Solar PV based water pumping system employing induction motor drive with SVPWM

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***Abstract-*In electric power generation the demand of renewable energy resource increasing day by day. Solar photovoltaic arrays (SPV) for water pumping system are used in industry and agricultural applications. A single ended primary inductor current converter (SEPIC) is interfaced between SPV and MLI for gaining more voltage from solar and fed the output to MLI. Cascaded multilevel inverter (CMLI) with space vector pulse width modulation technique (SVPWM) is proposed to generate three phase AC voltage and gives less total harmonic distortion, increases the efficiency of the system. The entire system of water pumping system and all components are designed in MATLAB/Simulink.**

Keywords— cascaded H-bridge multilevel inverter, SEPIC converter, Induction motor, water pumping system.

I.INTRODUCTION

The demand of energy is necessary for the development of any nation [1]. Solar energy is most commonly used renewable energy resource when compared to other conventional resources. Various advantages of using solar energy are pollution free, low maintenance, no moving parts. Solar PV cell converts sunlight directly into electricity [2].

SEPIC is a non-isolated DC-DC converter used to increase or decrease the output voltage from the solar. This converter can also make same voltage at both at input and output terminals and it gives non inverted output (that means having the same polarity both at input and output).

The multilevel inverter is used to convert the output of SEPIC converter i.e, DC into AC. The advantages of multilevel inverter are to minimum harmonics, high voltage application, less switching losses and higher voltage capability [3]. There are three different types of the multilevel inverter 1) neutral point diode clamped (NPC) 2) flying capacitor (FC) 3) Cascaded H-bridge multilevel inverter (CMLI). The CMLI is used to generate the AC voltage and the gate pulse is provided by SVPWM techniques. These MLI topologies are used in industrial and domestic applications.

The induction motor are widely used in water pump application because of many advantages as compared to DC motor are low cost, better ruggedness, low maintenance, reliable, higher efficiency. The applications of Induction motor are fans, pumps, blowers, etc [4].

Centrifugal pumps are common type of kinetic pump, it is widely used in the field of irrigation and industrial fluid pumping system application [5] the centrifugal pumps are mainly used because of low cost, low maintenance, highly utilized for longer periods, low irradiance is required compared to volumetric pump, reciprocating pump [6].

In this paper, the performance of a centrifugal pump driven by an induction motor is analysed, which is supported by a solar PV array with SEPIC converter assisted to MLI by SVPWM. The complete system is simulated in MATLAB/ Simulink.

The paper comprised following parts they are: Introduction is covered in section I, followed by system description in section II. In section III, the system modelling is presented, section IV the mathematical modelling of centrifugal pump is explained and the results and discussion part is given in section V. In last, section VI concludes the paper.

II. SYSTEM DESCRIPTION

It consists of mainly five parts a) PV array; b) SEPIC converter c) Cascaded multilevel inverter, d) Induction motor, e) Pump load. The layout of the system is shown below in Fig.1

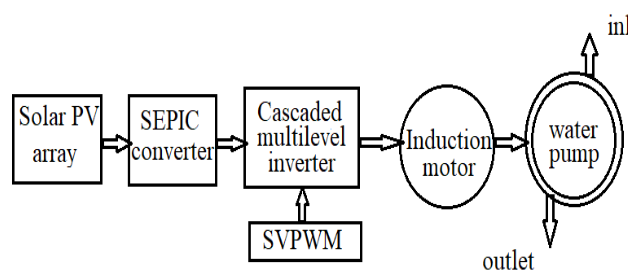

Fig.1 Schematic diagram of the system

The PV array is employed to generate the dc power, to increase the dc power SEPIC converter is used and then it converted into three phase ac with the help of Cascaded H-bridge multilevel inverter. The output of the inverter is fed into the induction motor driven water pumping system for remote areas.

III. PHOTOVOLTAIC SYSTEM AND INVERTER TOPOLOGY

A. Photovoltaic system

The amount of electricity produces from solar depends on the three important factors:

1. Size of the panel.
2. Efficiency of the solar cell.
3. Amount of sunlight the panel gets.

A PV array consists of several PV cells connected in series and in parallel. Series connections are responsible for increase in voltage of the module. Similarly parallel connections are responsible for increase in current of the module. Typically a solar cell can be modelled by a current source and inverted diode connected in parallel to it.

