PV Panels

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- *Speed Control of IM using a boost converter.*
- *Multilevel inverter with solar panels.*
- *IM performance using variable solar conditions.*

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Abstract: The increasing need for fuel in our daily lives makes us think about alternative energy solutions, and finding various other sources is essential. One of the important solutions to this problem is the energy of the sun due to its many advantages. A DC/DC voltage bucks' converter is used to control the value of the voltage generated by solar panels, as well as track the status of the panels and obtain the maximum power for power point tracking (MPPT). The solar panels were modeled to be variable in terms of temperature and radiation. A multilevel inverter was used to obtain the voltage from the inverter more accurately and to obtain an ideal alternating voltage so as not to affect the operation of the three-phase induction motor (IM) and its speed control. Simulation in MATLAB at all stages of the proposed system has proven its efficiency.

التحكم في سرعة المحرك الحثي على أساس العاكس متعدد المستويات مع محول جهد التيار المستمر باستخدام الألواح الكهروضوئية

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الخلاصة

إن الحاجة المتزايدة للوقود في حياتنا اليومية تجعلنا نفكر في حلول الطاقة البديلة، وإيجاد مصادر جديدة له أهمية كبيرة. ومن الحلول المهمة لهذه المشكلة هي طاقة الشمس، لما لها من مزايا عديدة. في هذا العمل، يتم استخدام محول DC/DC للتحكم في قيمة الجهد الناتج عن الألواح الشمسية، وكذلك تتبع حالة الألواح والحصول على الطاقة القصوى لتتبع نقطة الطاقة (MPPT). تم تصميم الألواح الشمسية لتكون متغيرة من حيث درجة الحرارة والإشعاع. تم استخدام عاكس متعدد الطور لجعل الجهد الخارج من العاكس أكثر دقة وللحصول على جهد متناوب مثالي حتى لا يؤثر على تشغيل المحرك ثلاثي الطور الذي تم تشغيله والتحكم في سرعته. لقد أثبتت المحاكاة في MATLAB في جميع مراحل النظام المقترح كفاءتها.

الكلمات الدالة: محول DC-DC؛ IM؛ عاكس؛ MPPT؛ الخلايا الشمسية الكهروضوئية؛ التحكم في السرعة.

1.INTRODUCTION

PV cell is a kind of energy collection technology. Many PV cells are used to generate electricity from solar energy [1]. Sun radiation levels are different during the day, affecting the power generated by the panels; MPPT works to select the maximum power of photovoltaic (PV) panels [2]. The types of MPPT are divided into several types, including according to the sensor, speed, and other requirements as needed [3]. MPPT torque control of doubly fed induction generator under different electromagnetic loads [4]. Solar panels provide clean and green energy. Using solar panels to generate electricity has no harmful greenhouse gas emissions, so solar PV power generation is environmentally friendly [5]. Split converter with MPPT for IM is used in [6]. Four-phase motor to achieve integrated and flexible charging functions charging system implementation in [7], which is roughly in the middle between conservative and optimistic forecasts [8]. Himavathi and Venkadesan [9] used a deadbeat of the state space of the inverter to estimate the SPWM duty cycle. Sun and Cheng [10] implemented MPPT with IM using a D/Dc buck-boost power converter to speed control. PV panels and artificial intelligence use the Perturb and Observation (P&O) [11]. Figure 1 shows that the new PV amplitude increased by more than 10% to about 120 gigawatts in 2023.

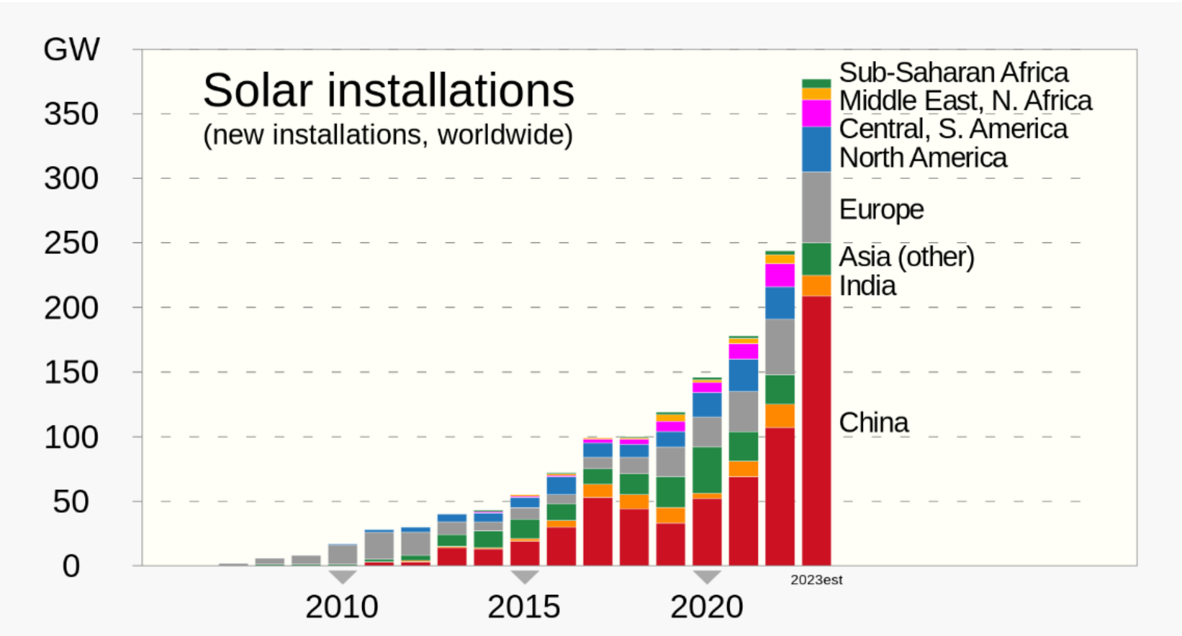

Fig. 1 Worldwide PV Installed Capacity Since 2010.

