Design and Simulation of Boost Converter for SPV Fed Water Pumping System

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Abstract: *The objective of this paper is to present a solar PV system based water pump for remote areas. The pump is driven directly coupled single phase induction motor and uses a boost converter to generate the rated voltage of motor. Sinusoidal pulse width modulation is used for inverter to feed single phase induction motor. The proposed control of boost converter uses PI controller to maintain DC link voltage at desired value during solar radiation variation. The proposed system is simulated in MATLAB/SIMLINK and obtained results are presented to demonstrate effectiveness of the proposed system.*

Keywords: *Photovoltaic system; DC-DC Boost converter; DC-AC SPWM inverter; Single phase Induction Motor; MATLAB Simulink.*

NOMENCLATURE

Vpv	Output voltage of a PV module (V)
Ipv	Output current of a PV module (A)
Tr	Reference temperature (298 K)
T	Module operating temperature in Kelvin
Iph	Light generated current in a PV module (A)
Io	PV module saturation current (A)
A /B	An ideality factor (1.6)
K	Boltzmann constant (1.3805 × 10-23 J/K)
q	Charge on electron (1.6 × 10-19 C)
Rs	Series resistance of a PV module
Rp	Parallel resistance of PV module
Iscr	PV module short-circuit current at 25^{o}C and 1000W/m^2
Ki	short-circuit current temperature co-efficient at Solar radiation 1000W/m^2
S	PV module illumination (W/m2) = 1000W/m^2
Ego	Band gap for silicon (1.1 eV)
Ns	number of cells connected in series
Np	number of cells connected in Parallel

I. INTRODUCTION

Efficient use of Energy is necessary for economic and social development of any country. Renewable or non-conventional energy resources are the best option due to increasing energy demand. Solar energy is considered as most abundant and sustainable energy source among renewable sources[1].

The solar photovoltaic energy conversion is picking up now-a-days due to advancement in material technology and power electronics.

SPV used for water pumping is playing an important role in agriculture where short of electricity, this system as a boon for farmers. The main advantage of solar powered water pumping system are low maintenance, easy installation, reliability and the matching power generated and water usage needs[2].

This paper presents a comprehensive model for SPV pumping system to be used in remote areas where no electricity is available.

PV module as a PV energy generation, which output characteristics depends upon the solar radiation and PV temperature. PV System has the nonlinear characteristics, so MPPT required for PV system application. The output of the Solar PV system is a low value DC voltage which is not suitable for load i.e. motor. So, there is need of a boost DC-DC converter. Further, this DC voltage needs inversion to feed the AC motor. Accordingly, a sine PWM inverter is required to drive the induction motor.

Next Section describes the solar PV system fed water pumping system through boost converter and SPWM inverter. Thereafter, Design equations and operation of PV array, DC-DC Boost converter, SPWM Inverter and SPIM drive. Various control method of boost converter and simulation result are presented to show the effectiveness of proposed system.

II. SYSTEM TOPOLOGIES AND CONFIGURATION

A Solar cell is the basic block of Photovoltaic system. An individual PV cell usually produces very small voltage and power. To increase the voltages and current of PV Solar cell series and parallel connection are done. PV module is made by cells in series and parallel combination[3].

This voltage level is further enhanced using boost DC-DC converter and fed to SPWM inverter. Water pumping system, to get sinusoidal supply so that Induction motor is operated at desired speed i.e. 1100 rpm Water pumping system.The control scheme diagram for the proposed system is shown as Fig.1.

Fig. 2, shows the circuit representation of SPV module the current source I_{ph} is cell photon current, R_s and R_p are series and parallel resistance of cell respectively. The SPV module can be represented mathematically as[5]- [6].