B. SEPIC converter

A SEPIC converter is essentially a boost converter followed by a buck boost converter, therefore it is similar to a traditional buck boost converter, and the output of the SEPIC converter is controlled by the duty cycle [6].

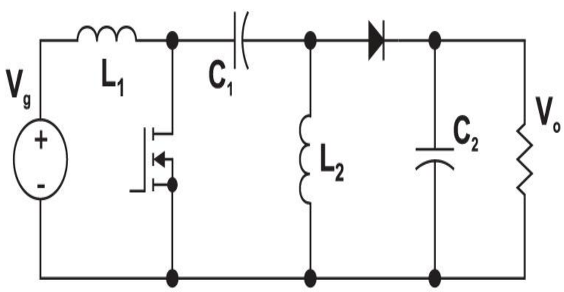

Fig.2 circuit diagram of SEPIC converter

SEPIC converter operates in two modes of operation:

*Mode:*1 0<t<DT when the switch is turned ON. The energy from the source is stored in the inductor L_1 and C_1 transfers its energy to the inductor L_2. The capacitor C_1 voltage is considered constant. The currents i_1 and i_2 increases linearly. During this stage diode D is in reverse biased and the energy stored in capacitor C_2 supplies to the load.

Mode:2 DT<t<T when the switch is turned OFF the diode D is in forward bias. The diode transferring the inductor stored energy to the load. The currents i_1 and i_2 decreases linearly.

From mode1 and mode2 the average voltage across one cycle is zero.

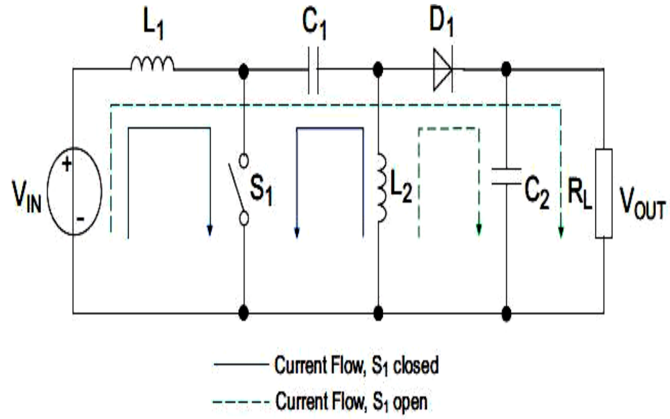

Fig.3 Modes of operation of SEPIC converter

The average output voltage is given by

$$\frac{V_D}{Vin} = \frac{D}{1-D} = \frac{\alpha}{1-\alpha}$$

$$D=\alpha=\frac{T_{ON}}{T}$$

Similarly output current of SEPIC converter,

$$I = \frac{P_{out}}{V_{out}}$$

TABLE I. Parameters of SEPIC converter

PARAMETERS	VALUES
Inductor L_1	$10e^{-3}$
Capacitor C_1	$3.3e^{-6}$
Inductor L_2	$60e^{-6}$
Capacitor C_2	$700e^{-6}$
Switching Frequency	1000Hz

For calculating L_1, L_2 and C_1

$$L_1 = \frac{D * V_{PV}}{f * \Delta I_{L_1}}, \quad L_2 = \frac{(1-D) * V_{out}}{f * \Delta I_{L_1}}$$

$$C_1 = \frac{D * I_{out}}{f * \Delta V_{C_1}}$$

C. CASCADED H-BRIDGE INVERTER

The cascaded H-bridge inverter consists of a series of H-bridge (single-phase, full bridge) has drawn tremendous interest due to the greater demand of medium-voltage, high-power inverters. A cascade multilevel inverter is a power electronic device built to synthesize a desired AC voltage from several levels of DC sources, which may be obtained from batteries, solar cells or fuel cells [8].

