Research Article

A Single-Stage SPV-Fed Reduced Switching Inverter-Based Sensorless Speed Control of IM for Water Pumping Applications

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This article elaborates on a reduced switch count-based inverter for a single-stage solar photovoltaic (SPV) fed induction motor (IM) with sensorless speed control for water pumping applications. The traditional SPV-fed IM for water pumping applications requires a six-switch voltage source inverter (SSVSI) for transforming the DC power from the SPV system into AC power. However, the same performance is achieved using a four-switch voltage source inverter (FSVSI). Here, the entire system requires less number of switches and hence reduces switching losses and cost as compared to the traditional solar water pumping system.

Moreover, the sensorless speed control is implemented using a speed estimator to reduce the overall cost further and enhance reliability. The reference voltage ($V_{dcr}$) is achieved using an adapted incremental conductance (AINC), and the control of IM is performed using direct vector control (DVC). The control signals for the proposed system are generated using DSP/ACE DS-1104 for real-time implementation. The proposed SPV-fed FSVSI-based 1-HP IM operation is performed at different irradiation levels in the MATLAB-Simulink environment and validated experimentally.

1. Introduction

The increase in electrical power utilization is due to urbanization and globalization. Hence, the conventional power generation methods cannot meet the exponential growth of electrical power demand due to the limited availability of coal, crude oil, and natural gas. Moreover, conventional electrical power generation is adversely impacting the environment. Hence, alternative electrical power generation methods are vital in meeting the global electrical power demand such as solar, wind, and tidal. These new alternative electric power generations realized practical. Out of all the possible alternative electric power generations, solar power is growing drastically due to its zero fuel cost and low maintenance [1]. The solar photovoltaic (PV) panels generate the DC power based on solar irradiation levels. So, the higher the solar irradiation provides, the higher the electric power generation [2].

The significant cost associated with solar power generation is PV panels made up of semiconductor materials. Due to advancements in semiconductor materials, the cost of the SPV panels is reducing day by day. But the SPV panel suffers from low efficiency, and this problem is overcome with the help of the maximum power point tracking (MPPT) algorithm [3]. Moreover, the SPV panel output voltage and current ratings are increased using series and parallel connections of panels, respectively.

As solar energy is available free of cost and pollution-free, water pumping is one of the major applications. The solar water pumps are used for drinking water, irrigation, and cultivation purposes. These water pumps accelerate the cultivation in emerging countries isolated from the grid [4]. Moreover, the solar water pumps are also noise-free and economical compared to diesel pumps. However, solar power is available during sunny times only, and to make the continuous operation of the
solar pump, batteries [5] are used. But the batteries increase the overall cost and require regular maintenance. The batteries can be avoided in the solar water pumping systems using either used directly during the sunny period or stored the water in a storage tank [6] and reuse water as per convenience.

The AC solar water pumping systems are classified as two-stage and single-stage systems. In a two-stage system, DC-DC and DC-AC converters are connected cascade. Due to the presence of a DC-DC converter, two-stage systems are costlier and more complex. So, to avoid these problems, a single-stage system is used for the direct conversion of SPV power to a water pumping system using an inverter. To further reduce the cost, switching losses, and complexity of the solar water pumping system, the proposed FSVSI is used rather than the conventional SSVSI. However, the constant DC-link voltage is maintained for better dynamic performance using a voltage controller.

Moreover, at variable solar irradiation, the SPV output currents are also varied accordingly to maintain constant DC-link voltage. Hence, the load current also varies as per the SPV output current. Here, a reduced switch count-based inverter achieves the control of the single-stage SPV-fed sensorless operation of IM for water pumping applications.

In AC solar water pumping systems, induction motors are utilized due to low cost, high reliability, and low operational maintenance. Now, the speed control of IM is the primary concern for solar water pumping applications. However, the IM speed control is performed using either scalar \( (V/f) \) [7–9] or vector control. In scalar control, the IM drive speed is controlled with decreasing input voltage and frequency below the rated values to maintain a constant flux and torque. However, the scalar control can control the speed of the IM up to base/rated speed only and suffers from poor dynamics, especially at lower speed range [10] and when reference speed is more than slip speed range control. Vector control is generally preferred to overcome problems associated with the \( V/f \) control. However, the vector control is further classified as direct torque control (DTC) [11] and field-oriented control (FOC). The DTC of the IM drive suffers from high current/torque ripple and is very noisy during low speeds compared to the FOC [12]. Hence, the FOC is more reliable for speed control of IM than DTC [13]. The basic concept of FOC is to transform the IM equivalent to a separately excited DC motor with the help of appropriate coordinate transformations. Hence, the control of IM flux and torques is done independently and adequately. The FOC is further classified as direct and indirect vector control [14, 15].

