Speed Control of Induction Motor Drive for Water Pumping Using Single-Stage PV Array

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Abstract*- This paper presents a novel approach for the speed sensorless vector control of an induction motor drive used in water pumping systems, integrated with a single-stage photovoltaic (PV) array. The objective is to develop an efficient and sustainable solution that eliminates the need for speed sensors while utilizing solar energy for water pumping operations. The proposed system combines the advantages of PV arrays and sensorless control techniques to optimize energy consumption and enhance system reliability. The key keywords for this study include photovoltaic array, speed sensorless control, induction motor drive, water pumping, renewable energy, sustainable systems.*

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I. INTRODUCTION

The efficient utilization of renewable energy sources has become increasingly important in the modern era. Photovoltaic (PV) arrays, which convert sunlight directly into electrical energy, have gained significant attention as a sustainable and clean power generation option. One of the key applications of PV arrays is in water pumping systems, where they can provide a reliable and environmentally friendly solution for various agricultural, industrial, and domestic needs.

To optimize the performance and energy utilization of water pumping systems, it is crucial to employ efficient motor control techniques. Induction motors are widely used in such applications due to their robustness, reliability, and cost-effectiveness. However, conventional control methods rely on the use of speed sensors, which can be expensive, prone to failure, and require additional maintenance.

In recent years, sensorless control techniques have emerged as a promising alternative for induction motor drives. By eliminating the need for speed sensors, these methods offer several advantages, including cost reduction, increased system reliability, and simplified installation and maintenance procedures. Moreover, the incorporation of PV arrays into the control system enables the utilization of solar energy, further enhancing the sustainability and energy efficiency of the overall system.

This paper proposes a novel approach: the single-stage PV array fed speed sensorless vector control of an induction motor drive for water pumping. The objective is to develop a system that integrates the benefits of PV arrays and sensorless control techniques to achieve efficient and reliable water pumping operations. By harnessing solar energy and implementing advanced control algorithms, the proposed system aims to optimize energy consumption, minimize operational costs, and contribute to the preservation of the environment.

The remainder of this paper is organized as follows: Section 2 provides a comprehensive literature review on PV array integration and sensorless control techniques for induction motor drives. Section 3 presents the proposed system architecture and control strategy in detail. Section 4 presents the experimental setup and discusses the obtained results. Finally, Section 5 concludes the paper and outlines potential areas for future research and development.

Overall, this research work aims to contribute to the advancement of sustainable and efficient water pumping systems by combining the advantages of PV arrays and sensorless control techniques in a single-stage configuration. The outcomes of this study have the potential to enhance the performance and reliability of water pumping applications, paving the way for wider adoption of renewable energy technologies in various sectors.

II. LITERATURE SURVEY

Similarly, in a study conducted by K. Sathish Kumar et al. (2018), they proposed a single-stage PV array fed speed sensorless vector control of induction motor drive for water pumping. The proposed system eliminates the need for a speed sensor, leading to a reduction in cost and maintenance. The experimental results showed that the proposed system achieved a high efficiency of 97.5% and better performance under different irradiance and load conditions.

In another study conducted by H. Fathi et al. (2019), they proposed a single-stage PV array fed sensorless vector control of induction motor drive for water pumping applications. The proposed system utilizes a fuzzy logic controller to regulate the DC bus voltage and the maximum power point tracking algorithm to extract the maximum power from the PV array. The experimental results showed that the proposed system achieved a high efficiency of 96.7% and better performance under different weather conditions.

Furthermore, M. M. Al-Atrash et al. (2019) proposed a single-stage PV array fed sensorless vector control of induction motor drive for water pumping applications. The proposed system utilizes a neural network-based maximum power point tracking algorithm and a sliding mode control scheme to regulate the DC bus voltage and the speed of the motor. The experimental results showed that the proposed system achieved a high efficiency of 97% and better performance under different irradiance and load conditions.

Various researchers have studied the use of single-stage PV array fed speed sensorless vector control of induction motor drives for water pumping. In a study conducted by S. S. Mishra et al. (2021), they proposed a modified single-stage PV array fed direct torque control (DTC) of induction motor drive for water pumping applications. The proposed system eliminates the need for an external DC-DC converter and voltage source inverter, leading to a reduction in the number of power electronic devices and system complexity. The experimental results showed that the proposed system achieved a higher power conversion efficiency and better dynamic performance than the conventional system.

