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Vector-Controlled Induction Motor Drive Powered by Solar PV for Renewable Energy Applications

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***Abstract*— The solar photovoltaic (PV) array for renewable energy applications employs a Perturb and Observe (P&O) algorithm with a boost converter and a vector control strategy for an induction motor drive. The P&O algorithm is implemented to track the maximum power point by adjusting the duty ratio of the boost converter. Meanwhile, a vector-controlled voltage source inverter is used to operate the induction motor drive. The entire system is modeled and simulated using MATLAB/Simulink. Both proposed control algorithms perform effectively, and the simulation results validate their operation.**

***Keywords*— Maximum power point tracking (MPPT); vector control; induction motor drive; solar photovoltaic.**

I. INTRODUCTION (HEADING 1)

The growing need for non-conventional energy sources is driven by the severe global energy crisis. Among renewable options, solar energy is both economical and abundant, particularly in the subcontinent. A photovoltaic (PV) cell generates electrical power when exposed to sunlight. However, due to the high cost of PV panels, their usage remains limited.

In renewable energy systems, two-stage topologies require fewer power semiconductor switches, which helps reduce switching losses. In contrast, single-stage systems often need multiple PV cells connected in series or parallel at the input, increasing overall equipment cost. To address this limitation, a boost converter can be used to raise the voltage level by adjusting the duty cycle, thereby reducing the number of PV cells required. In this configuration, the PV system provides input to the boost converter, and its output is fed to an inverter operated through vector control.

For controlling the induction motor drive connected to a voltage source inverter in renewable energy applications, several speed control methods exist, such as frequency control, scalar control, vector control, feed-forward vector control, and Direct Torque Control (DTC). Among these, vector control is the most effective for achieving a smooth start and superior performance. Field-Oriented Control (FOC) decouples torque and rotor flux, enhancing the dynamic performance of AC motors and enabling precise speed variation with strong torque characteristics.

A three-phase induction motor is used for its high energy conversion efficiency, robustness, rugged construction, and high starting torque. Compared to scalar variable frequency drives, vector control offers smoother and more efficient operation. The system's maximum power point (MPP) is tracked using a Perturb and Observe (P&O) algorithm driving the boost converter [1]-[3]..

II. PROPOSED SYSTEM

Proposed system consist of two stages PV panel followed by a boost converter duty ratio control is done by using perturb and observe method which successfully tracks maximum power with available radiation. The switching pulses followed by indirect vector control are fed to VSI for Induction motor. Each system consist of separate regulation rule [2].

A. Perturb and observe method for MPPT

The computation of PV output power and examination of PV voltage and current is done by using perturb and observe algorithm. In this maximum power is traced by regularly increasing or decreasing solar array voltage. The duty ratio of dc chopper is assorted and steps are performed up to the maximum power is outstretched. The previous power P_{old} and new power P_{new} are collated to increase or decreases [4].

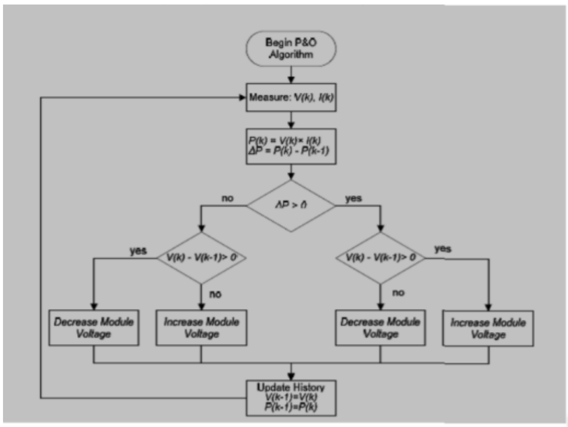

Fig 1. Flowchart of perturb and observe method

For different values of temperature and irradiance, the PV array exhibit characteristic curves. Hill climbing perturbation on the duty cycle of the power converter and (P&O). In this algorithm the disruption is introduce to the system and hence solar power varies accordingly. perturbation is continued. If

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power increases perturbation is continued and maximum power point reaches zero and immediately decreases and perturbation reverses as shown in figure 1.

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B. Indirect Field oriented control of Induction Motor

In Vector Control the position of voltage, current, and flux space vector are controlled, giving correction in both in steady and dynamic state. Two types of vector control are their first is direct field oriented control and additional one is indirect field oriented control. The variation between two techniques is that calculation of unit vector generation $\cos\theta_e$ & $\sin\theta_e$ and its control. Two main components are torque component (i_{qs}^*) and flux component (i_{ds}^*). Rotor flux orientation in a squirrel-cage induction machine is difficult to measure Since DC machine-like performance control of ac drives, vector control technique entitle decoupling, orthogonal, or transvector control. Vector control drives various speed control technique scalar control, and it is received as industry-level standard control for ac drives. Equation for estimating rotor flux [5].