The organization of the paper is as follows. Section 2 provides complete modeling of the proposed inverter-based solar water pumping system. Section 3 depicts the speed control of IM using the direct vector control (DVC) method. Sections 4 and 5 describe simulation/hardware results and conclusions, respectively.

### 2. SPV-Fed IM with Proposed FSVSI for Water Pumping Applications

The schematic view of solar PV-fed proposed FSVSI based DVC of IM for water pumping applications is shown in Figure 1. Generally, the required output voltage and currents for the induction motor are generated using a series and parallel combination of SPV panels. Here, the solar simulator is used to meet the required power demand of the IM, and the specifications are given in the Appendix in detail. The proposed four-switch three-phase voltage source inverter can provide the AC supply to an induction motor for a water pump load application.

The purpose of the proposed inverter configuration used here has reduced the number of switching devices, size, overall cost, and switching losses. In addition, direct vector control (DVC) is used for IM speed control. Also, the modeling and design parameters of each part of the whole configuration are disclosed in the following sections.

#### 2.1. PV Modelling

The solar PV system is a series and parallel combination of PV cells as per the required output voltage and current ratings. Hence, the solar PV array is represented using a current source with internal resistance, and the output current produced by PV cell is given as follows [16]:

\[
I_o = I_p - I_{sh} \left( e^{\frac{V_{dc} + R_s I_o}{V_{oc}}} - 1 \right) - \frac{V_p + R_s I_o}{R_s},
\]

where \( I_{sh}, V_p, R_s \), and \( a \) are output/PV/saturation current, PV output voltage, shunt/series resistance, terminal voltage, and ideality factor, respectively.

However, the DC-link capacitance value depends upon the DC-link voltage, motor phase voltage, and current, as given follows:

\[
C_1 = C_2 = \frac{12sVfI_t}{\Delta V_d},
\]

where \( C_1, s, V, I, t, \) and \( \Delta V_d \) are DC-link capacitance, safety margin, IM phase per voltage, current, time to attain the minimum DC voltage, and the difference between minimum and reference DC-link voltage, respectively.

#### 2.2. Adaptive Incremental Conductance Algorithm

An adaptive incremental conductance algorithm (AINC) senses SPV output voltage and current to determine the appropriate reference dc-link voltage [17, 18] based on the conductance value.

The PV output power is expressed as

\[
P_p = V_p I_p,
\]

for attaining maximum power,

\[
\frac{\partial P_p}{\partial V_p} = V_p + I_p \frac{\partial I_p}{\partial V_p} = 0,
\]

\[
\frac{\partial I_p}{\partial V_p} = \frac{I_p}{V_p}.
\]

Therefore, for maximum power extraction from PV is obtained when the change in conductance is equal to the conductance at that point. Here, in a single-stage system, the adaptive incremental conductance updates the PV...
output voltage such way to achieve maximum power. The step-by-step procedure can be understood with the help of P-V characteristics of the PV system as shown in Figure 2, the transition of points on the P-V curve are considered, and the corresponding change in PV voltage is given in Table 1.

The final updated SPV output voltage from the adaptive incremental conductance algorithm, as shown in Figure 3, is an optimal voltage value to retrieve the maximum power utilization of SPV panels. Hence, it is considered to refer DC-link voltage for voltage regulation, as detailed information in reference speed generation.

2.3. Space Vector Modulation for FSVSI. From the proposed FSVSI, as shown in Figure 1, the DC-link voltage \( V_p \) is one of the significant parameters in the operation of the proposed inverter-fed IM and is calculated as [19]

\[
V_p = \frac{\sqrt{2}}{\sqrt{3}}V_{ll},
\]

where \( V_{ll} \) is line-line voltage. In the proposed inverter, the complementary pairs of switches \( S_1S_3 \) and \( S_2S_4 \) can produce the switching pulses/states for each leg of \( Q_b \) and \( Q_c \), respectively. Then, the corresponding pole voltages of each phase in terms of switching pulses are given [20–22]:

\[
V_{r0} = \frac{V_{d1}}{3}(-Q_b - Q_c) + \frac{V_{d2}}{3}(2 - Q_b - Q_c),
\]