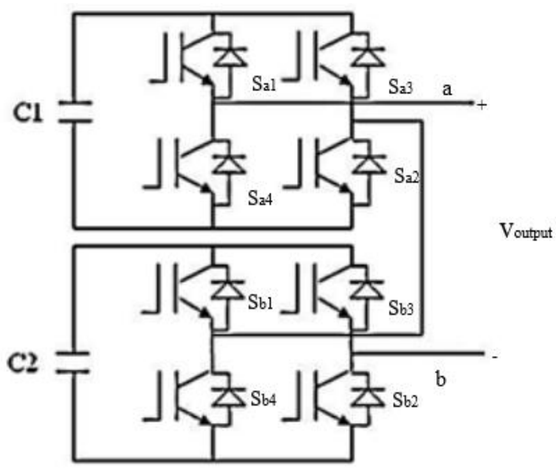

Fig 4 Single leg of 5-level cascaded multilevel inverter

In CMLI it doesn't requires any clamping diodes and any balancing capacitor, least number of components can be used when compared other multilevel inverter.

TABLE II. Switching table of 5-level CMLI

Voltage\switches	S_{a1}	S_{a2}	S_{a3}	S_{a4}	S_{b1}	S_{b2}	S_{b3}	S_{b4}
0	1	0	1	0	1	0	1	0
$+V_{dc}$	1	1	0	0	1	0	1	0
$+2V_{dc}$	1	1	0	0	1	1	0	0
$+V_{dc}$	1	1	0	0	1	0	1	0
0	1	0	1	0	1	0	1	0
$-V_{dc}$	0	0	1	1	1	0	1	0
$-2V_{dc}$	0	0	1	1	0	0	1	1
$-V_{dc}$	0	0	1	1	1	0	1	0

Space vector modulation (SVM) is a algorithm for the control of pulse width modulation (PWM). Instead of using conventional SVM, Triangular carrier based SVM is implemented to avoid computational burden. The method is based on the duty cycles ratio that SVPWM displays. In these pulses can be generated by comparing the duty ratio with a triangular carrier of higher frequency as in the case of sinusoidal PWM [9].

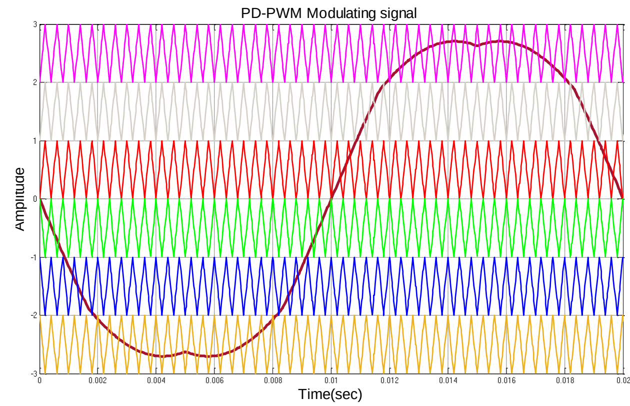

Fig.5 PD PWM modulating signal

Triangular carrier based PWM permit efficient and quick implementation of SVPWM in which sector determination is not required. In SVM instead of using three modulating signal for three phase, a revolving voltage vector can be used as reference voltage.

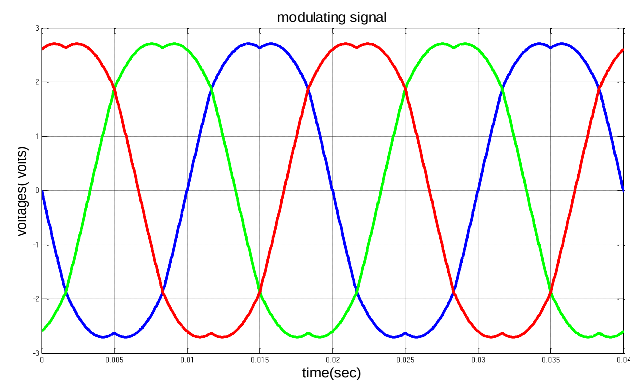

Fig.6 Three phase modulating signal

D. Induction motor based water pump

For industrial and domestic application mainly induction motor is used. Squirrel cage induction motor (SCIM) when operated with constant line voltage (50Hz) it operates at constant speed [5]. SCIM with centrifugal pump can be utilized for large scale with low irradiation. The stator reference frame equations in terms of d-q frame