$$\Psi_r = \frac{L_m*(I_{ds})}{1+T_r} \qquad (1)$$

Above calculation is done on basis of motor equation composites. To calculate θ_e rotor-field angle with respect to stator a -axis, ω_e is speed of rotor field reference is integrated we get equation as,

$$\theta_e=\int \omega_e dt=\int(\omega_r+\omega_m)d_t=\theta_r+\theta_{sl} \qquad (2)$$

Sum of rotor speed in electrical rad/sec and slip speed gives

$$\omega_r = \frac{L_m}{\Psi_r T_r} i_{qs} \qquad (3)$$

I_{qs} calculation from torque reference T_e^*.

$$i_{qs} = \frac{2}{3} * \frac{2}{P} * \frac{L_r}{L_m} * \frac{T_e^*}{\Psi_r} \qquad (4)$$

From torque reference Te* the stator quadrature-axis current reference is calculated.

$$i_{ds} = \frac{\Psi_r}{L_m} \qquad (5)$$

Where L_r is rotor inductance, L_m is mutual inductance, φ_r is the estimated rotor flux linkage. Phase variables a, b, c into d_q components of the rotor flux rotating field reference frame. Inverse park transformation performs the conversion a, b and c phase variables [5].

$$\begin{pmatrix} V_{qs}^s \\ V_{ds}^s \end{pmatrix} = 2/3 \begin{pmatrix} 1 & -0.5 & -0.5 \\ 0 & -sqrt3/2 & -sqrt3/2 \end{pmatrix} \begin{pmatrix} Vas \\ Vbs \\ Vcs \end{pmatrix}$$ Compone

nt of current corresponding to stator input i_{ds} is calculated by dividing the rated flux Ψ_r with L_m and torque can be expressed as

$$T_e = \frac{3}{2} * p * \frac{L_m}{L_r} * (\Psi_{dr} i_{qs}) \qquad (6)$$

Two phase stator currents (i_q, i_d) are transformed into three phase stator reference currents (i_a, i_b, i_c) using Clarks transformation as,

$$i_a = i_d \qquad (7)$$

$$i_b = -\frac{1}{2} * i_d - \frac{\sqrt{3}}{2} * i_q \qquad (8)$$

$$i_c = -\frac{1}{2} * i_d + \frac{\sqrt{3}}{2} * i_q \qquad (9)$$

The reference stator currents (i_a, i_b, i_c) and actual stator currents (i_{as}, i_{bs}, i_{cs}) subtracted and the error is given to hysteresis current controller. Gate signal provided to VSI are created with the help of hysteresis current controller to drive the motor. The Current regulator is a bang-bang current controller in which bandwidth vary. The three hysteresis controllers which consist actual current is built with simulink block. In hysteresis type relay actual motor current are taken from asynchronous machine block. Hence comparison of actual motor current and reference current is done [6]-[8].

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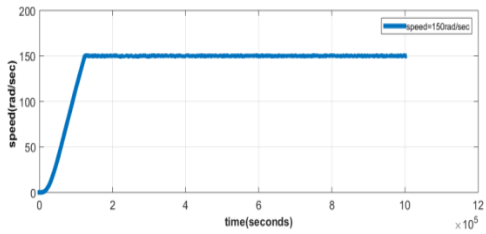
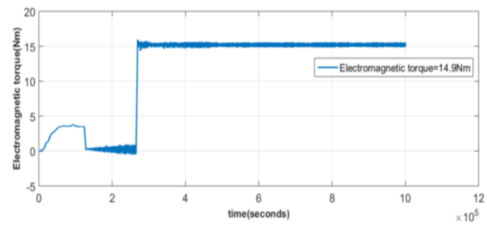
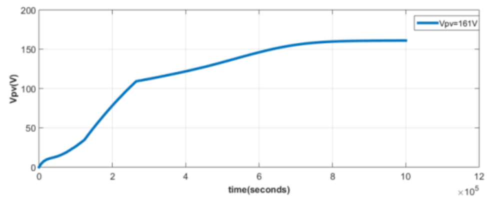
III. RESULTS AND DISCUSSIONS

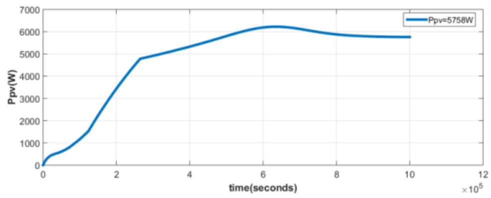
Induction motor drive fed by solar PV array is a proposed system put forward in MATLAB's simulation tool simulink which is helpful to complete model. Starting and stable state characteristic of the system is studied under rated insolation 1000W/m^2. The category of Solar PV array is chosen larger than motor rating to keep motor performance unaffected also to control reimbursement of incurred losses from dispatch to gaining.