Module photo-current:

$$Iph = [Iscr + Ki\ (T - 298)] * \frac{S}{1000} \quad (1)$$

Module reverses saturation current Irs:

$$Irs = \frac{Iscr}{\left[exp \left[\frac{qVoc}{NsKAT}\right] - 1\right]} \quad (2)$$

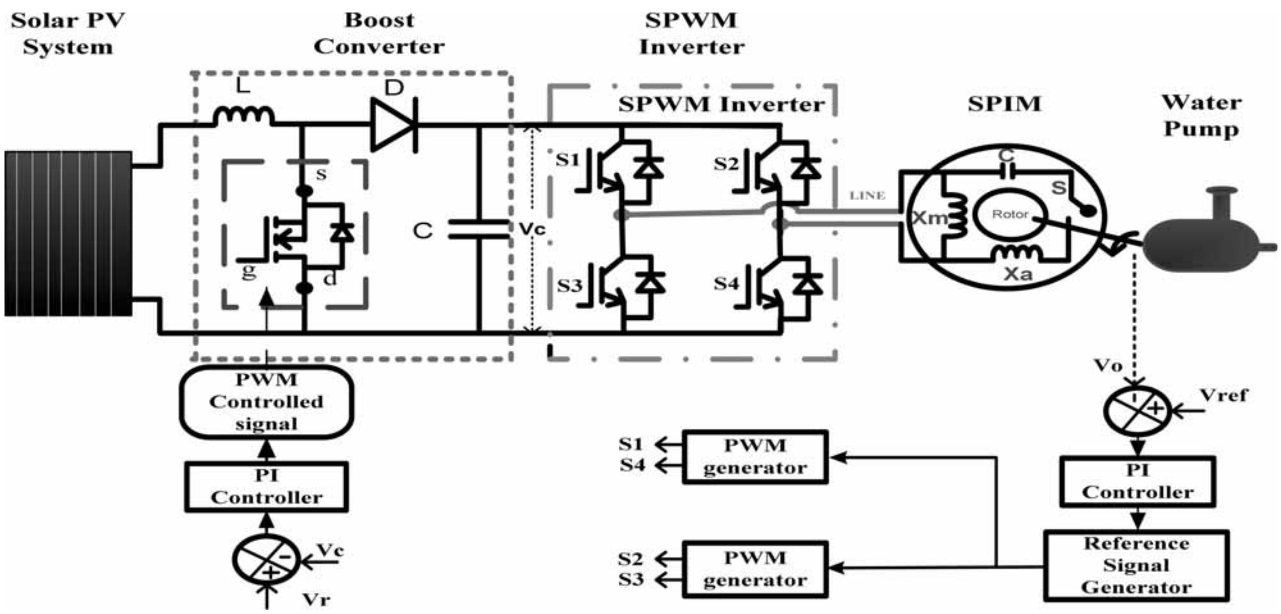

Fig. 1: Control scheme diagram of SPV fed SPIM drive for Water Pumping system

A. Solar PV System

A solar cell is basically fabricated p-n junction semiconductor device. Generation of electricity by Solar radiation .When Solar radiation incident on the solar cell as a packet of photon, energy of photon greater than band gap energy of semiconductor forms some electrons hole pair[4].

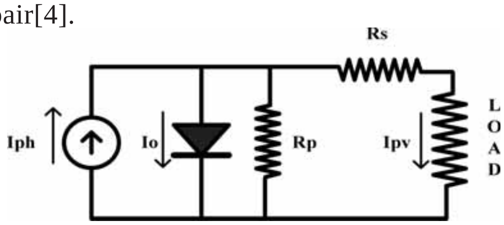

Fig. 2: PV cell modeled as Diode circuit

The module saturation current Io varies with the temperature of cell:

$$Io = Irs \left[\frac{T}{Tr}\right]^3 exp\left(\frac{qEgo}{AK} * \left\{\frac{1}{Tr} - \frac{1}{T}\right\}\right) \quad (3)$$

The current output of PV module is Ipv:

$$Ipv = Np * Iph - Np * Io\ [exp\ \{q* \frac{Vpv + IpvRs}{NsKAT}\} - 1] \quad (4)$$

The Induction motor considered in this paper has 1Hp rated power at 1440 rpm. Accordingly PV modules of 250W each model CS6P [7] of Canadian company is considered whose data is given in Table 1.

