# Steady and Transient State Performance of Solar Water Pumping Employing Induction Drive using Direct Torque Control

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*Abstract*— This paper deals with the standalone solar photovoltaic (SPV) array fed induction motor drive for water pumping system. To extract maximum power from SPV array, a SEPIC converter is employed and to control the speed of induction motor direct torque controlled (DTC) scheme is employed. The smooth starting of a induction motor is achieved by controlling the SEPIC converter through the incremental conductance maximum power point tracking (MPPT) technique. The induction motor is well matched to proposed control drive a type water pump due to its load characteristics. It is well suited to the MPPT of the PV array. The proposed system is properly designed and system performance is simulated in MATLAB/Simulink platform. Simulated results are demonstrated to validate the design and control of the proposed system.

***Keywords:*** Solar Photo Voltaic (PV) Array, SEPIC Converter, Incremental Conductance Maximum Power Point Tracking (MPPT) Technique, Three Phase Induction Motor

## I. INTRODUCTION

The photovoltaic (PV) electrical power generation system as a renewable energy source being inexhaustible, and non -polluting is becoming increasing rapidly in modern electrical power system [1-5]. The main issue in the photovoltaic generation system is the low conversion efficiency that lie between 12–18% [6-10].

PV panels demonstrate current-voltage (I–V) and power-voltage (P–V) characteristics which are nonlinear [3]. It is important to make PV power system function in a province that extracts maximum power from the PV panel system for most advantageous utilization at a fixed solar irradiation, load and temperature. Thus, among the methods to get the most out of the obtainable PV system output, maximum power point tracking (MPPT) control for DG integration and correct Network reconfiguration, is of utmost importance [11]. For the period of irregular fluctuations in solar irradiation, load and temperature, the MPPT control algorithm controls the duty ratio (D) of the power electronics converters i.e. a DC-DC buck-boost converter connected between the PV panel and load end, so that it identify the operating point of the buck-boost converter and the MPP of the PV panel coincides for extract the maximum power from the PV panel to the load. The attention of most of the researches is on the expansion, and realization of tracking algorithms pertaining to MPP functionality. Nevertheless, the individual performance of power electronics interfacing DC-DC converters relating to duty ratio variation in MPPT implementation still remains to be investigated in-depth [12-13].

This paper presents a standalone Solar PV based Induction Motor drive for water pumping system. In the proposed control scheme duty cycle of the SEPIC converter is controlled to maintain the DC link voltage at required level. Induction machine has been controlled using direct torque control scheme. The speed of the Induction Motor drive is a function of solar irradiation.

Fig. 1 shows the proposed system configuration of standalone solar photovoltaic (SPV) array fed induction motor drive for water pumping system. A 3.5 HP three phase Induction Machine is used to drive the water pump system. The Solar energy is converted to electrical energy using solar PV cells. A SEPIC converter topology has been used to step up the low voltage output of PV array to a high level voltage and is being controlled to maintain constant DC link voltage.

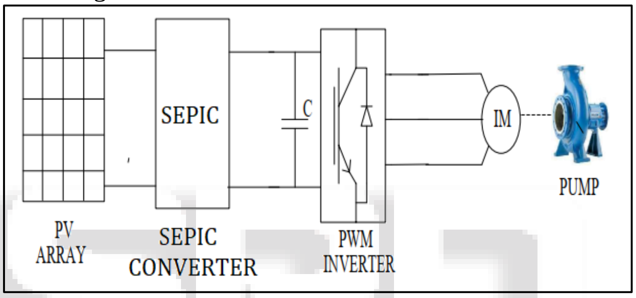

Fig. 1: Configuration of proposed system

To obtained variable speed operation for achieving MPPT, the induction machine has been driven by PWM inverter. Direct torque control has been used for controlling the induction machine. The SEPIC converter controls the DC link voltage of the PV system. The speed of the Induction Motor drive has been controlled by the PWM inverter according to the MPPT scheme.