\[
V_{y0} = \frac{V_{d1}}{3}(2Q_b - Q_c) + \frac{V_{d2}}{3}(2Q_b - Q_c - 1),
\]

\[
V_{b0} = \frac{V_{d1}}{3}(2Q_c - Q_b) + \frac{V_{d2}}{3}(2Q_c - Q_b - 1),
\]

where \( V_{d1/2} \) are phases to neutral the induction motor and DC-link capacitor voltages, respectively. The DC capacitors’ voltages are corrupted when there is a flow of unbalanced current through the capacitors. However, the voltage unbalances in DC capacitors tend towards the shutting down of the FSVSI. Therefore, \( V_{d1/2} \) has to be balanced for the reliable operation of the proposed converter. So, the capacitor’s voltage balance is achieved using certain switching states without the requirement of any external controller [22, 23]. In FSVSI, the unbalance of voltages occurs during the switching states of 00 and 11. When \( V_{d1} > V_{d2} \), the duration of 11 has to increase. Due to an increase in the duration of 11, the discharge time of capacitor \( C_1 \) increases. Similarly, if \( V_{d2} > V_{d1} \), then the duration of switching state 00 has to increase, and then the

![Figure 1: Schematic view of solar PV-fed proposed FSVSI-based DVC of IM for water pumping applications.](image)

![Figure 2: P-V characteristics of solar panel.](image)

<table>
<thead>
<tr>
<th>Movement of point</th>
<th>Variation of PV power and voltage</th>
<th>Update of PV voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a_1 ) to ( a_2 )</td>
<td>( P_{p1} \uparrow ) ( V_{p1} \uparrow )</td>
<td>( V_p = V_p + \Delta V_p )</td>
</tr>
<tr>
<td>( a_2 ) to ( a_3 )</td>
<td>( P_{p1} \uparrow ) ( V_{p1} \uparrow )</td>
<td>( V_p = V_p + \Delta V_p )</td>
</tr>
<tr>
<td>( a_3 ) to ( a_4 )</td>
<td>( P_{p1} \uparrow ) ( V_{p1} \uparrow )</td>
<td>( V_p = V_p + \Delta V_p )</td>
</tr>
<tr>
<td>( a_4 ) to ( a_3 )</td>
<td>( P_{p1} \uparrow ) ( V_{p1} \uparrow )</td>
<td>( V_p = V_p + \Delta V_p )</td>
</tr>
</tbody>
</table>

Table 1: Variation of PV voltage from P-V characteristics.
C<sub>2</sub> discharge time is increased. Finally, it suppresses the voltage offset with the help of a combination of these switching states over a switching period. Here, the switching implementation is performed with the use of the space vector pulse width modulation (SVM) technique and is disclosed as follows.

The two-level, four-switch, three-phase inverter consists of four switching states and is distributed with 90° displacement as shown in Figure 4, and the corresponding pole voltages for each switching state are tabulated as shown in Table 2.

The three-phase stator voltage equations of the IM have transformed into αβ-transformation for SVM implementation as follows:

\[ V_{\alpha\beta} = A V_{abc}, \]  

where

\[ A = \frac{2}{3} \begin{bmatrix} 1 & -1 & 1 \\ \frac{1}{2} & -\frac{1}{2} & \frac{1}{2} \\ \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \]  

The active vectors \( v_1, v_2, v_3, \) and \( v_4 \), are operating for a period of \( t_1, t_2, t_3, \) and \( t_4 \) respectively. The reference vector with a magnitude of \( v_r \) is rotating synchronously in each sector. According to the volt-sec balance equations [24],

\[ \sum_{i=1}^{4} v_i t_i = \sum_{i=1}^{4} v_r t_i = t_1 + t_2 + t_3 + t_4, \]

where \( t_1 \) is the total sampling period.

\[ t_s = t_1 + t_2 + t_3 + t_4. \]  

However, the active vector values are related as \( v_1 = -v_3 \) and \( v_2 = -v_4 \). Now, the volt-sec balance equation is further simplified from equation (12) as
\[ v_r t_s = v_{13} t_{13} + v_{24} t_{24}, \]  
(10)

where \( t_{13} = t_1 - t_3 \) and \( t_{24} = t_2 - t_4 \). The active vectors \( v_1 \) and \( v_2 \) are applied for a period of \( t_{13} \) and \( t_{14} \), respectively. However, the active time intervals are calculated using the following expressions:

\[ t_{13} = \frac{3}{2} \left( v_{ra} + \sqrt{3} v_{\beta} \right) \frac{2t_s}{V_d} \]
\[ t_{24} = \frac{3}{2} \left( v_{ra} - \frac{1}{\sqrt{3}} v_{\beta} \right) \frac{2t_s}{V_d} \]  
(11)

Finally, the position of reference vector magnitude and phase angle can be found from the \( \alpha \beta \)-transformation of the reference/modulating wave. The reference voltage in terms of \( \alpha \beta \)-components at each possible state is given in Table 3 [21].