This study deals with MPPT algorithms, PV modeling, and speed controllers of induction motors, followed by results and ended with conclusions. MPPT works to choose the best amount of power from DC-DC, which improves the matching between panels and battery [12]. There is an urgent need for a control system to get the highest point of solar energy for the summer. There are a lot of MPPT methods [13]. The solar output is stored in the battery. Batteries connected multilevel-inverter and inverter to load [14]. Figure 2 shows a diagram of the integrated system.

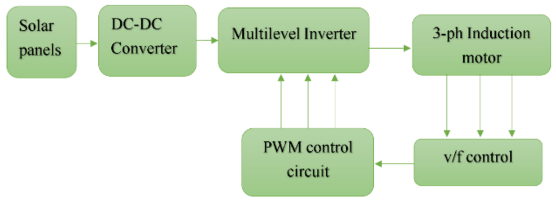

Fig. 2 Diagram of the Integrated System.

2.MODELING OF PV PANELS

PV cells absorb sunlight from the photons, energy carrying the electron to be released and circulated in a closed loop through the load to supply it with the energy [15]. Shunt resistance (RSH) is an important PV performance. The output energy of the array is determined by the leakage current of adjacent cells under different electrical standards, and cell degradation is caused by the local heating of one cell. The effect of current leakage resistance or parallel PV resistance is discussed in [16]. Figure 3 demonstrates the PV cell.

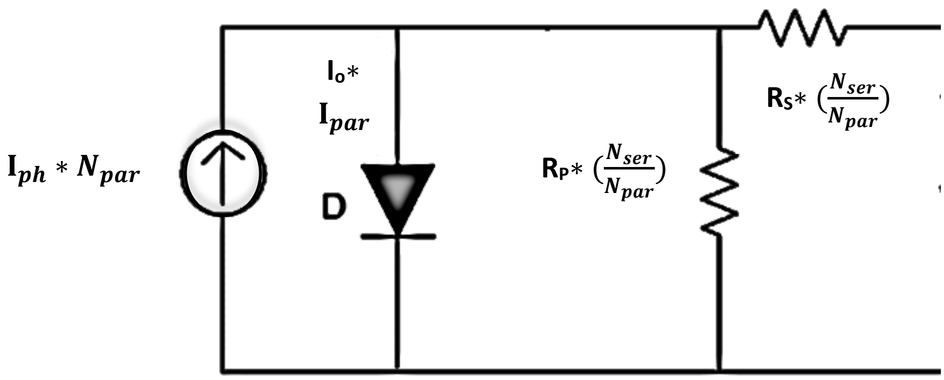

Fig. 3 Modeling of a PV Cell.

Using KCL, the current of the PV cell can be calculated from:

$$I = I_L - I_d - Ish \quad (1)$$

$$I = IL - Is[exp\frac{(V+IRs)q}{akTNs} - 1] - \frac{(V+IRs)}{Rsh} \quad (2)$$

$$I_L = Ir\frac{Isc}{Iro} \quad (3)$$

$$Is = Isc/[exp\frac{Voc}{aVt} - 1] \quad (4)$$

$$I_d = I_s/[exp(\frac{V+IR_s}{aV_t}) - 1] \quad (5)$$

$$I_{sh} = (V + IR_s)/R_{sh} \quad (6)$$

$$Vt = KTN_S/q \quad (7)$$

where Ns denotes the cells connected in series, I_L denotes the light current, I_d denotes the diode current, I_{Sh} denotes the shunt current, I_S denotes the reverse current, R_S denotes the series resistances, Rsh denotes the parallel resistances, Vt denotes the temperature voltage, k= 1.3806503×10^{-23} J/K, T denotes the temperature, Ns denotes the series PV cells, and q= 1.60217646×10^{-19} C, The MPP of the PV cell can be expressed as:

$$P_m = I_m V_m = FF * I_{sc} V_{sc} \quad (8)$$

where FF denotes the fill factor, Im denotes the maximum current, and Vm denotes the maximum voltage. $FF = Ptheoretical_{max}$

The efficiency of the PV panel can be calculated as in (9):

$$\eta = P_{out}/P_{in} \quad (9)$$

where P_{in} denotes the input power, and P_{out} denotes the output power.

$$P_{out} = P_{max}(W|m^2) \quad (10)$$

3.MPPT ALGORITHMS

MPPT is an electronic converter from DC to DC that improves the matching between solar panels, battery packs, or network facilities. Simply put, it outputs high-voltage DC from solar panels, and some wind turbines need low-voltage charging. There is an urgent need for a control system to get the highest point of solar energy for the summer. There are several MPPT methods [17]. Basic MPPTs are such incremental conductance IC method and Perturbation & Observation (P&O) method. The P & O method is a special MPPT algorithm most commonly used in self-improvement [18]. In the P & O, the value of PV power is compared with past power value, giving difference power $PPresent, PPast$ (ΔP), e.g., if ΔP is greater than zero, the continuity of the process is the same as the further turbulence; otherwise, it will move in opposite direction. The P&O flow chart explains that the main disadvantage of the algorithm in various steps is that the MPP of the swing of the operation point on the PV panel is the unstable MPP. To reduce the oscillation of the working point or improve the stability, an improved algorithm is required to improve the tracking speed of MPPT. Considering the instability of the MPP, the high oscillation of MPP is considered. The MPPT changes with temperature and radiation. Energy is wasted before accessing MPP [19]; therefore, the efficiency of the solar power unit developed by the P & O algorithm is reduced. MPP is achieved by providing more interference and control steps without wasting energy fluctuation [20]. Perturbation and Observation around MPP occurs due to the fixed $\Delta V/\Delta i$ value [21]. The reference current/voltage in the Perturbation and Observation algorithm can be expressed as:

$$P = V * I \quad (11)$$

$$V *, I *= I *, V * + \Phi \times f(x) \quad (12)$$

where $I*$, $V*$is the reference current/voltage, and $f(x)$ is one of the mathematical functions.

4.SPEED CONTROLLERS OF IM

Over the years, induction motors have been widely used in various applications, such as paper mills, steel mills, cement, robotics, and wind power systems, due to their simple and reliable structure, ease of maintenance, and high durability. Figure 5 overviews the variable speed control method of an induction motor [22].

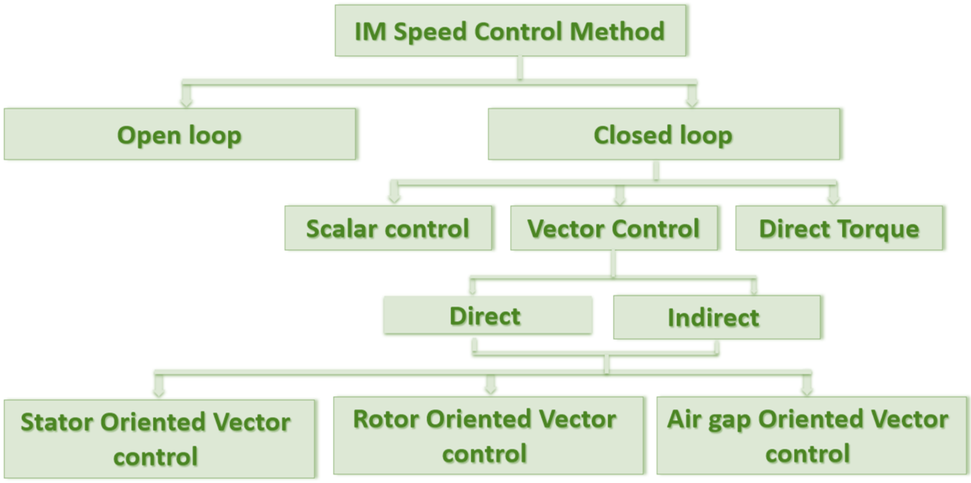

Fig. 5 Overview of IM Speed Control Methods.

In the present work, the mathematical model of the system consisted of a PV panel, a DC-DC buck converter, a sine PWM voltage inverter, and an IM. A three-phase IM drive with one stage of PV system was proposed. In the system, a deadbeat control algorithm was used with the sine PWM control to MPPT of sunlight. Figure 6 shows the PWM circuit. Figure 7. shows the circuit used to obtain a mathematical model of IM.

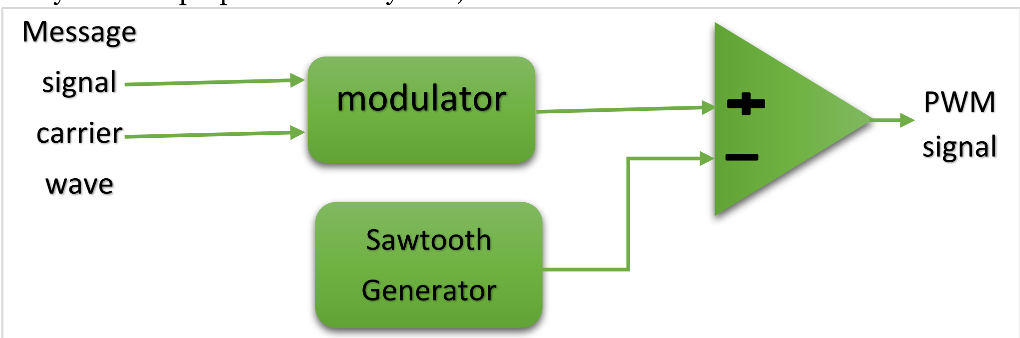

Fig. 6 PWM Generation Technique.

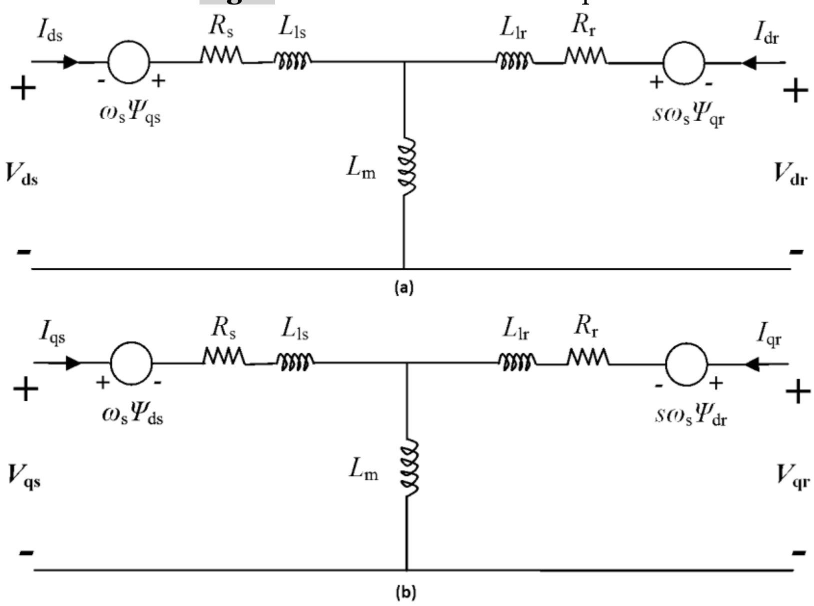

Fig. 7 The Circuit Used for Obtaining the Mathematical Model of 3-ph IM.