## II. PROPOSED SYSTEM CONFIGURATION

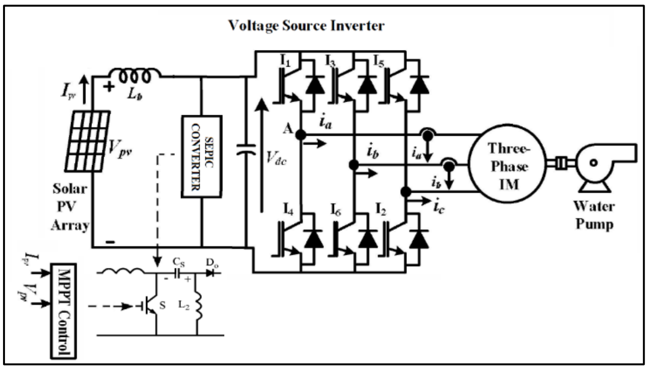

Fig. 2: Proposed system

### A. Design of Solar PV Generator:

The solar PV array is designed for a 4.5kW peak power capacity. The open circuit voltage (Voc) and short circuit current (Isc) for a module are 32.9 V and 8.2 A.The maximum power from the solar PV generator is as,

$$P_{mpp} = (N_s \times V_{mpp})(N_p \times I_{mpp}) = 2.4\text{Kw} \quad (1)$$

Where $V_{mpp}$ is the voltage of a module at MPPT, $I_{mpp}$ is the current of a module at MPPT, Pmp is the maximum power of a module at MPPT and $N_s$ and $N_p$ are series and parallel connected PV modules.

It has been investigated that $V_{oc}$ and $I_{sc}$ at peak power are 85% of its original values [12-13]. The Pmpp is generally achieved under this condition as,

$P_{mpp}$ = ($N_s$ x 85% of $V_{oc}$ x $N_p$ x 85 % of $I_{sc}$) = 2. 4 kW (2)

Thus, $I_{mpp}$ is 6.97 A and $V_{mpp}$ is 27.97 V of every module. Considering, PV array open circuit voltage ($V_{oc}$) = 400 V.

The PV modules connected in series string are estimated as,

$V_{oc}$ =$N_s$ * $V_{oc}$, (3)

thus $N_s$ = 400/32.9; 12 Modules

Current of the PV generator at MPP is given as,

$I_{mpp}$ = $P_{mpp}$ 1 (0.85 x 400) = 7. 41 A

The PV modules connected in parallel are calculated as,

$I_{mpp}$ = $N_p$ *$I_{sc}$, thus $N_p$ =1 Modules

So connecting 12 modules in series and I modules in parallel, a 2. 4 kW solar PV array is designed.

Design of DC Link Capacitor of VSI:

Fundamental voltage frequency of the VSI is equivalent to the rated speed of the induction motor. The Orated is estimated as,

$$\omega_{rated} = 2*\pi*f_{rated} = 2*\pi*\frac{N_s*P}{120} \quad (4)$$

$$= 2*\pi*\frac{1500*4}{120} = 314rad/\sec$$

The DC bus capacitor is estimated as,

$$\frac{1}{2}C_{dc}[V_{dc}^2 - V_{dc1}^2] = 3\text{aVIt}$$

$$\frac{1}{2}C_{dc}[400^2 - 375.59^2] = 3X1.2X132.79X0.004$$

$$C_{dc} = 1656.42\mu F$$

where $V_{dc}$ is the reference DC bus voltage of VSI, a is the overloading factor, $V_{dc}$ is minimum DC link voltage, I in the phase current of the motor and t is the time by which the DC link voltage is to be changed. The capacitor value is selected as 1600 uF.