Table 1: Key Specification of CS6P-250M Module under STC

Electrical Characteristics	CS6P-250M
Nominal Power	250W
Optimum Operating Voltage	30.4V
Optimum Operating current	8.22A
Open circuit voltage Voc	37.5V
Short circuit current Isc	8.74A
Temperature coefficient	0.005A/oC

System should have the maximum power transfer, so design of PV module is 746 W i.e. 1HP .If Three module of CS6P-250M connected in series and output PV voltage and current are 91.2V and 8.22 A respectively.

B. DC-DC Boost converter

DC converter is used boost dc convert unregulated dc voltage to a regulated dc output..A boost converter using a power MOSFET with high switching frequency is considered to reduce the size of filter[8].

The design equation s governing the duty ratio and other values are given as [9].

a. *Current Ripple Factor (CRF):* According to IEC harmonic standard CRF should be bounded within 30%.

$$\frac{\Delta I_1}{I_1} = 30\% \tag{5}$$

b. *Voltage Ripple Factor (VRF): According to IEC harmonic standard VRF should be bounded within 5%.*

$$\frac{\Delta V_o}{V_o} = 5\% \tag{6}$$

c. *Switching frequency*

Fs = 20 KHz

Given data	Input voltage	$V_{in} = 91.2V$
	Output voltage	$V_o = 311.12V$
	Output current	$I_o = 2.3978A$

Step I: Calculation of duty cycle

$$V_o = \frac{\Delta V_o}{V_o} = 5\% \tag{7}$$

Step II: Calculation of Ripple current

$$\Delta I_L = 0.3 * I_L \tag{8}$$

Step III: Calculation of inductor in mH

$$L = \frac{Vin * D}{fs * \Delta I_L} \tag{9}$$

Step IV: Calculation of capacitor in µF

$$\frac{\Delta Vo}{Vo} = \frac{D * Ts}{RoC} \tag{10}$$

Where $R_o = V_o / I_o$, Ro =129.75ω.

Parameter for boost converter are measured as D = 70.69%,

L = 4.6049 mH, C = 13.6µF.

C. SPWM Inverter

Sinusoidal Pulse width Modulation technique is very popular used in control scheme for inverters. A high frequency triangular waveform compares with desired frequency sinusoidal reference waveform and PWM is generated[10].