$$V_{ds} = R_s i_{ds} + \frac{d}{dt}\psi_{ds}$$

$$V_{qs} = R_s i_{qs} + \frac{d}{dt}\psi_{qs}$$

Where,

$$\psi_{ds} = L_{ls} i_{dr} + L_m(i_{ds} + i_{dr})$$

$$\psi_{qs} = L_{ls}i_{qs} + L_m(i_{ds} + i_{dr})$$

The rotor reference frame equations in terms of d-q frame as shown below

$$V_{dr} = R_r i_{dr} + \omega_r \psi_{qr} + \frac{d}{dt}\psi_{dr}$$

$$V_{qs} = R_r i_{qr} - \omega_r \psi_{ds} + \frac{d}{dt}\psi_{qr}$$

Where,

$$\psi_{dr} = L_{lr}i_{dr} + L_m(i_{ds} + i_{dr})$$

$$\psi_{qr} = L_{lr}i_{qr} + L_m(i_{qs} + i_{qr})$$

V_{ds}, I_{ds} and V_{qs}, I_{qs} are the voltages, currents of stator d-q frame. R_s, R_r, L_m, ω, ω_r are the stator and rotor resistances, inductances, angular velocity, electrical angular velocity. V_{dr}, I_{dr} and V_{qr}, I_{qr} are the voltages and currents of rotor references frame.

The torque of induction motor is given by

$$T_e = 3/2(P/2)(\psi_{ds}i_{qs} - \psi_{qs}i_{ds})$$

Due to simple operation, the centrifugal pump is employed. In induction motor energy is converted into the kinetic energy in the form of liquid flow by accelerating the revolution.

IV. MATHEMATICAL MODELLING OF CENTRIFUGAL PUMP

Centrifugal pump is a mechanical device designed to move fluid by means of transferring rotational energy from one or more driven rotors, called impeller. The pump casing is specially designed to constrict the fluid from the pump inlet, direct it into the impeller and then slowly control the fluid before when it gets discharge.

Centrifugal pumps are mainly used for pumping water, solvents, oils, acids and any ‘thin’ liquids in industrial, agricultural and domestic applications.

Centrifugal pump [10] is designed in Simulink model by using the following equations:

$P_H = \rho gQH$ (Hydralic power)

$T_L = g/\omega$ (in N-m)

$Q = T\omega/(gH*1000)$ (water flow discharge in ltr/s)

Where,

1. $\rho = 1000$ kg/m^3 (water volumic mass)
2. H = manometric head of well (10m, 20m,..)
3. g = 9.81 m^2/s (specific gravity)
4. ω = speed in rad/sec
5. T = Torque in N-m

The product of speed and torque from induction motor is fed to centrifugal pump and multiplied by a product to give the numerator block of discharge. Similarly total row head, density of mass, specific gravity are multiplied by a product block to give denominator of discharge.

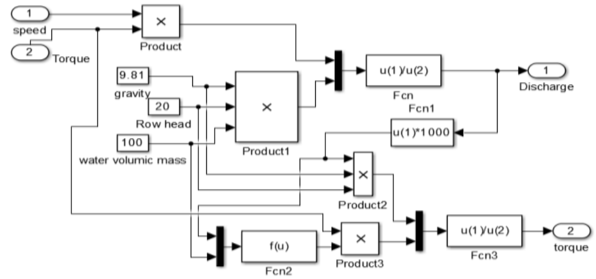

Fig. 7 Simulink model of centrifugal pump

In this way water flow rate through pump is calculated i.e, Discharge. Based on the gravity and speed the load torque can be determined.

V. SIMULATED RESULTS

The solar PV array based water pumping system simulation diagram is shown in figure8.