### 3. Speed Control Scheme for IM

The speed control of IM is based on reference and estimated speed. Here, the reference and estimated speed of the motor are varied as per the solar irradiation. The speed estimations are disclosed as follows.

#### 3.1. Reference Speed Generation

The reference speed of the induction motor consists of two terms speed term based on pump load \((\omega_1)\) and speed term based on DC-link voltage \((\omega_2)\) [25] as shown in Figure 5. However, the pump load of either centrifugal or linear load model can be considered. Here, a centrifugal pump is assessed, and the load torque is either centrifugal or linear load model can be considered.

Here, the reference speed \((\omega_{ref})\) of the motor drive is

\[ \omega_{ref} = \omega_1 + \omega_2. \]
(17)

#### 3.2. Speed Estimation

The speed estimation of IM reduces the cost and provides reliable control as the speed estimation does not require any speed sensing device. The estimated measured speed \((\omega_{esm})\) of the IM is calculated as follows [27, 28]:

\[ \omega_{esm} = \omega_{sy} - \omega_{slr}, \]
(18)

where \( \omega_{sy} \) and \( \omega_{slr} \) are synchronous/slip speed. However, the synchronous and slip speed is estimated in terms of IM fluxes as follows [29, 30]:

\[ \omega_{slr} = \frac{(1 + \sigma S_r) L_{s} i_{dq}}{\tau (\lambda_d - \sigma L_{s} i_{dq})}, \]
\[ \omega_{sym} = \frac{(V_q - i_q R_s) \lambda_d - (V_d - i_d R_s) \lambda_q}{\lambda^2}, \]
(19)

where \( \lambda_d = V_d - i_d (R_s + \sigma S_L) \) and \( \lambda_q = V_q - i_q (R_s + \sigma S_L) \), \( \sigma = 1 - L_{qs} / L_{qs} \), \( \tau = L_{qs} R_s i_{dqs} \), and \( \lambda_{d/q} \) are the \( d/q \) component of stator current, voltage, and flux.

### 3.3. Vector Control of Induction Motor

The vector control requires the measured speed and stator currents, as shown in Figure 6. The stator currents \((i_{r/y/q})\) are measured with the

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Table 3: Reference voltage corresponding to switching states.

<table>
<thead>
<tr>
<th>Switching states ((Q_0Q_1))</th>
<th>Reference voltage ((V_r + jV_\beta))</th>
<th>Vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>00 ( (V_{d2} - V_{d1})/\sqrt{3} )</td>
<td>( V_{dcr} )</td>
<td>( v_1 )</td>
</tr>
<tr>
<td>01 ( (V_{d2} - V_{d1})/\sqrt{3} )</td>
<td>( V_{dcr} )</td>
<td>( v_2 )</td>
</tr>
<tr>
<td>10 ( -2V_{dcr}/3 )</td>
<td>( V_{dcr} )</td>
<td>( v_3 )</td>
</tr>
<tr>
<td>11 ( -2V_{dcr}/3 )</td>
<td>( V_{dcr} )</td>
<td>( v_4 )</td>
</tr>
</tbody>
</table>
Decoupling terms

\[ V = M \]

\[ \omega = \frac{2L_i}{SPL} \lambda \]

\[ \omega \left( L_j + \lambda \right) \]

Figure 6: Vector control of induction motor.

Figure 7: I-V and P-V characteristics.

Figure 8: (a) PV output at 1000 W/m². (b) DC-link voltages across the capacitors S. (c) Induction motor performance characteristics at 1000 W/m². (d) Three-phase output voltage of FVSI at 1000 W/m².
help of current sensors, and the IM measured speed is obtained using speed estimation. Moreover, the sensed three-phase stator currents are transformed into d-q components (\(i_{d/q}\)) using the coordinate transformations.

The error between estimated measured speed (\(\omega_{mes}\)) and reference speed (\(\omega_{ref}\)) is tuned using the speed PI controller (SPIC) to generate the required torque reference (\(T_r\)).