## III. Direct Torque Control (DTC) Scheme

Fig. 3 shows the direct Torque Control (DTC) control scheme. The DTC control is implemented by using only three blocks flux and torque hysteresis controller, flux, torque and speed controller, and voltage switching logic as shown in Fig. 3. The DTC technique controls the flux and torque directly rather than controlling the stator currents as in vector control method. The torque of an induction motor is directly proportional to the product of stator flux and rotor flux and angle between them. In large squirrel cage induction motor, rotor time constant is much larger. So it can be assumed that rotor flux magnitude and position are unchanged. In this system, one component of reference speed is generated from the PV power using the pump affinity laws. It determines the flow rate of the water pump.

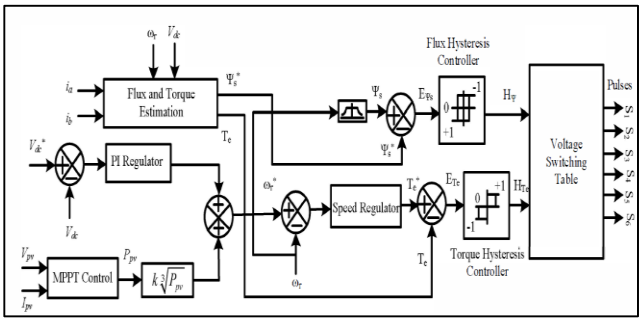


Fig. 3: DTC scheme of the proposed system

## IV. Results and Discussion

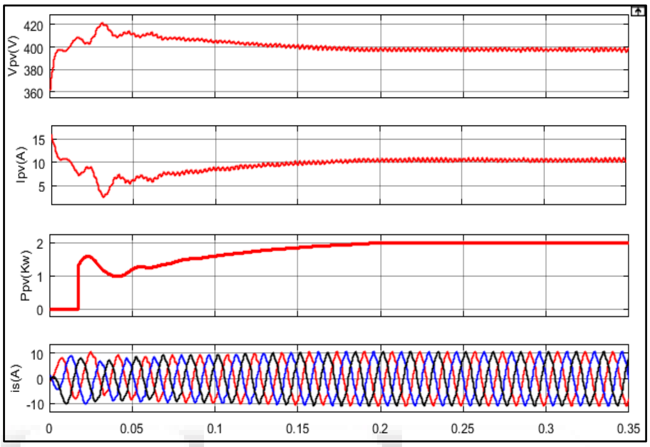


Fig. 4: Simulation results of proposed system

The proposed solar PV array fed DTC controlled induction motor drive for water pumping is modeled and its performance is simulated in MALAB/Simulink. In this section, steady state performance, dynamics performance and starting performance of the proposed system are discussed based on simulated results.

Fig. 4 shows the steady state performance of the solar PV fed DTC controlled induction motor drive. The proposed system not only feeds the power to the induction motor it also regulates the DC link of VSI. The speed of the induction motor is controlled by the DTC scheme and the reference speed is decided by the PV power, insolation and DC bus voltage controller. The obtained steady state results show that DC bus voltage is maintained to its reference value and MPPT algorithm is worked well for extracting maximum power from the solar PV array at solar insolation 1000 W/m2. It observed that current and voltage fluctuations are less in proposed system compared with existing system. This is achieved by using incremental conductance and SEPIC converter based MPPT algorithm. The speed PI controller has controlled the motor stator current and controlled the flow rate of pump. Simulation results have demonstrated that the performance of the controller has been found satisfactory under steady state as well as dynamic conditions.

## V. Conclusion

A standalone water pumping system powered by a solar PV array has been modelled with an induction machine drive. The objective of the proposed investigation was to maintain a constant DC voltage along with ensuring MPPT under constant and variable solar irradiation. The proposed system has been simulated and compare the results with existing system, and observed that current and voltage fluctuations are less in proposed system compared with existing system. This is achieved by using incremental conductance and SEPIC converter based MPPT algorithm. The speed PI controller has controlled the motor stator current and controlled the flow rate of pump. Simulation results have demonstrated that the performance of the controller has been found satisfactory under steady state as well as dynamic conditions.

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