The mathematical model of the induction motor in the dq- reference frame.

$$\begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \end{bmatrix} = \frac{1}{{L_m}^2 - L_s L_r}\left(A \begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \end{bmatrix} + \begin{bmatrix} L_s 0 L_m 0 \\ 0 L_r 0 L_m \\ L_m 0 L_r 0 \\ 0 L_m 0 L_r \end{bmatrix} * \begin{bmatrix} v_{sd} \\ v_{sq} \\ v_{rd} \\ v_{rq} \end{bmatrix}\right) \quad (13)$$

$$A = \begin{bmatrix} \frac{-(R_s + R_r (L_m/\tau_r)^2)}{\sigma L_s} & 0 & \frac{L_m}{\sigma L_s L_r \tau_r} & \frac{\omega_r L_m}{\sigma L_s L_r} \\ 0 & \frac{-(R_s + R_r (L_m/\tau_r)^2)}{\sigma L_s} & \frac{-\omega_r L_m}{\sigma L_s L_r} & \frac{L_m}{\sigma L_s L_r \tau_r} \\ \frac{L_m}{\tau_r} & 0 & -\frac{1}{\tau_r} & -\omega_r \\ 0 & \frac{L_m}{\tau_r} & \omega_r & -\frac{1}{\tau_r} \end{bmatrix} \quad (14)$$

where $wr, tr, Ls, Lr, Lm,$ and σ IM angular velocity $\left(\frac{rad}{s}\right)$, rotor time constant, the stator inductance, rotor inductance, mutual inductance, and leakage coefficient, respectively [23]. The method of controlling the speed in IM is using the V/f method. Speed is converted to frequency, and voltage is generated from frequency by maintaining a V/f ratio fixed value for any value of speeds [24].

Figure 8 shows scalar control. The IM V/f control computes voltage based on reference frequency (f_s^*) as:

$$V_s^* = \left(\frac{V_n - V_{min}}{f_n - f_{min}}\right) f_s^* \quad (15)$$

where $Vmin$ is the minimum voltage, $fmin$ is the minimum frequency, fn is the rated frequency, and Vn is the rated voltage. The equations of voltage reference:

$V_\alpha^* = V_s^* \cos(2\pi f_s^* t)$, $V_\beta^* = V_s^* \cos(2\pi f_s^* t)$

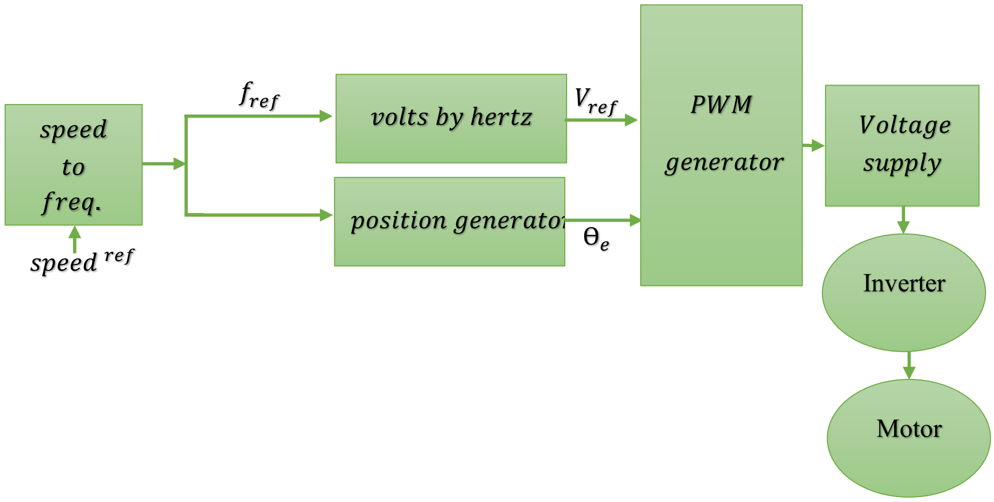

Fig. 8 Scalar Control.

5.RESULTS AND DISCUSSION

The Simulink implementation of a complete closed-loop PV system is shown in Figure 9. The system was modeled in MATLAB R2018b, and the results shown below were obtained. Figure 10 shows a multilevel inverter. Table 1 shows IM (Squirrel Cage) specifications and parameters. Figure 11 shows the three-level inverter voltage. After the first second of operation, the voltage coming out of the inverter was between 220 and -220 volts. The torque of the IM was settled on 3.2 Nm after the transient response for less than 1 sec, as shown in Figure 12. When the IM started, the starting current was high, reaching 14 amp. The stator current of the IM was settled on 2.5 Amp after the transient response for less than 1 sec, as shown in Figure 13, and the same for the rotor current, as shown in Figure 14. The speed of the IM was settled at 1460 RPM after the transient response of less than 1 sec, as shown in Figure 15. Figure 16 shows the current and power during the application of the MPPT algorithm for different irradiance values. Figure 17 shows that the sudden change in temperature and irradiance was continuous from 1.1 seconds to 1.7 seconds.

