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Induction Motor Driven Solar PV Array Fed Water Pumping System with Zeta Converter

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Abstract— In this work, three phase induction motor drive (IMD) using field oriented control (FOC) for irrigation is fed by solar PV array with MPPT algorithm is proposed. It includes solar PV array, a voltage source inverter (VSI) with SVPWM and Zeta converter. The main objective of this work is to extract maximum power from the PV array as well as speed control of the motor drive. The utilization of a Zeta converter in intermediate stage of DC-DC converter is to achieve the maximum efficiency of the solar PV array and the soft starting of the IMD by proper control. The Zeta converter with a least number of components and single switch exhibits very good conversion efficiency. To drive a centrifugal type of water pump, an induction motor is employed because of its load characteristic is well matched to the maximum power locus of the PV generator. The transient, dynamic and steady state behaviors of the proposed system are evaluated under the rapid and slowly varying atmospheric conditions and simulation results have been successfully verified by using the MATLAB/Simulink.

Keywords— solar PV array, Zeta converter, SVPWM, inverter,induction motor and field oriented control.

I. INTRODUCTION

Now a day's with rapid utilization of fossil fuels, there has been a need for research on renewable energy sources. Wind and solar energy are the most suitable energy sources for the replacement of conventional energy sources. In Indian subcontinent the availability of solar energy is more and cheap in stand-alone systems more effectively it can be utilized. Where grid is unpredictable or shortage of electricity, mostly in rural areas for standalone water pumping system solar energy can be used. Recently there have been a lot of efforts on solar PV fed irrigation, industrial and household pumping systems.

Till now the water pumping has become a cost effective application of SPV energy due to this the application was quite slow. The major problem with the SPVs is the non linear characteristics between power and voltage. Mainly the characteristics are depends on many aspects such as solar radiation, ambient temperature and structure of PV. Because of this reason the overall efficiency of the system is quite low. For improving the performance and maximum efficiency of the system is achieved through a maximum power point tracking (MPPT) algorithm [1] and it employed with the DC-DC Converters. There have been online and offline tracking algorithms for MPPT. Most effective online is the Adaptive Incremental conductance method (AINC) [2].

In this work, a cost effective solution for solar PV based water pumping system has been presented. It consists of solar PV array, a voltage source inverter, DC-DC converter and three phase filed oriented control IMD [3]-[4]. Solar PV array is designed by using series and parallel connections for the required power, voltage and current rating of the motor. Different DC-DC converter topologies such as buck, boost, buck-boost, Cuk, SEPIC (Single Ended Primary Inductor Converter) have been used for MPPT solar PV array based applications [5]. From this it has been concluded that the new topology of DC–DC converter in the MPPT solar PV system is the Zeta DC–DC converter [6] because of more advantages and also it has capable to achieve optimal operation without depends on load value. When the buck and boost converter is used for MPPT, it is restricted to operate within the stable region. Besides that the Cuk and SEPIC converters contribute to their disadvantage because of the highest values of energy storage components.

Till now, in double-switch buck-boost converter topology also used for DC-DC converter with buck converter is placed before a boost converter [7]. But in this Zeta converter placed before the inverter, it offers additional advantages in SPV array fed FOC IMD water pump. The placement of the zeta converter at the output of SPV array, then the low voltage of SPV is converted in to high voltage with one stage conversion. This input current is continuous because in the zeta converter input inductor works as a ripple filter. Secondly, the capacitor is placed at the back end of this converter and before the VSI contributes to get the continuous output current and soft starting of the induction motor. The proposed converter is must always operated in continuous conduction mode (CCM), due to this the stresses on the devices and components is reduced. The zeta converter operation and working principle is explained in the following sections.

A zeta converter exhibits the following major advantages compared to conventional buck, boost, buck-boost converters and Cuk converter when employed in SPV based applications [8].

- The zeta converter may be operated either to increase or to decrease the output voltage depends upon the requirement. So, it gives a boundless region for maximum power point tracking (MPPT) of a SPV array. But, for a simple buck and boost converter if MPP of solar PV array occurs within prescribed limits then only the MPPT can be performed.
- And it also facilitates the soft starting of induction motor unlike a boost converter which habitually steps up the voltage level at its output, not ensuring soft starting.
- The zeta converter has a continuous output current, unlike a classical buck-boost converter. The output inductor of the zeta converter makes the current continuous and ripple free.
- The zeta converter can operates as non-inverting buck-boost converter, even though it consisting of same number of components as a Cuk converter unlike an inverting buck-boost and Cuk converter. It avoids the requirement of associated circuits for negative voltage sensing. So it reduces the complexity and probability of slow down the system response. Because of these advantages the zeta converter is favorable for proposed SPV array fed water pumping system.