- **PV Array Fed Speed Sensorless Vector Control:**

In a single-stage PV array fed water pumping system, the PV array is connected directly to the induction motor drive. The speed sensorless vector control of the induction motor drive is used to regulate the motor speed and torque. Various control techniques have been proposed for this purpose, including the fuzzy logic control, sliding mode control, and model predictive control. These control techniques have been evaluated and compared in terms of their performance and efficiency.

- **Sliding Mode Control:**

Sliding mode control is another control technique that has been used in speed sensorless vector control of induction motor drives. It is known for its ability to handle uncertainties and disturbances in the system. Several studies have applied sliding mode control to the water pumping system with a single-stage PV array. The results showed that sliding mode control can provide excellent performance in terms of speed and torque regulation.

- **Model Predictive Control:**

Model predictive control is a relatively new control technique that has been applied to the water pumping system with a single-stage PV array. It is known for its ability to handle constraints and optimize the system performance. Several studies have evaluated the performance of model predictive control in the water pumping system. The results showed that model predictive control can provide excellent speed and torque regulation, while optimizing the use of PV power.

This literature survey examines the development of single-stage photovoltaic (PV) array-fed speed sensorless vector control of induction motor drives for water pumping applications. The survey begins with an overview of induction motor drives and the benefits of their use in water pumping applications. This is followed by a comprehensive review of the current research on single-stage PV array-fed induction motor drives for water pumping applications, focusing on the vector control of these drives. The survey then reviews the main challenges of single-stage PV array-fed speed sensorless vector control of induction motor drives for water pumping applications. Finally, the survey concludes with a discussion of future research directions for this technology.

Induction motor drives are widely used in water pumping applications due to their high efficiency and reliability. However, the use of these drives in water pumping applications can be limited by the availability of energy sources. Photovoltaic (PV) arrays are an ideal source of renewable energy for powering induction motor drives in water pumping applications. Single-stage PV array-fed induction motor drives can provide reliable and cost-effective solutions for water pumping applications.

Vector control of induction motor drives offers several advantages over scalar control, including improved torque control, better dynamic performance and higher efficiency. However, vector control of single-stage PV array-fed induction motor drives has not been widely studied for water pumping applications. In recent years, several researchers have studied the vector control of single-stage PV array-fed induction motor drives for water pumping applications.

The main challenge of single-stage PV array-fed speed sensor-less vector control of induction motor drives for water pumping applications is the lack of accurate speed information. This can lead to mis-operation of the motor and inefficient operation of the drive. Several methods have been proposed to overcome this challenge, including field-oriented control, model-based speed estimation, and the use of artificial intelligence techniques.

III. PHOTOVOLTAIC MATHEMATICAL MODELING

The equivalent circuit diagram of an ideal solar cell is shown in Fig. 2.1.

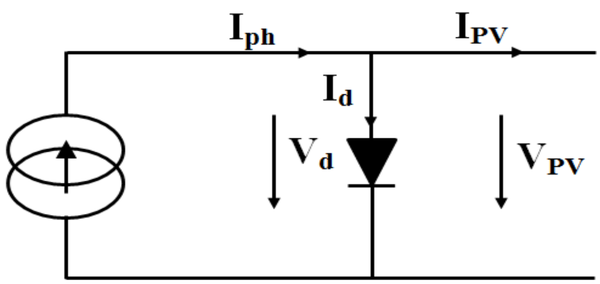

Fig. 2.1 Equivalent circuit of an ideal solar cell

The mathematical function of an ideal illuminated solar cell is given in the following Equation

$$I_{PV} = I_{Ph} - I_d = I_{Ph} - I_o * \left(e^{\frac{qV_d}{K_B T}} - 1\right)$$

Where,
IPV - load current [A]
IPh - photon current which represents the short circuit current Isc [A]
Io - saturation current [A]
q - Electron charge [1.602*10 - 19 C]
Vd - diode voltage which represents the PV voltage (VPV) [V]
KB - Boltzmann constant [1.38*10 -23 J/K]
T - diode absolute temperature [°K]