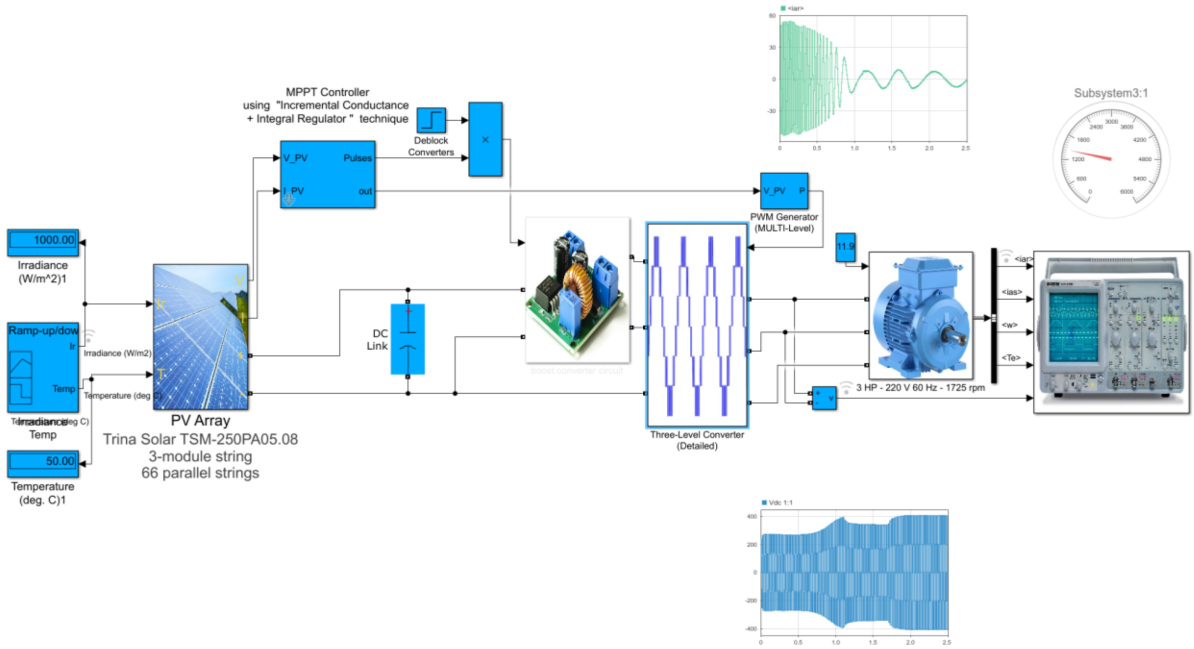

Fig. 9 Closed-Loop PV System.

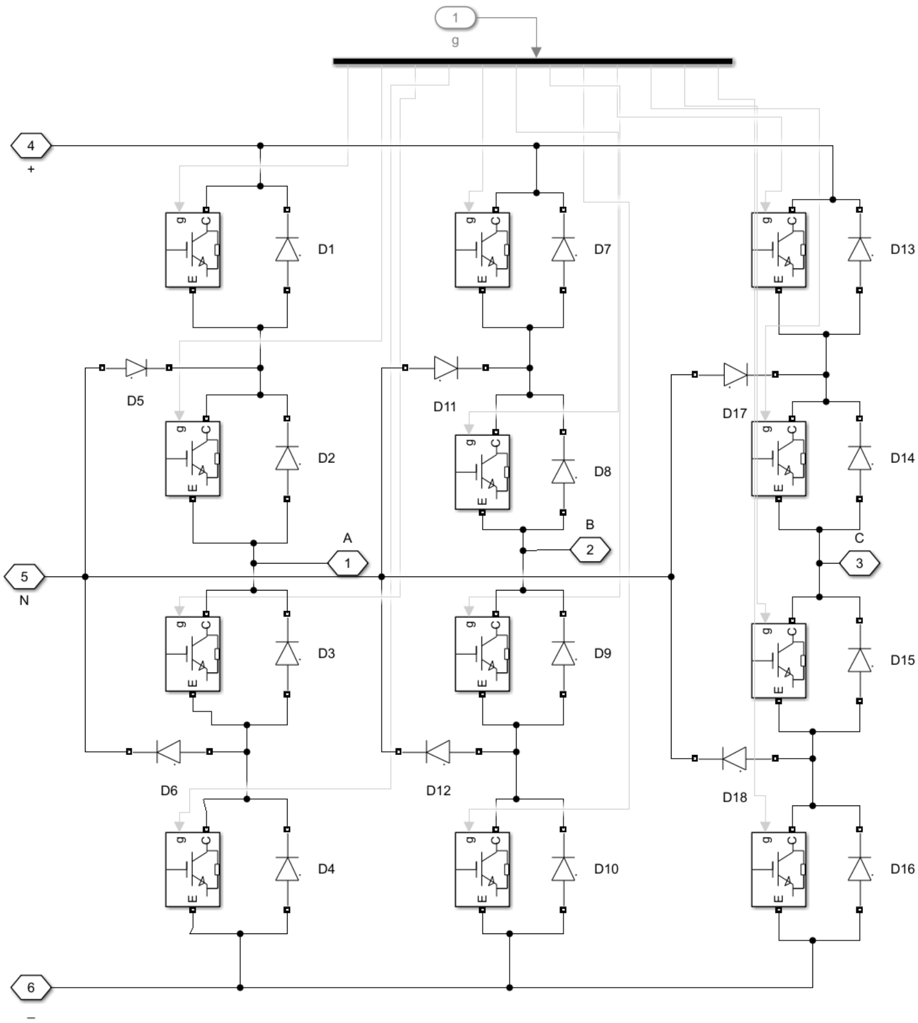

Fig. 10 Inverter in MATLAB.