And also in this work, the induction motor fed by voltage source inverter. The power semiconductor switches of the inverters are operated by the PWM control technique [9]. Then compared to the SPWM the total harmonic distortions are reduced in SVPWM [10]. The output of inverter is given to the IM. To get the good performance and speed controlling of the IM, the field oriented control technique is employed. The water pumping, a standalone application of the SPV array generated electricity is receiving wide attention now a days for irrigation in the fields, household applications and industrial use.

The starting, dynamic and steady state performances of an electronically commutated induction motor coupled with a water pump fed by SPV array-zeta converter are analyzed under the variation of atmospheric conditions through simulated results using MATLAB/Simulink and experimental validation.

II. PROPOSED SYSTEM CONFIGURATION

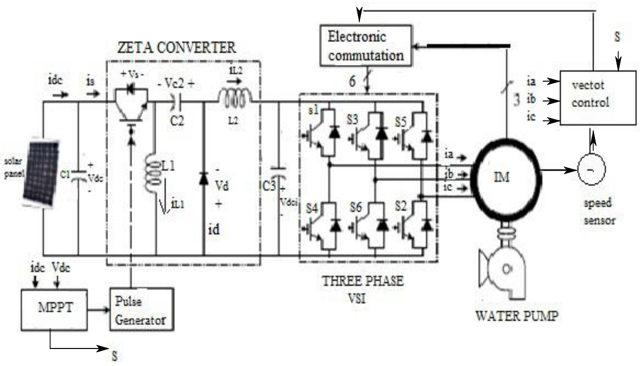

Fig.1 Configuration of the MPPT baded SPV array – Zeta converter fed Induction motor driven water pumping system

The configuration of the proposed solar PV based Zeta converter fed induction motor drive for water pumping is shown in Fig.1. From left to right, the proposed system consists of a solar PV array with MPPT algorithm, a Zeta DC-DC converter, a voltage source inverter (VSI) with SVPWM, Filed oriented control of induction motor and a centrifugal type of water pump. These features offer an increased simplicity of proposed system.

III. WORKING PRINCIPLE OF PROPOSED CONVERTER

As shown in Fig.1, the electrical energy generates by using solar PV array and feeds the DC-DC Zeta converter. The IGBT (Insulated Gate Bipolar Transistor) is the power semiconductor switch of the Zeta converter and the switch (turn on and turn off) must be operated through an MPPT algorithm of adaptive incremental conductance (AINC) method. So that the operation of the solar PV array is optimized and efficiency of the SPV array is increased and also the induction motor has a soft starting. The Zeta converter is always must be operated in continuous conduction mode only, so then the stress on the components and semiconductor device is reduced. Further, the Zeta converter feeds power to the VSI, supplying the induction motor employed to a centrifugal pump. Switching sequence of the VSI is provided by space vector pulse width modulation (SVPWM) technique with the help of field oriented control of induction motor. The design and the control of the proposed system are elaborated in the following sections.

IV. DESIGN OF PROPOSED SYSTEM

In the proposed system a SPV array with MPPT algorithm, a Zeta converter, VSI with SVPWM switching sequence and a induction motor employed to a water pump. As per the demand of the water pump load fed by the SPV array, the components of the SPV array, Zeta converter and the water pump are designed. A Induction motor of 5kW power rating is selected to drive a water pump and various components of the proposed system are designed accordingly as elaborated in the following sections.