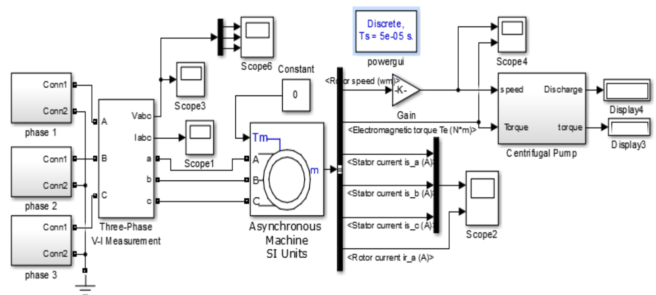

Fig.8 Simulink model of the system

The PV array is used to generate DC voltage, in order to increase the voltage SEPIC converter is employed. The output of the converter is fed to a multilevel inverter for converting the DC input voltage to an AC voltage at 50 Hz frequency. The induction motor based water pump is fed by the cascaded multilevel inverter output supply. The PV array output is generated approximately to 90volts.

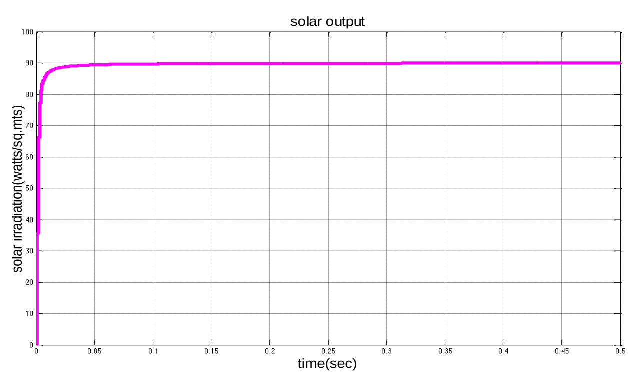

Fig.9 voltage of PV array

The SEPIC converter increases the solar output to approximately 200volts.

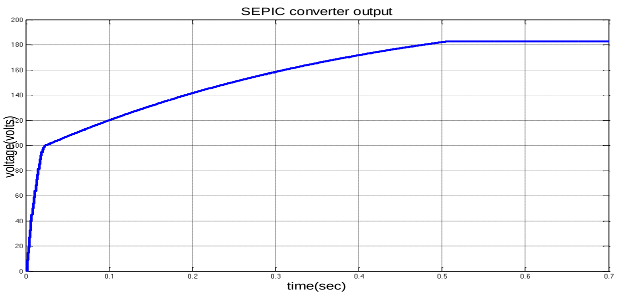

Fig.10 SEPIC converter output voltage

The induction motor is running at no load in starting and taking high currents, after some seconds of time motor is gaining full speed at no load condition.

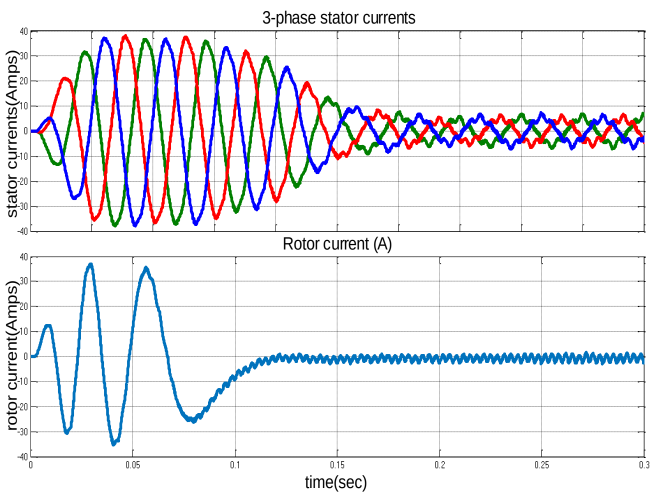

Fig.11 stator and currents of induction motor

The no load speed of induction motor is 1500 rpm and when the load is connected then the speed becomes less, as load increases the speed of the induction motor gets reduces. In induction motor speed and torque are inversely proportional.

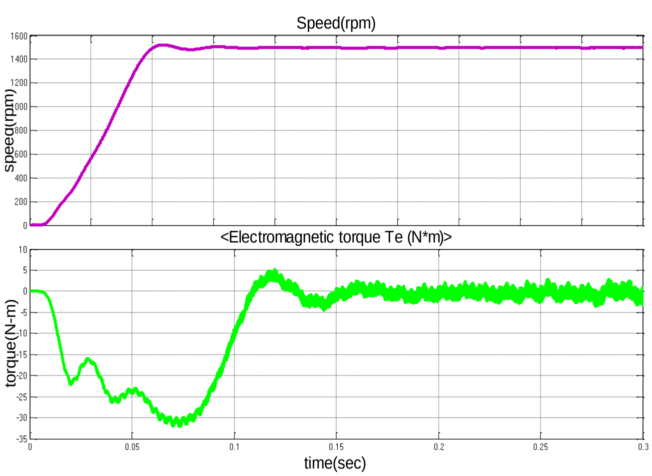

Fig. 12 Speed and electromagnetic torque of IM

The multilevel inverter three phase voltage and phase to phase voltage waveform is shown below.