Table 1 IM (Squirrel Cage) Specifications and Parameters.

Quantity	N. Values	Symbol
Power	0.5hp	Pa
Supply frequency	50Hz	F
Number of pair poles	2	P
Supply voltage	220V	V
Stator resistance	12Ω	RS
Rotor resistance	7.2Ω	Rr
Stator inductance	0.6422H	Ls
Rotor inductance	0.6422H	Lr
Mutual inductance	0.4222H	Lm
Inertia coefficient	0.02Kg2/s	J
Friction coefficient	0N.s/rd	f

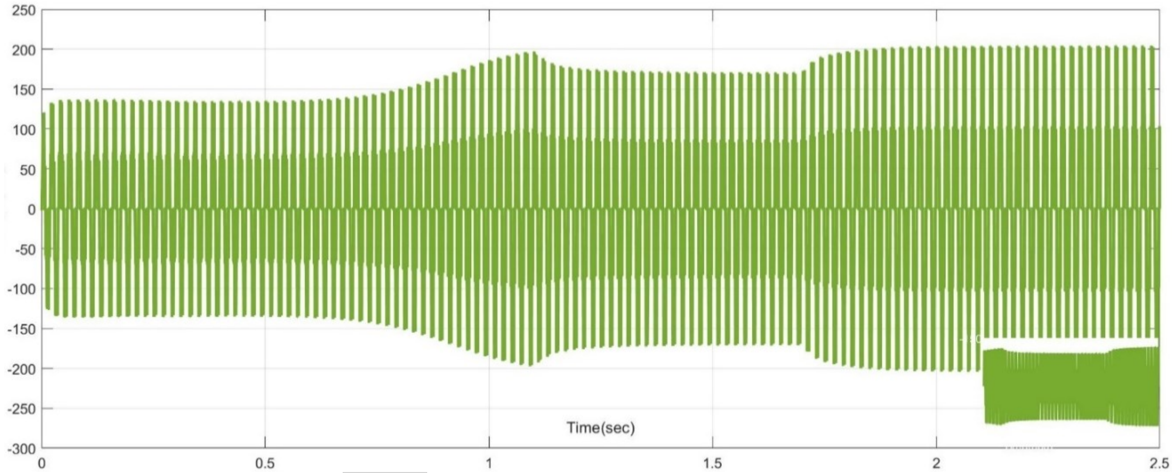

Fig. 11 Inverter Voltage with Three Levels.

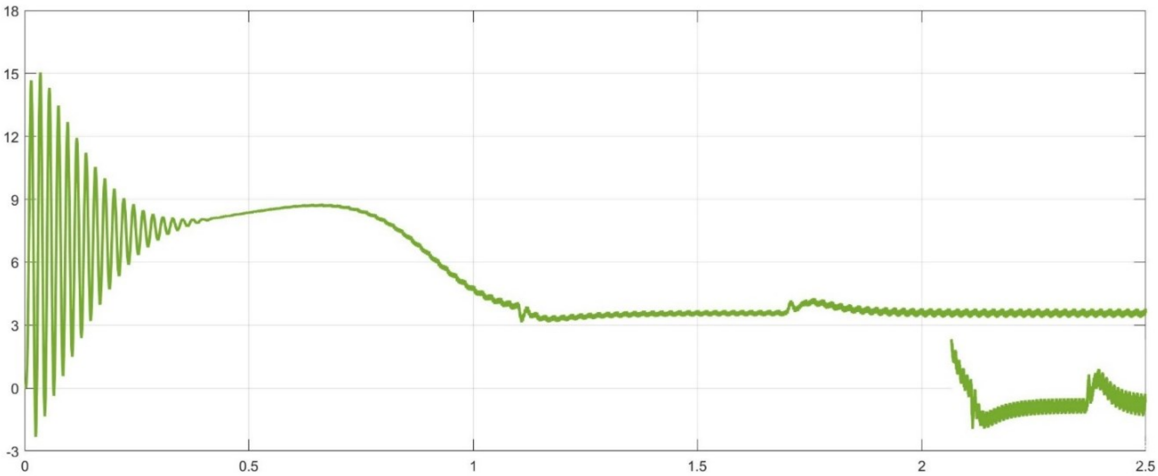

Fig. 12 Torque of the IM.