A. *Design of SPV Array*

The rating of solar PV array depends upon the motor rating. Always the solar PV array rating is selected more than the motor rating, due to that the performance of the motor is unaffected by the losses in the converter and motor [11]. So that the solar PV array of 5.2 kW maximum power rating is designed to drive the 5kw induction motor drive. It consists of 36 cells in series connection are used to design the SPV array of maximum power rating, *Pmpp* = 5.2 kW at the standard value of solar insulation (1000 W/m2). The open circuit voltage of this module is 32.9V and the short circuit current of the module is 10.4 A. The maximum power that can be drawn from the system is given by,

$$P_{mp} = \left(N_S * V_{mpp}\right) * (N_P * I_{mpp}) \tag{1}$$

where,
P_{mp} = maximum power of module at MPP
V_{mpp} = maximum voltage of module at MPP
I_{mpp} = maximum current of module at MPP
Ns = series connected number of modules
Np = parallel connected number of modules

It has been observed that the maximum power must be collected at the voltage and current of a module at MPP is 85% of its open circuit voltage and short circuit current respectively. So, the voltage (*Vmpp),* Current, (*Impp)* and power, *P* of this module at MPP are 28 V, 8.85 A and 240 W respectively.

$$P_{mp} \approx \left(N_S * 0.85 * V_{oc}\right) * (N_P * 0.85 * I_{sc}) \tag{2}$$

Designing the open circuit voltage of the panel as 500V

$$I_{mpp} = \frac{5200}{500} = 10.4A \tag{3}$$

Numbers of modules required to connect in series are as,

$$N_S = \frac{V_{oc}\, of\ panel}{V_{oc}\, of\ cell} = \frac{500}{32.9} \approx 16 \quad (4)$$

Numbers of modules required to connect in parallel are,

$$N_P = \frac{I_{mpp}}{I_m} = \frac{10.4}{8.85} \approx 2 \quad (5)$$

Based on these calculations by connecting 16 modules in series and 2module in parallel, a 5.2 kW solar PV array is designed.

B. *Design of Zeta Converter*

The design of a Zeta converter [12] is consists of an input inductor (L_1), output inductor (L_2) and intermediate capacitor (C_2). These three components are designed, so that the zeta converter always operates in Continuous Conduction Mode resulting in reduced stress on its components and devices. An estimation of the duty cycle, *D* initiates the design of zeta converter which is estimated as

$$D = \frac{V_{dc}}{V_{dc} + V_{in}} = \frac{430}{430 + 102.5} = 0.807 \quad (6)$$

Here,

Zeta converter input voltage =102.5V

Output voltage = 430 V

For the design of this converter and analysis of the converter by using MATLAB/Simulink are used with the following Parameters:

Input-capacitance(C1)=0.75μF
internal resistance R=100 Ω
C2 = 0.1 μF
Inductance L1=0.06 mH
L2=0.06 mH

C. *Design of Water Pump*

Based on the rated speed and power of the induction motor a water pump is designed and selected. Since the rated speed, *Nrated* and power of the motor, *Pm* are 2000 rpm and 5kW respectively, *Kpump* is estimated as,

$$K_{pump} = \frac{T_{load}}{w_{rated}^{2}} = \frac{P_m}{w_{rated}^{3}} \quad (7)$$

$$K_{pump} = \frac{5000}{(2*\pi*2000/60)^3} = 5.45*10^{-4}\, w/(rad/\sec)^3$$

where, *Kpump* = Constant in W/(rad/sec)3

w_{rated} = mechanical speed of the IM in rad/sec

A suitable water pump with these data is selected for the proposed system.

V. CONTROL SCHEME FOR PROPOSED SYSTEM

In this proposed system only a single stage system which consists of only one power converter. Here two algorithms are implemented for maximum power point tracking (MPPT) and FOC of the cage IM respectively. MPPT algorithm calculates the reference speed to be fed into FOC algorithm and which intern determines the switching strategy for the VSI.

A. *Adaptive Incremental Conductance method for MPPT tracking*

Solar PV array has non-linear power versus voltage characteristics. There have been various online as well as offline tracking algorithms are discussed in section I (I. introduction). The simplest method is perturb and observe mechanism. In this method, the reference quantity which can be voltage, duty ratio or frequency is

perturbed until there is a positive change in the power. It suffers from inefficient performance at MPP due to continuous perturbation and power loss associated with it. AINC method takes advantage of the varying tangent of the power versus voltage curve. The slope of the curve is zero, negative and positive at MPP, right side and left side of MPP respectively [2].

$$P_k = V_k * I_k \tag{8}$$

$$\frac{dP_k}{dV_k} = I_k + V_k * \frac{dI_k}{dV_k} = 0 \tag{9}$$

from above equation it is clear that at MPP the slope of the P-V characteristic should be zero.