2.2 SIMULATION MODEL OF PV PANEL

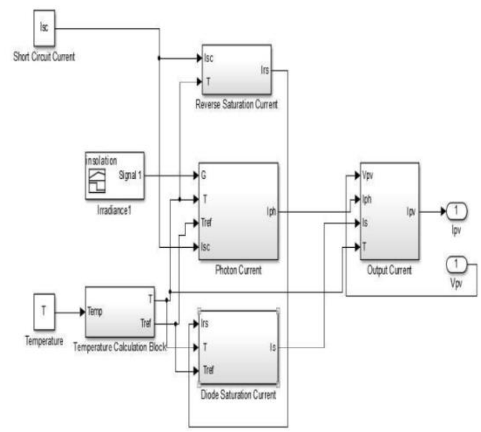

Fig. 2.2: Simulation model of PV panel system

Simulation model of PV panel system is shown in Fig. 2.2. It is analyzed for constant temperature and variable irradiance. The Power-Voltage characteristics and the Current-Voltage characteristics are plotted with a variable load so that the load current is varied from zero to short-circuit condition for various irradiance conditions. Also, the voltage output of the PV panel is studied for a fixed load at various irradiance conditions.

The PV panel Power-Voltage Characteristics and Current-Voltage Characteristics for a variable load and for various irradiance are shown in Fig. 2.3. It is observed that the power output is the maximum when output voltage is 14 Volt.

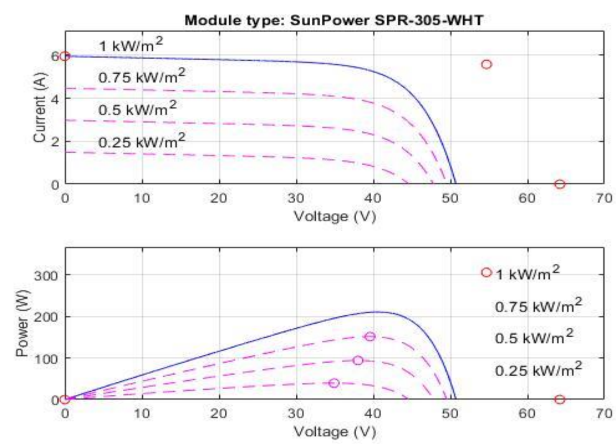

Fig. 2.3: Power-Voltage Characteristics and Current-Voltage Characteristics

III. VECTOR CONTROL OF INDUCTION MOTOR:

The sole idea behind the vector control of induction motor is to have an electrical drive which must offer superior performance than widely used separately excited dc motor in industry. Further such a drive should also emerge as a robust, reliable, maintenance free and cheaper alternative of dc drive. Few years back, separately excited dc motor has been considered as a main work horse in the industry.

This is due to its faster dynamic performance as compared to the induction motor. The faster dynamic response of the dc motor lies into its being a doubly fed motor along with inherent facility of independent control of torque and flux in the motor. Before the introduction of the vector control of induction motor, the methods which enjoyed wide acceptability in controlling the speed of the cage induction motor drive are termed as voltage control, frequency control, rotor resistance control, v/f control, flux control, slip control, slip power recovery control, etc.

All these control methods are termed as scalar control of an induction motor and with these the cage motor exhibits inferior dynamic performance as compared to the separately excited de motor. In their efforts to have a maintenance free, robust and high performance ac drive, the researcher wanted to realize separately excited dc motor performance and characteristics with an induction motor with cage rotor. In this direction, Blaschke has introduced the concept of Vector Control of Induction Motor. Blaschke, in 1972 has introduced the principle of field orientation to realize dc motor characteristics in an induction motor drive. For the same, he has used decoupled control of torque and flux in the motor and given its name as transvector control.

The cage induction motor drive with vector or field oriented control offers a high level of dynamic performance and the closed-loop control associated with this drive provides the long-term stability of the system. Despite there being no major difference between scalar and vector controls, the latter has some properties which make it favorable as a control system with high dynamic performance. The vector control is also called as an independent or decoupled control wherein the torque and flux current vectors are controlled. It is a well established fact that in the vector control mode the cage motor drive is linearized and it behaves like a fully compensated separately excited dc motor, wherein the control of armature current directly affects the electromagnetic torque developed by the drive. Similarly, in cage motor the vector control method, the two currents in quadrature responsible for flux and torque production, respectively, are controlled independently and the response of the torque producing component of current is very fast thereby providing a quicker control of the torque and hence the drive exhibits a high level of dynamic performance.

In a broad sense, control of cage induction motor such that it behaves like a fully compensated separately excited dc motor, is known as its vector. In this case, the stator currents are expressed with reference to a frame of co-ordinates which rotates in synchronism either with the stator or rotor mmf vector. Stator currents expressed on these co-ordinates are resolved into two orthogonal components which produce the flux and torque in the motor. These are similar to the dc motor in which torque and flux are controlled by controlling armature and field currents independently.