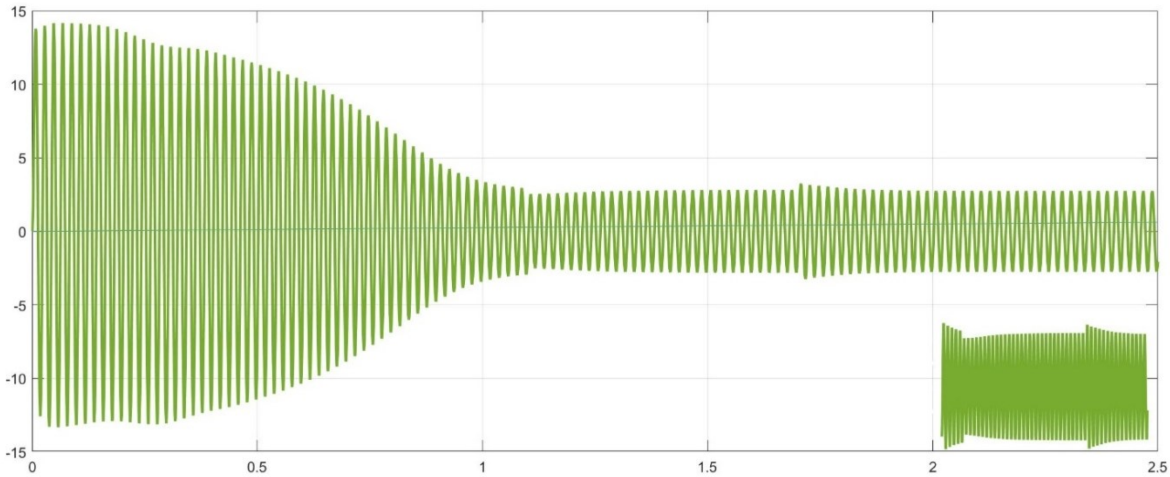

Fig. 13 IM Stator Current.

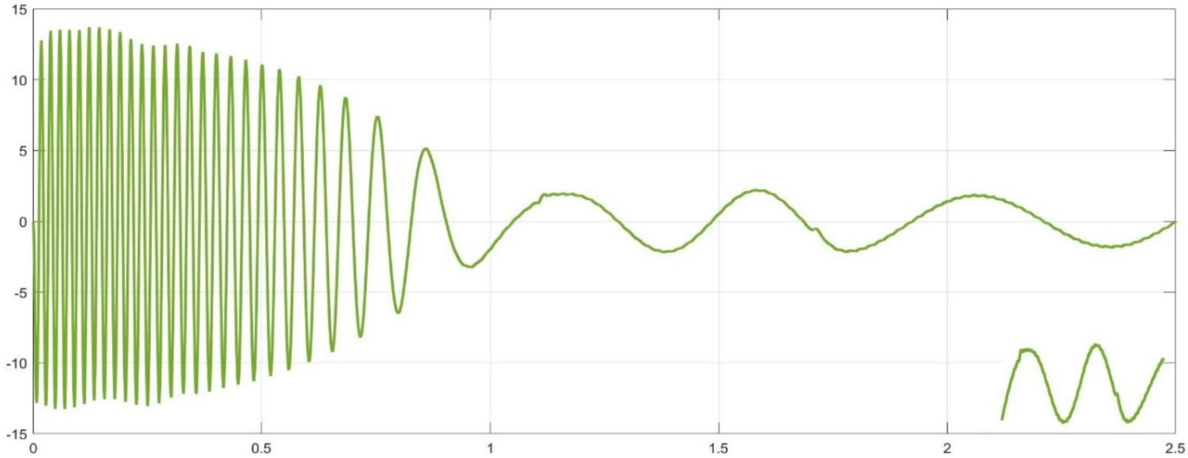

Fig. 14 IM Rotor Current.

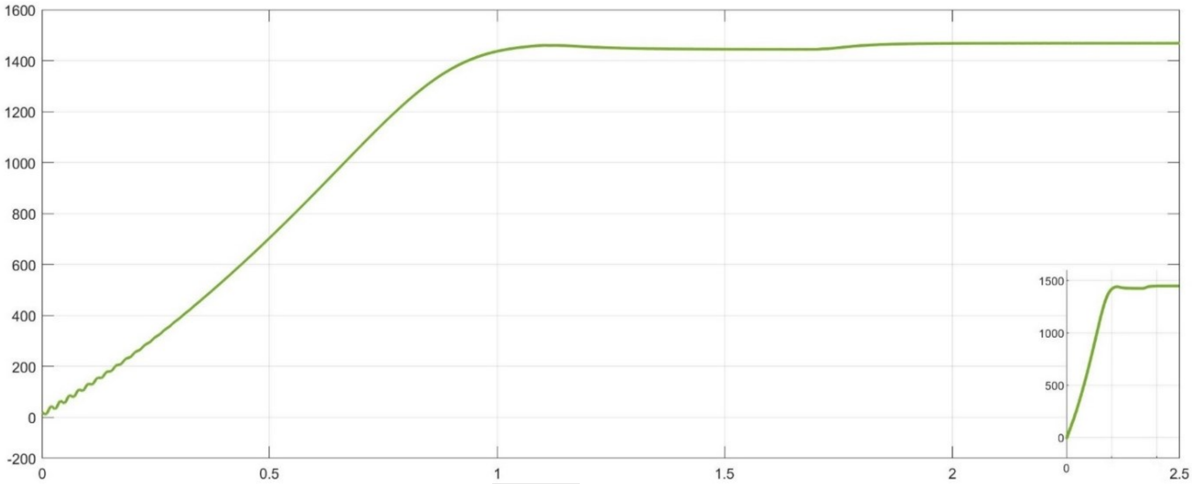

Fig. 15 IM Speed.