$$\frac{dI_k}{dV_k} = -\frac{I_k}{V_k} \tag{10}$$

Where, V_k = Instantaneous voltage
I_k = Instantaneous current

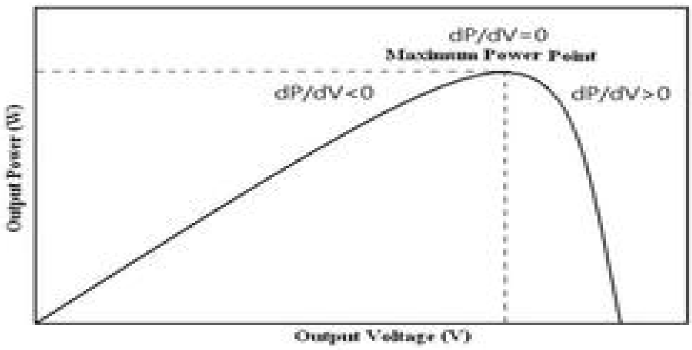

Fig.2 Incremental Conductance approach utilizing the slope of P-V curve

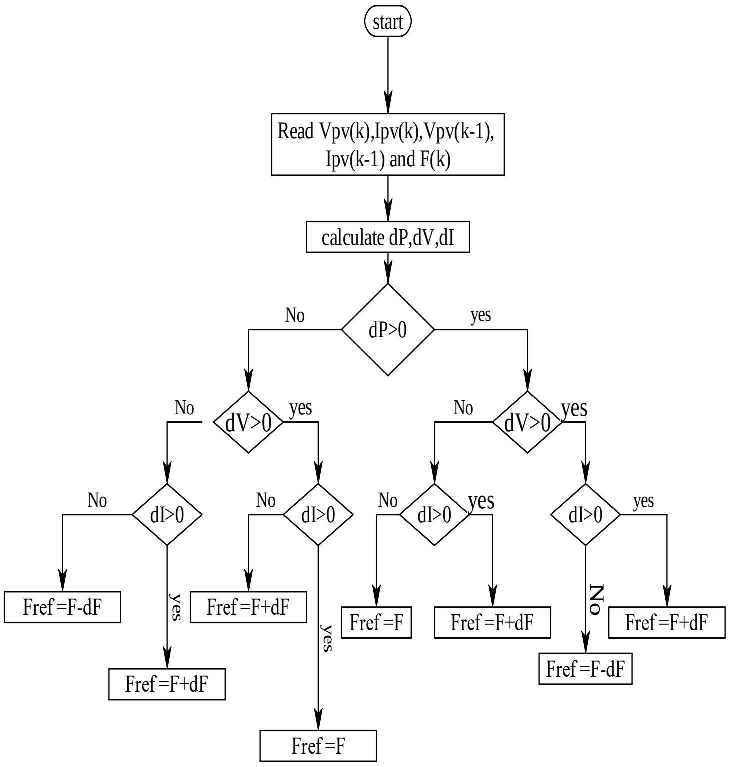

Fig.3 Frequency change according to the AINC algorithm [2]

In Fig. 2 on the right side of MPP, slope is negative which suggests that $\frac{dI_k}{dV_k} < -\frac{I_k}{V_k}$, and on the left side slope is positive meaning $\frac{dI_k}{dV_k} > -\frac{I_k}{V_k}$. At MPP slope is zero means that $\frac{dI_k}{dV_k} = -\frac{I_k}{V_k}$. Based on the AINC approach Fig. 3 shows method to perturb the reference frequency to be given to FOC algorithm. Inputs to the MPPT algorithm are sampled PV voltage and current. Moreover, with decrease in slope the step in frequency is also reduced for better dynamic performance and minimizing power losses.