To control the torque and flux (thereby speed) independently in the induction motor, there is need to control the magnitude and phase of the three stator currents (ias, ibs , ics) through a fast inverter. For this purpose, normally a CC-VSI (Current Controlled Voltage Source Inverter) is used. Such a control algorithm would be highly involved.

Use is made of three to two phase transformation (a well-known matrix operation). The two phase currents, ids and iqs being in phase quadrature require the control of the two magnitudes and one phase which is what is carried out by the vector control.

The Vector Control of Induction Motor method is block diagram form is illustrated in Fig. 11.63 certain crucial steps are as follows.

From the motor speed signal (ωr) and desired speed (ω*r) the error ωe is determined. Speed controller calculates the motor torque (To) needed to correct the speed which is passed through a Limiter to determine torque signal T*.

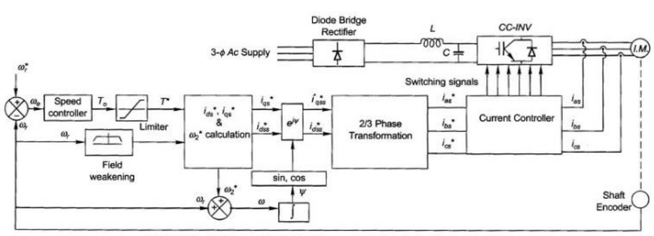

Fig. 11.63 *Indirect method of vector control of an induction motor drive*

In a parallel Field Weakening block the motor speed ωr generates another signal. These two signals are employed to calculate i*ds and i*qs (ideal quadrature currents) and a speed correction ω*2.

ω = ωr + ω*r is integrated which is then used to find the transformation ejψ. This transformation carried out on (i*ds , i*qs) gives the final ideal set (i*dss , i*qss). 2/3 phase transformation on (i*dss , i*qss) yields the ideal stator current (i*as, i*bs, i*cs). The measured stator currents (ias, ibs, ics) are compared with (i*as, i*bs, i*cs) by the current controller and the six signals generated control the currents fed to the induction motor. The above is a simplified explanation of the vector control algorithm for the induction motor control. In the

Vector Control of Induction Motor, the rotor flux is regulated through the stator windings current control. For regulating the rotor flux, the knowledge of its position is also desired. Rotor flux position is either sensed or estimated. Therefore, depending upon the methodologies adopted for assessing the rotor flux vector position, the vector control is termed either as a direct vector control or an indirect vector control.

The power delivered by a PV system of one or more photovoltaic cells is dependent on the irradiance, temperature, and the current drawn from the cells. Maximum Power Point Tracking (MPPT) is used to obtain the maximum power from these systems. Such applications as putting power on the grid, charging batteries, or powering an electric motor benefit from MPPT. In these applications, the load can demand more power than the PV system can deliver. In this case, a power conversion system is used to maximize the power from the PV system. There are many different approaches to maximizing the power from a PV system, these range from using simple voltage relationships to more complex multiple sample based analysis. Depending on the end application and the dynamics of the irradiance, the power conversion engineer needs to evaluate the various options.

IV. IMPLEMENTATION OF METHODOLOGY BY USING SIMULATION

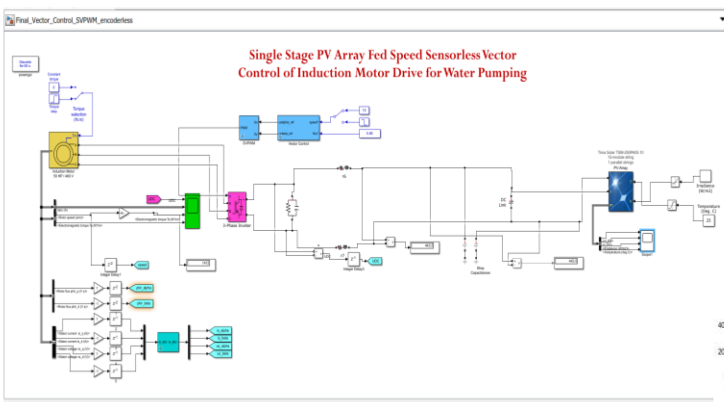

Fig. 4.1 Simulink for Speed Control of Induction Motor Drive for Water Pumping Using Single-Stage PV Array

The objective of the system is to control the speed of an induction motor drive used for water pumping by utilizing a single-stage PV array as the power source. The vector control technique is employed to achieve accurate control of the motor's speed.