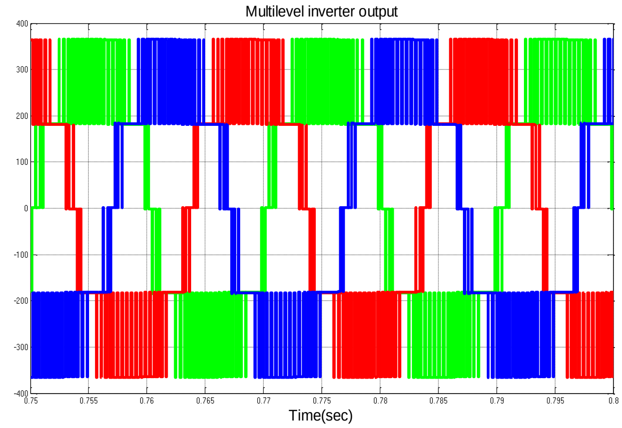

Fig.13 Three phase voltage of multilevel inverter

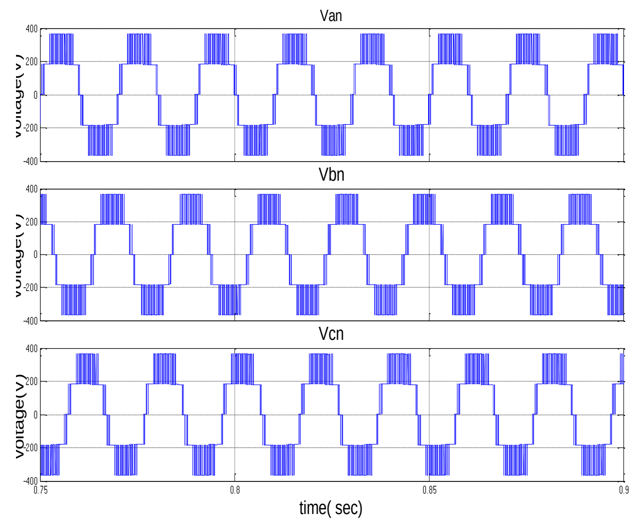

Fig 14.Phase to phase voltage of multilevel inverter

For power quality improvement the harmonic content should be less. The total harmonic distortion (THD) in the stator current of one phase in induction motor is 2.71%.

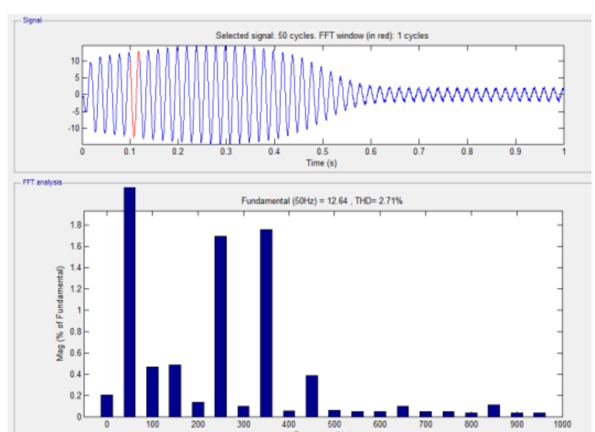

Fig 15. Total harmonic distortion of stator current of one phase

V. CONCLUSION

The PV array employed SEPIC converter based cascaded multilevel inverter for motor driven pump system as analyzed. The Cascaded multilevel inverter is employed with triangular carrier based SVPWM technique to reduce total harmonic distortion. when the load is increased induction motor take some time to reach steady state. The THD of the stator current of induction motor is obtained as 2.71% with SVPWM technique.

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