B. *Field oriented control of IMD*

The primary vector control parameters, i_{ds}^* and i_{qs}^*, which are the DC components used in synchronously rotating frame, are transformed into stationary frame with the help of a standard unit vector ($\cos\theta_e$ & $\sin\theta_e$) generated from flux vector signals ψ_{dr}^s and ψ_{qr}^s. The obtained stationary frame components are then transformed to phase current commands for the inverter. The flux signals ψ_{dr}^s and ψ_{qr}^s are being generated from the machine terminal voltages and currents with the help of voltage model estimator. The torque component of current i_{qs}^* is generated from the speed control loop through a bipolar limiter. The torque proportional to i_{qs} (with constant flux), can be bipolar. It is negative with negative i_{qs} and correspondingly, the phase position of i_{qs} becomes negative. The error of the reference speed and actual speed of the IMD is gives the Torque reference. The actual speed of the induction motor can be sensed from tachogenerator. The difference of the both speeds is fed to PI controller which minimizes the error and provides torque reference. An Additional torque control loop can be added within the speed loop, if desired [13]-[15].

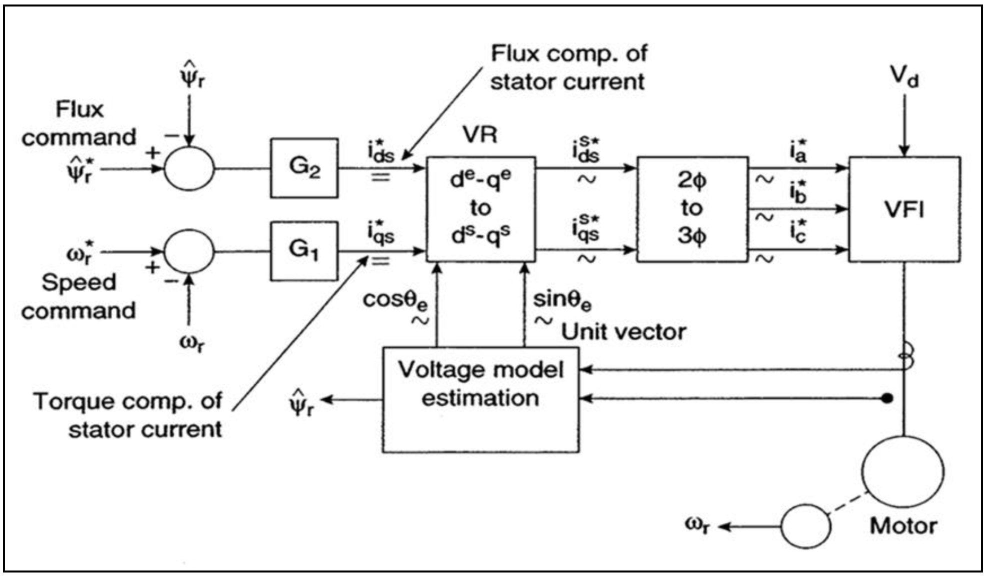

Fig.4. Direct vector control with rotor flux orientation[3]

Finally, by using fig.3 we get the electromagnetic torque of the IM is given by,

$$T_e = \frac{3}{2}\left(\frac{p}{2}\right)\frac{L_m}{L_r}(\Psi_{dr}^s i_{qs}^s - \Psi_{qr}^s i_{ds}^s) \qquad (11)$$

For analysis using MATLAB/Simulink, 5KW, 4-pole three phase induction motor are used with the following Parameters:

Stator Resistance, Rs = 2.65 ohms
Rotor resistance, Rr = 2 ohms

Stator inductance, Ls = 301.4 mH
Rotor inductance, Lr = 306.5 mH
Mutual inductance, Lm = 291.1 mH
Number of poles, P = 4
Inertia constant, J = 0.0055 kgm^2/sec
Frequency, F =50 Hz
Rated voltage, V= 600 V
Rated power, P =5KW

VI. RESULTS AND DISCUSSION

The performance of the proposed configuration of solar photovoltaic fed filed oriented vector controlled for water pumping is modeled and its simulation has been performed in MATLAB/ Simulink using Sim Power System toolbox. In this section, performance of the drive is analyzed in starting, steady state and with solar radiation based on the simulated results. For analysis using MATLAB/Simulink, 5KW, 4-pole three phase induction motor are used. The following simulated results show that the system performs quite satisfactorily.