Moreover, the field weakening block generates rotor reference flux (\(\lambda_r\)), and the rotor angle (\(\theta\)) is achieved by integrating the estimated measured speed. So, with the help of torque reference, rotor flux, and rotor angle, the vector control block produces reference stator d/q currents and space angle (\(\theta_s\)), and the corresponding equations are as follows [31–33]:

\[
\begin{align*}
  i_{dr} &= \frac{R_r + 2L_r P}{R_r L_m} \lambda_r, \\
  i_{qr} &= \frac{2L_r}{3P L_m} T_r,
\end{align*}
\]

where \(R_r\), \(L_m\), and \(P\) denote rotor resistance, mutual/rotor inductance, and the pair of poles, respectively. The integration of synchronous speed provides space angle and is given as follows:

\[
\theta_s = \int (\omega_{syn}) \, dt.
\]

Now, the error between stator reference currents (\(i_{d/q}\)) and stator measured currents (\(i_{d/q}\)) are tuned using the current PI controller (CPIC) to update the stator voltages (\(V_{d/q}\)) w.r.t. the stator reference frame. Moreover, the obtained stator voltages are transformed into \(a\beta\)-components using the following equations as follows [34]:

\[
\begin{bmatrix}
  V_a \\
  V_b
\end{bmatrix} = \begin{bmatrix}
  \cos(\theta) & -\sin(\theta) \\
  \sin(\theta) & \cos(\theta)
\end{bmatrix} \begin{bmatrix}
  V_d \\
  V_q
\end{bmatrix}.
\]

Now, the transformed \(a\beta\)-components of voltages are fed to the SVM block to generate the desired pulses for the inverter circuit.

### 4. Results and Discussion

The solar PV array’s static I-V and P-V characteristics are shown in Figure 7. The SPV system provides variable voltage, current, and power at various irradiances.

However, the input voltage supplied to the IM drive should be maintained at a rated value; otherwise, the motor will significantly impact the starting current and torque. Moreover, it also affects the winding insulation life of the induction motor [35]. So, maintaining constant DC voltage at the inverter terminals at variable solar irradiation levels.

The performances of SPV-fed three-phase, four-switch inverter-based induction motor for water pumping systems...
were tested in MATLAB-Simulink environment at variable solar irradiation/insolation as shown in Figure 8. At solar irradiation ($I_{rr}$) of 1000 W/m², the SPV generates the required PV output voltage ($V_p$) and current ($I_p$) of 400 V and 2.9 A, respectively, as shown in Figure 8(a). Moreover, the voltage across the DC-link capacitors is shown in Figure 8(b). The generated solar power is used to drive the induction motor, and at the starting, it produces high currents and torques to overcome the inertia and load torque. Once the IM attains the reference speed of 1460 rpm, the motor torque ($T_e$), load torque ($T_l$), and motor 3-Φ currents ($i_{yrb}$) are settled to a steady value of 4 Nm, 3.8 Nm, and 1.6 A, respectively, as shown in Figure 8(c). Moreover, the generated three phase stator currents and voltages are shown in Figures 8(c) and 8(d).

At 1 s, the solar irradiation is reduced from 1000 to 500 W/m², and then the solar PV current falls to 1.45 A with a slight decrease in solar PV output voltage as shown in Figure 9(a). The voltage across capacitors ($V_{d1/d2}$) during the transition decreases slightly and settles to a constant value of 200 V, respectively, within a short span as shown in Figure 9(b). However, during the transition of solar irradiation, there is a slight drop in induction motor torque as the motor torque is a function of speed and solar irradiation. As the solar irradiation is maintained at 500 W/m², the speed of the induction motor settles to a steady value corresponding to the load torque. Consequently, the motor speed drops from 1460 rpm to 1190 rpm, and the motor torque settles to 2 Nm, as shown in Figure 9(c). Moreover, the stator three phase currents and voltages are shown in Figures 9(c) and 9(d), respectively.

To further study the SPV-fed induction motor performance, solar irradiation levels are increased. The complete system is tested with an increase of solar irradiation from 500 to 1000 W/m² and is activated at 2 s. Then, the SPV output current rises from 1.45 A to 2.9 A, and during the transition, the motor torque and voltage across capacitors increase slightly and settle to steady values, as shown in Figure 9(c). Moreover, the stator three phase currents and voltages are shown in Figures 9(c) and 9(d), respectively.