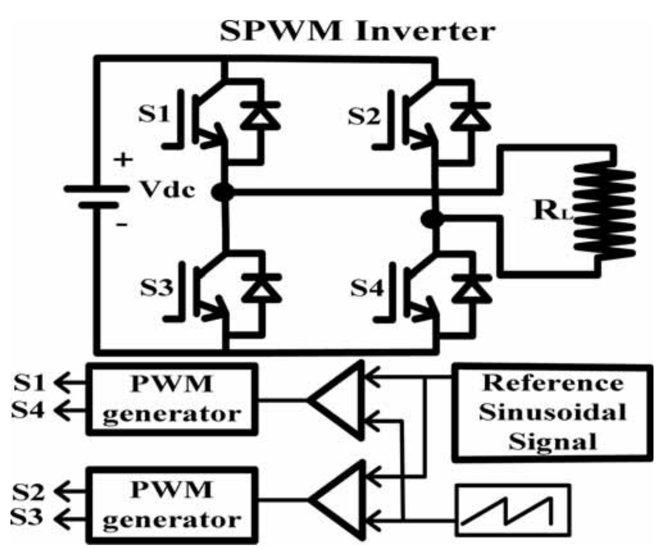

Fig. 3: Circuit Diagram of SPWM Inverter and switching method

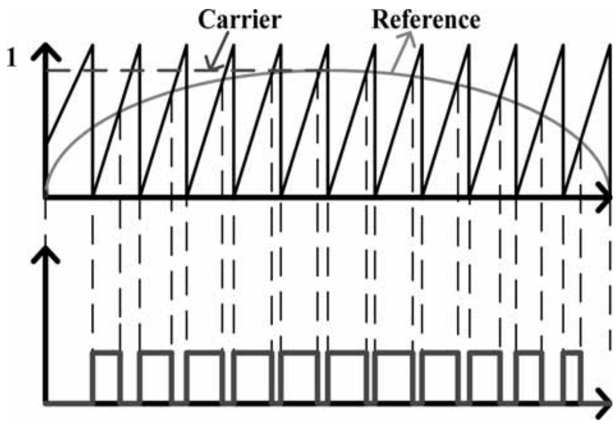

Fig. 4: Generation of SPWM switching scheme

In this Paper, the sinusoidal reference signal has unity magnitude and 50 Hz frequency with saw tooth sequence of 20 KHz frequency.

In SPWM inverter control the pulses of different widths, distortion factor (DF) and Low order Harmonic (LOH) result is reduced [10].

D. Single Phase Induction Motor

A single phase Induction motor (SPIM) is not Self starting Motor and some methods to start the motor: Split phase motor, Capacitor start motor, Capacitor start run Motor, Shaded pole motor. SPIM used in Pumps, compressor, Air conditioner fan, refrigeration, exhaust fan, record player etc [11]. This paper uses a capacitor start SPIM.

III. CONTROL STRATEGY

Fig. 1, shows control strategy for a standalone Photovoltaic fed SPIM drive for water pumping system. The control of boost converter to maintain dc link voltage.

DC-DC boost converter output may affected by solar radiation. The Low voltage will be developed in dc link which will be not suitable and acceptable for system. So, the closed loop accepted. In closed loop system the output of converter compares with the desired reference voltage and error generate and give to PI controller. Output of controller compares with repeating sequence form PWM generation which controls the switch as per the requirement.

The dc link voltage V_c and reference voltage V_r, PI controller is used to estimate the DC voltage error at K^{th} sampling instant

$$V_{dce} = V_c(k) - V_r(k) \tag{11}$$

The output of PI controller at K^{th} sampling instant and K_p and K_i are the two controller parameter which plays an important role to generate the output of PWM generator. There is no direct formula to calculate the K_p and K_i.

IV. RESULT AND DISCUSSION

The model of a standalone solar PV based SPIM drive system for water pumping system application is created in MATLAB/SIMULINK.

A. Solar PV model

Solar photovoltaic system modeled in MATLAB/ Simulink library. The model is based on the mathematical