A. Input voltage to zeta converter from solar PV

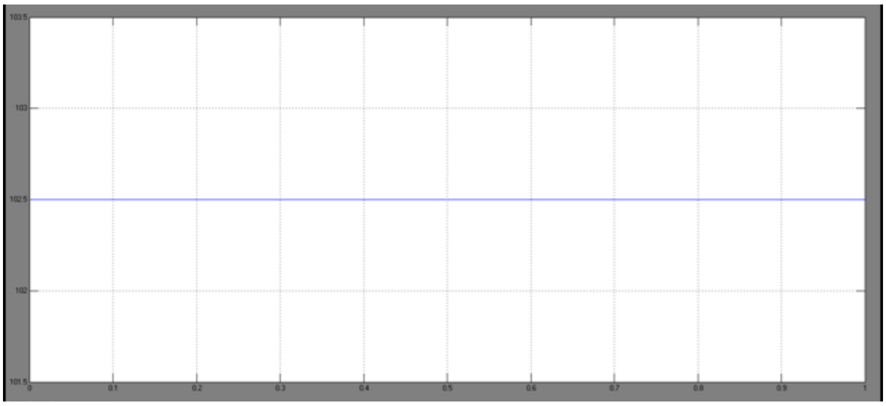

Fig.5 input voltage of zeta converter

The input voltage of proposed zeta converter is DC voltage from solar PV array. The input voltage of converter is 102.5V. The input voltage of zeta converter is variable and the output voltage is constant.

B. Output voltage of zeta converter

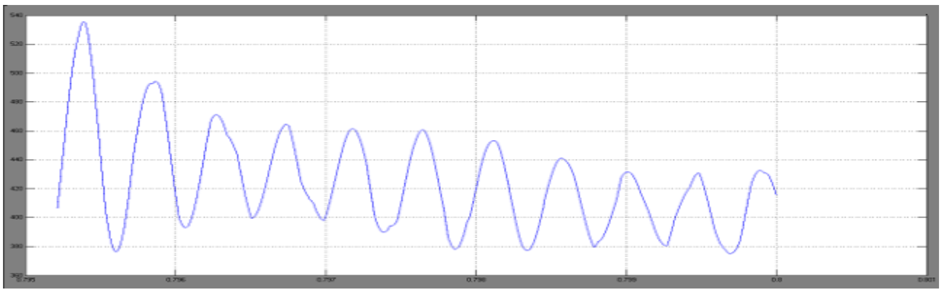

Fig.6 output voltage of zeta converter (i.e. input to the VSI)

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C. *Voltage source inverter output*

The Voltage source inverter input is 415 DC voltage. This voltage is converted into 415 AC voltage and supplied for driving the Induction Motor. The switching operation of VSI, PWM signals are given to gate terminal of IGBT switches from Electronics Commutation.