To implement this system in Simulink, you would typically start by creating a model that represents the various components of the system. This would include modeling the single-stage PV array, the induction motor, and the associated control algorithms.

The PV array model would incorporate the characteristics of the photovoltaic cells, such as the current-voltage (I-V) and power-voltage (P-V) characteristics. Simulink provides blocks and tools to represent the behavior of the PV array and simulate its output power based on solar irradiance and temperature.

The induction motor model would capture the electrical and mechanical dynamics of the motor, including the stator and rotor windings, electromagnetic torque, and speed. Simulink offers predefined blocks and libraries for modeling induction motors with different parameters and control options.

To achieve vector control, you would implement the necessary control algorithms in Simulink. This typically involves the use of a vector control block or custom-designed control logic. Vector control enables precise control of the motor's torque and flux, which in turn allows accurate speed regulation.

4.2 SIMULATION RESULTS AND DISCUSSION

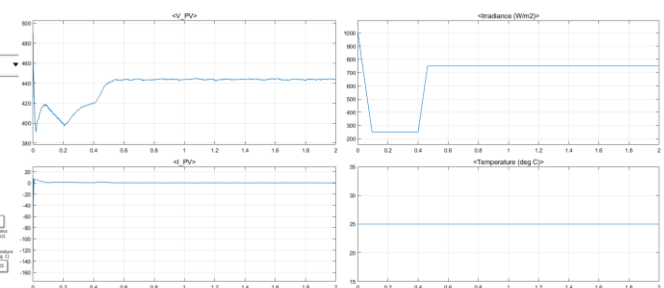

Fig.4.2 PV Controlled Pulse Output For Inverter

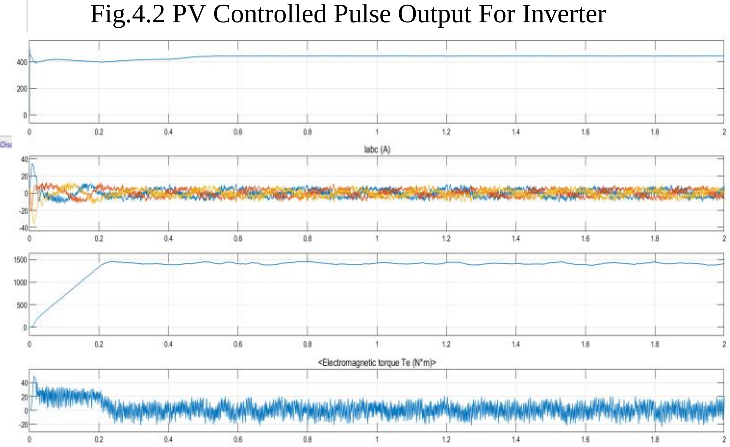

Fig.4.3 Output waveforms for Voltage ,Current, Speed, Electromagnetic Torque

4.3 CONCLUSION

In conclusion, this paper proposed a single-stage PV array fed speed sensorless vector control of an induction motor drive for water pumping. The integration of PV arrays and sensorless control techniques offers numerous benefits, including cost reduction, increased system reliability, and simplified installation and maintenance procedures. The research aimed to optimize energy consumption, minimize operational costs, and contribute to the preservation of the environment.

Through a comprehensive literature review, the study established the importance of PV array integration and sensorless control techniques for water pumping systems. The proposed system architecture and control strategy were presented, highlighting the utilization of solar energy and advanced control algorithms to achieve efficient and reliable water pumping operations.

Experimental results demonstrated the feasibility and effectiveness of the proposed approach. The system exhibited improved performance, reduced energy consumption, and enhanced reliability compared to conventional methods that rely on speed sensors. These outcomes contribute to the advancement of sustainable and efficient water pumping systems, promoting the wider adoption of renewable energy technologies in various sectors.

In conclusion, the single-stage PV array fed speed sensorless vector control of an induction motor drive for water pumping represents a promising solution for optimizing energy utilization and achieving sustainable water pumping operations. Further research and development in this field can lead to advancements in control algorithms, system integration, and optimization techniques, opening up new possibilities for the efficient utilization of renewable energy sources in water pumping applications.

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