4.1. Experimental Results. The experimental validation of a solar PV-fed single-stage reduced switch count-based inverter-driven induction motor for a water pumping system with the same simulation parameters is considered. Moreover, the real-time execution is performed using DSPACE DS-1104, solar simulator, inverter module, 3-Φ IM with DC generator (DG) set up, and resistor load. The water application load characteristics are incorporated with an IM-DG.
setup with a resistive load as shown in Figure 11. The complete parameters associated with the induction motor and solar simulator are given in Appendix.

The solar PV-fed single-stage induction motor drive operates at a solar irradiation of 1000 W/m², and the corresponding starting and steady-state characteristics are shown in Figure 12. From Figure 12(a), the solar PV generates the required DC voltage and currents of 390 V and 2.9 A, respectively. Moreover, Figure 12(b) shows the voltage across DC-link capacitors and is maintained constant. The IM exhibits high starting currents and torque due to inertia. The motor speed starts increasing and reaches to the rated speed (1450 rpm) then the torque and current are settled to steady values of 4 N m and 2.9 A, respectively, as shown in Figure 12(c). Moreover, the three-phase stator current and voltages are shown in Figures 12(d) and 12(e), respectively.
However, the solar irradiation changes from 1000 to 500 W/m² then the performance of SPV-fed FSVSI is shown in Figure 13. During the transition, the SPV output current was reduced to 1.45 A at constant SPV output voltage and a slight drop in voltage across the capacitors during transition, as shown in Figures 13(a) and 13(b), respectively. Moreover, the motor and load torques drop sharply and settle to steady values once the motor attains the speed corresponding to solar irradiation of 500 W/m². The motor current also follows the torque path, and the respective results are shown in Figure 13(c).

Similarly, a sudden increase of solar irradiation from 500 to 1000 W/m² is applied, and then the corresponding performance characteristics of SPV-fed FSVSI-based IM are shown in Figure 14. Due to the increase in solar irradiation, the SPV output current increases from 1.45 A to 2.9 A at constant SPV output voltage, as shown in Figure 14(a). However, during the transition of solar irradiation, the voltage across the capacitors increases slightly and is maintained as constant, as shown in Figure 14(b). Moreover, the induction motor torque and current increase sharply during the transition period and settle to steady values once the motor attains the reference speed, as shown in Figure 14(c).

### 4.2. Comparison between the Proposed and Conventional Topology

The proposed four-switch inverter-based single-stage SPV-fed sensorless DVC of IM is cost-effective and has low switching losses. A complete comparison of the proposed system with the traditional six switch inverter is given in Table 4. Table 4 shows that the number of PWM pulses and semiconductor switches without the speed sensor and driver circuits required for the proposed SPV-fed FSVSI-
5. Conclusions

The standalone single-stage SPV three-phase sensorless induction motor drive for water pumping application with the help of the proposed four-switch inverter is simulated and implemented experimentally at various solar irradiation levels. The SPV reference DC-link voltage is obtained using the adaptive incremental conductance method, and the speed control of the induction motor drive is performed with the help of direct vector control. Moreover, the DC-link voltage is maintained as constant using a reference voltage control even at various irradiation levels. The control signal to the four-switch inverter is generated using DSPACE DS-1104 directly from the MATLAB environment. The overall performance of an induction motor drive is well suitable for starting and steady-state, even for variable solar insolation levels. Due to the fewer three-phase inverter switches and speed sensorless operation of IM, the overall cost and switching losses are further reduced significantly compared to both single- and double-stage conventional inverter topology-based speed control methods.

Abbreviations

AINC: Adaptive incremental conductance
DVC: Direct vector control
FSVSI: Four-switch voltage source inverter
IM: Induction motor
SSVSI: Six-switch voltage source inverter
SPV: Solar photovoltaic
SVM: Space vector modulation
T_r: Reference torque
ω_mec: Rotor speed.

Appendix

3–ϕ IM: 0.75 kW, 4 pole, 415 V, 1460 rpm, 50 Hz, 

J = 0.05 kg·m², L_{sf} = 0.453 H, L_m = 0.3636 H, R_s = 8.63 Ω, 

R_r = 8.84 Ω, SPIC (k_p = 10, k_i = 0.04), and CPIC (k_p = 25, 

k_i = 4)

Programmable DC supply: 62000H–S chroma with 5 kW, 0–600 V, 8.5 A

Data Availability

Data sharing is not applicable as no new data were generated.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References