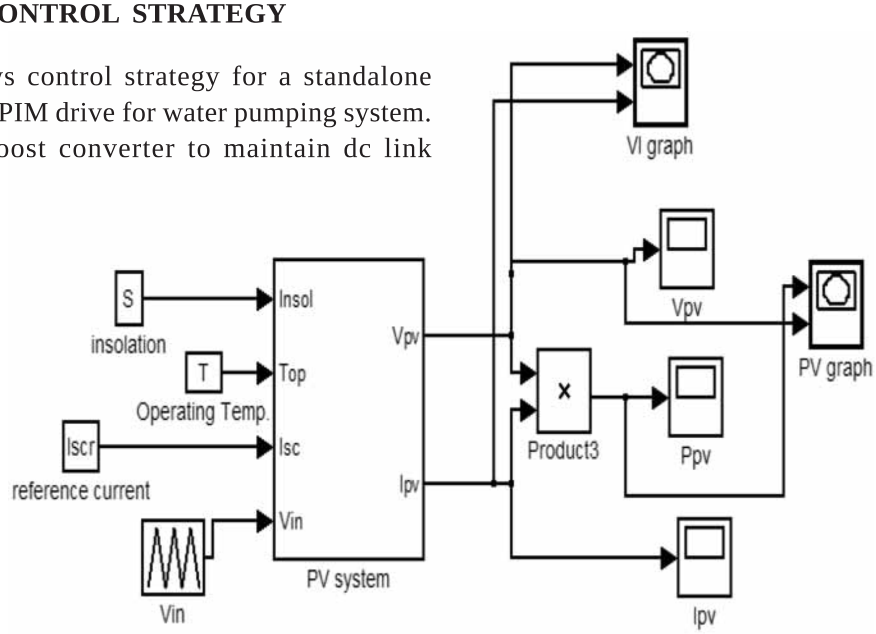

Fig. 5: Simulink model of cell

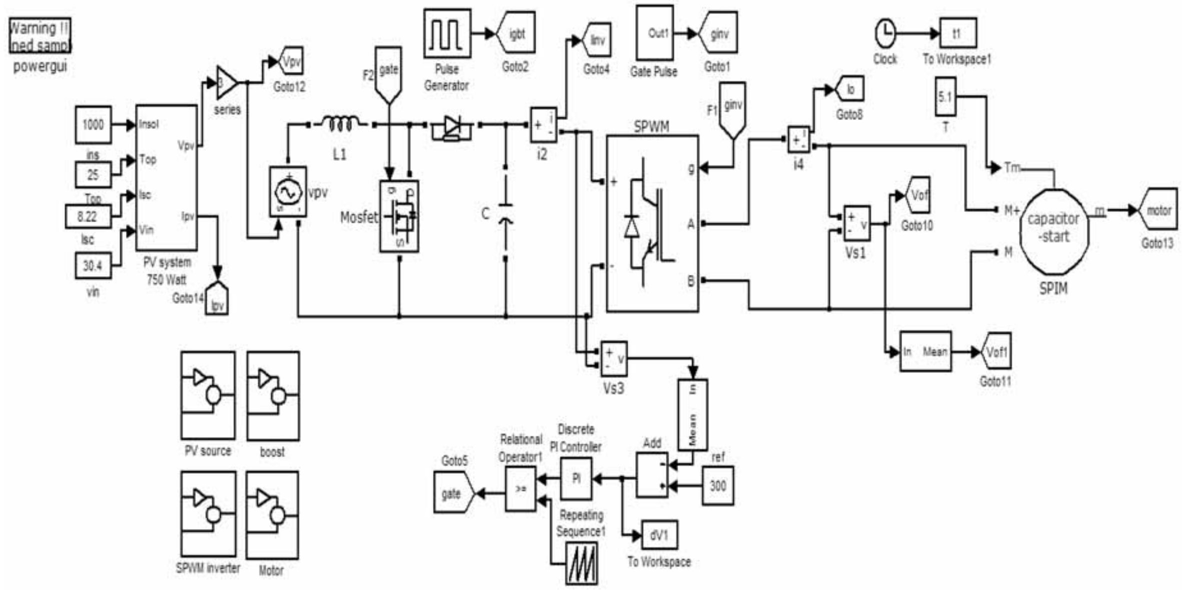

Fig. 6: Simulink Model and control scheme of SPV fed boost converter for SPIM Drive

equations of PV cell. Single Module generates 250 W and three modules are connected to obtain 750 W and load require 746 W. Simulink model shown in Fig. 5.

B. Boost Converter

SPV based boost converter modeled in simulink library and PWM technique applied to control the output. SPIM drives as a load which shown in Fig. 6.

The output of the boost converter is controlled by the PI controller K_p and K_i are the parameter and performance of system as follows.

Table 2: Controller Parameter on System Performance

Response	***Rise time***	***Overshoot***	***Settling time***	***Steady state error***
Kp	Decrease	Increase	Minor Change	Decrease
Ki	Decrease	Increase	Increase	Eliminate

C. Performance of System

The performance of system varies due to changing the solar radiation or temperature of PV system. These Two factors are affect the system, but the controller of the boost converter used to remove all constrains. Here, Discussion of the SPIM Drive when converter with feedback.