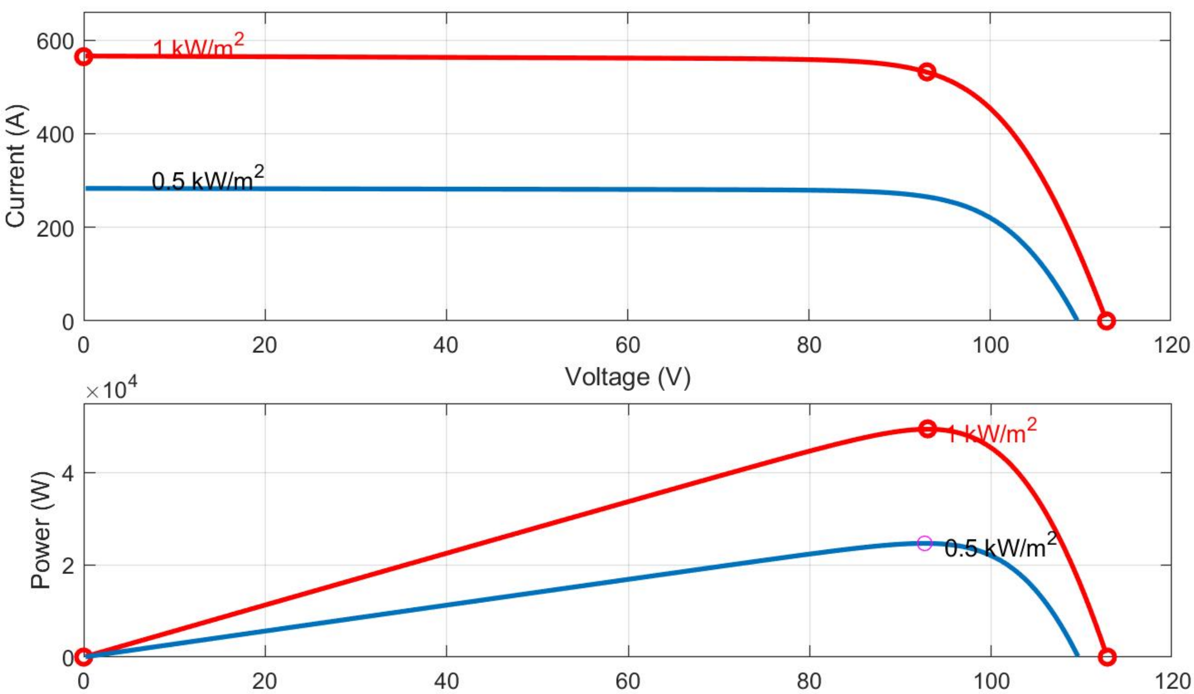

Fig. 16 Current (Top) and Power vs Voltage.

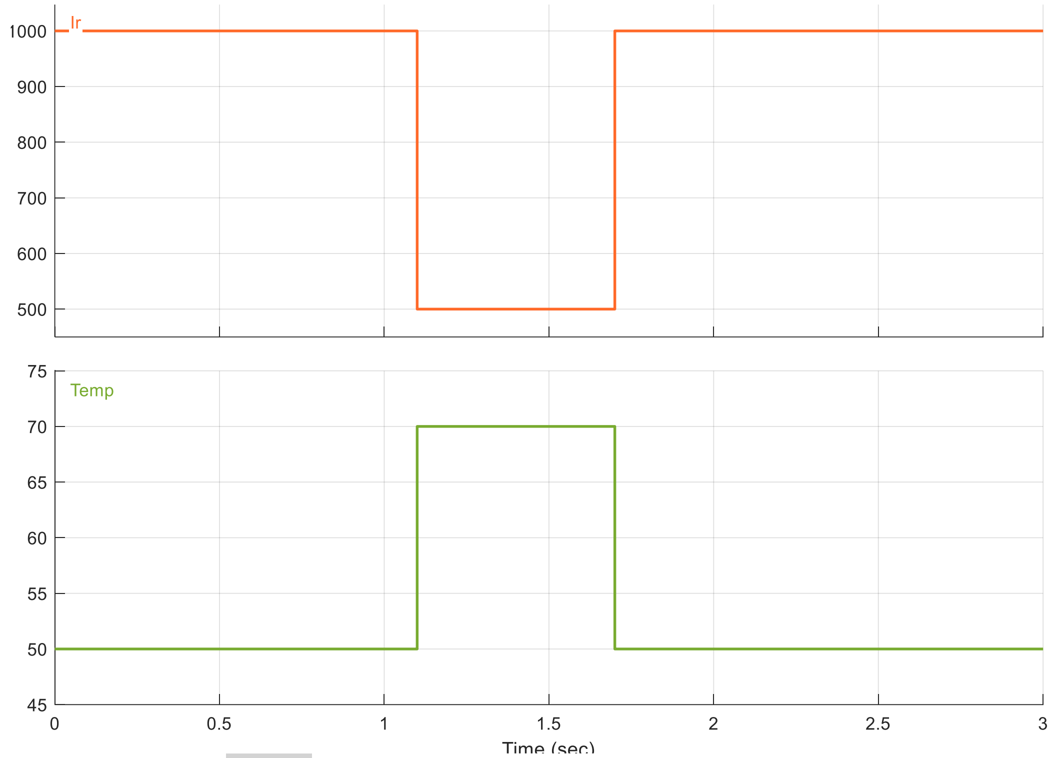

Fig. 17 The Change in Temperature and Irradiance.

6.CONCLUSIONS

This research presents a study of a simple yet efficient PV system. The focus was on speed control of the IM. The designed PV system can be used for several applications. Connecting Simulink to the computer was accomplished in MATLAB/Simulink using P&O technology, the SPWM technique, and the V/f method to control the speed of the 3-phase IM motor. The Voltage Inverter varied the voltage value accordingly so that the V/f ratio remained the same. It was observed that the max torque remained constant across the speed range. The change in temperature and irradiance had a clear role in the performance of the IM and all the results in terms of voltage, torque, and current; however, this effect was slight. Hence, the system showed outstanding performance of the PV panel as well as IM with the 3-level to drive 3-ph IM inverter as presented in this paper, and successful speed control of 3-phase IM was achieved.

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