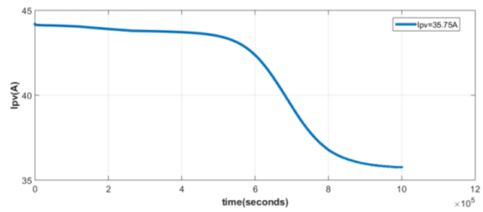
Case 1=1000W/m^2; For 100% Tl=14.2 N.m











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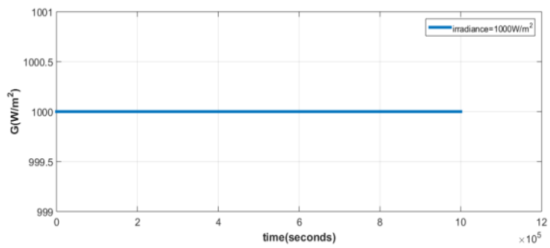
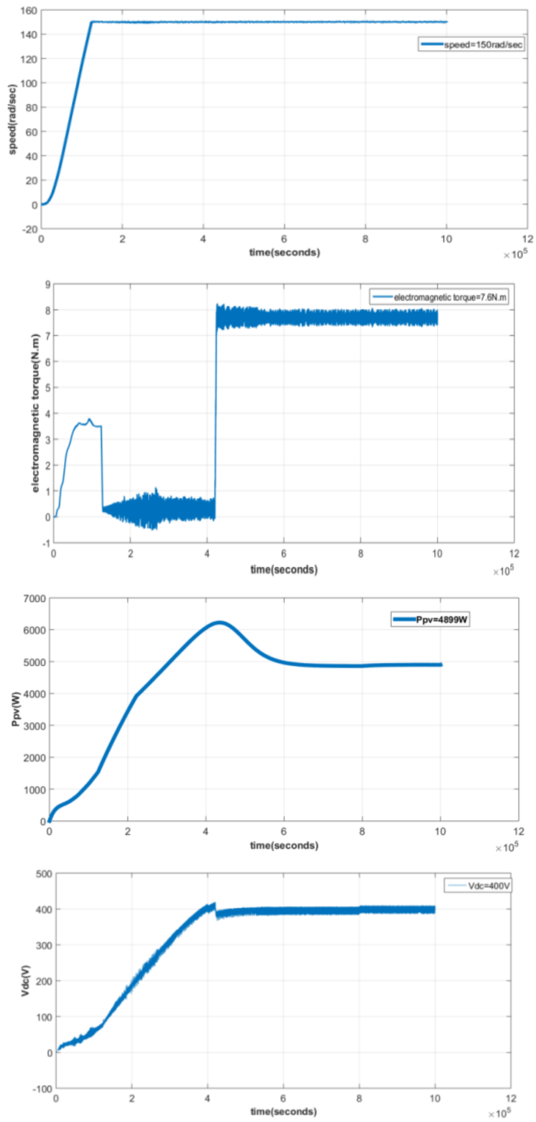


Fig 2. Starting characteristic and system representation at 1000W/m^2 Solar PV array parameters. Under rated insolation level 1000W/m^2. When MPP is reached, PV voltage and current reach their top values the motor is started smoothly the generated electromagnetic torque is 14.9N.m. The motor speed (ω_m) follows the reference speed (ω_{ref}), it achieves 150rad/s in quick sequence.

Case 2=1000W/m^2; For 50% Tl=7.4 N.m



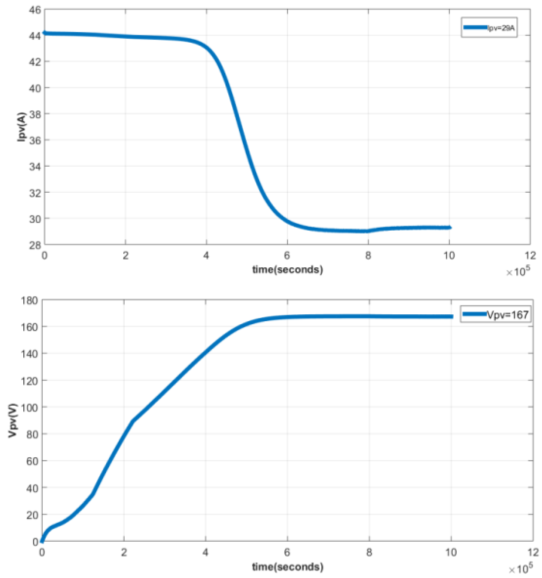


Fig 3. Starting characteristic and system representation at 1000W/m^2 Solar PV array parameters.

CONCLUSIONS

This paper shows double stage in proposed system each system consists of separate control algorithm. Inspite of atmospheric variation MPPT algorithm based on perturb and observe fed solar PV array reaches. Even and dynamic response is achieved within time by giving switching pulses with help of Indirect vector control technique to inverter. Hence switching order achieves desired electromagnetic torque at motor shaft. In this paper clear study of two stages PV system is done using MATLAB/Simulink Software. This paper shows that motor produces sufficient electromagnetic torque to drive the load. Speed is reached with good precedence.

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