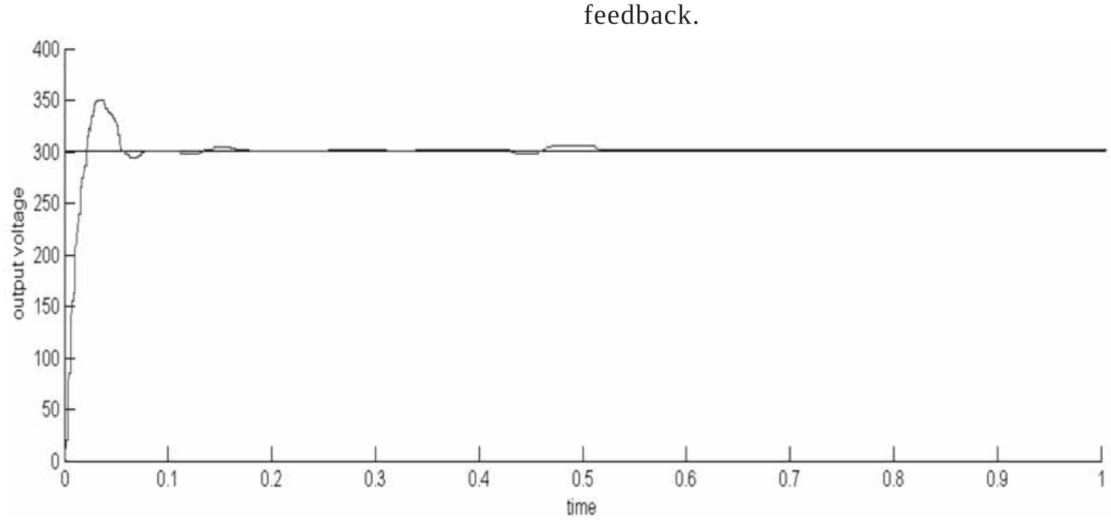

Fig. 7: Simulation Result of Boost Converter

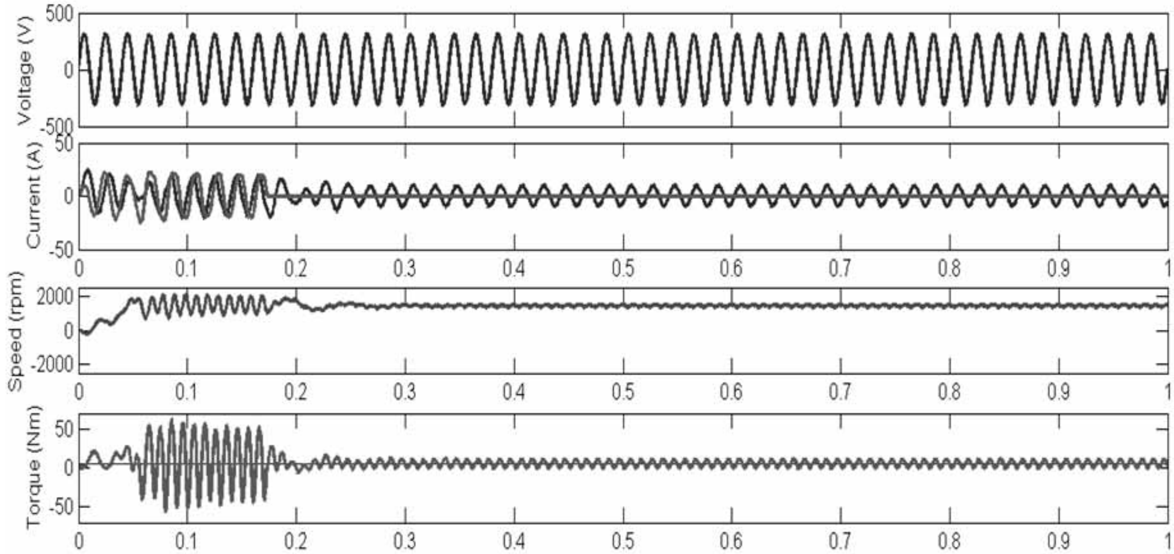

Fig. 8: Simulation Result of SPIM Drive

V. CONCLUSIONS

The modeling and simulation of standalone SPV fed water pump using SPIM drives has been carried out in this paper to demonstrate and effectiveness of the system. Boost converter designed using mathematical equation and control of converter using PWM technique. It is hoped that this paper shall be helpful reference for the professionals working in area of SPV based power electronics drives.

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