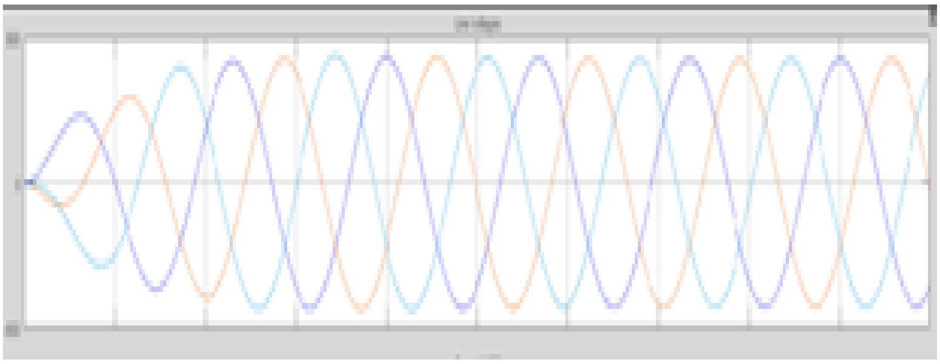

Fig.7 Output voltage waveforms of VSI

D. Performance of an Induction Motor

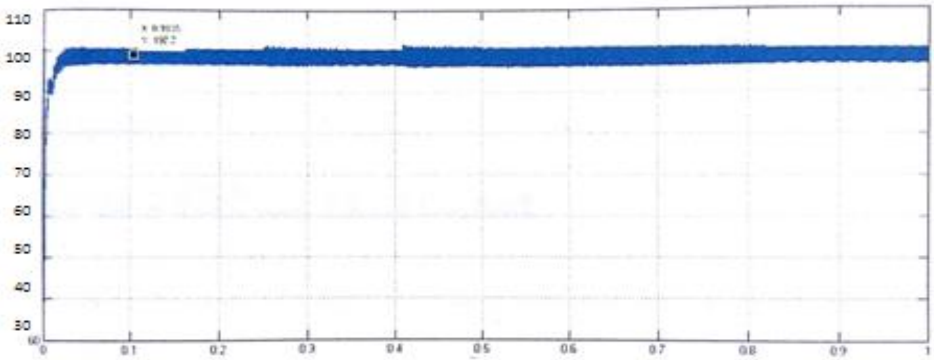

Fig.8 Solar PV array output Voltage

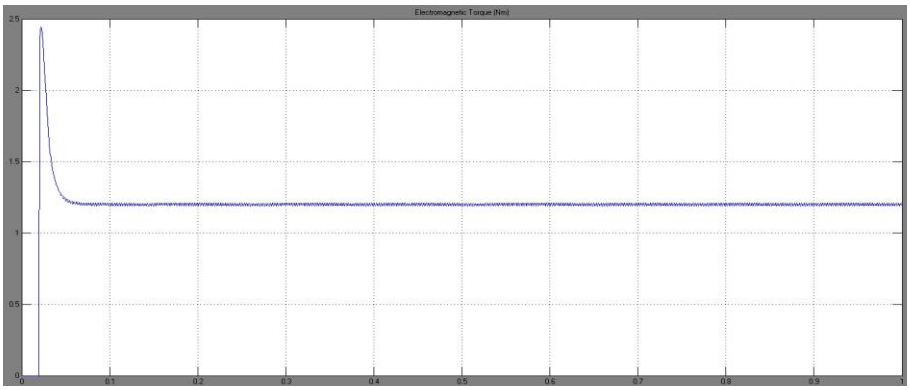

Fig.9 Electromagnetic torque waveform of steady state model

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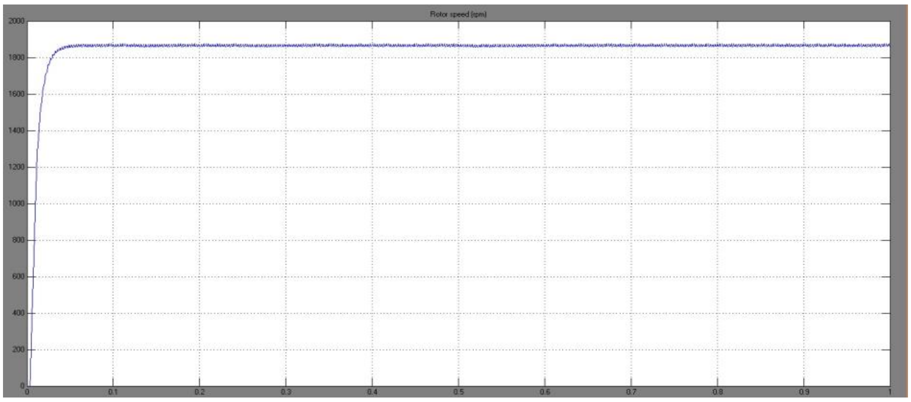

Fig.10 IM speed waveform of steady state model

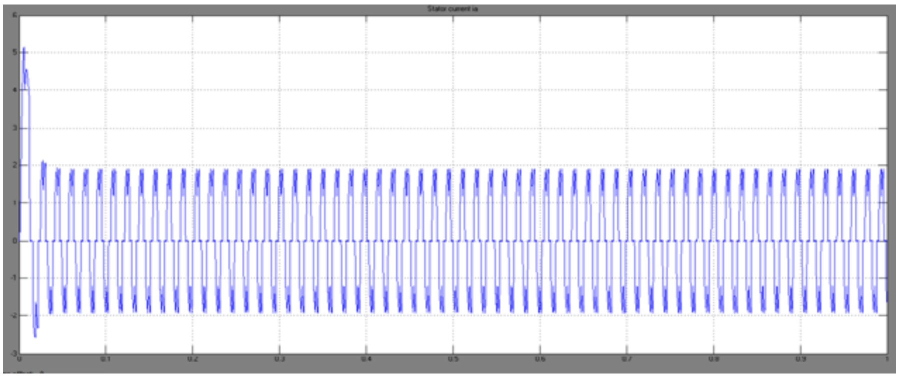

Fig.11 IM stator current wavefors

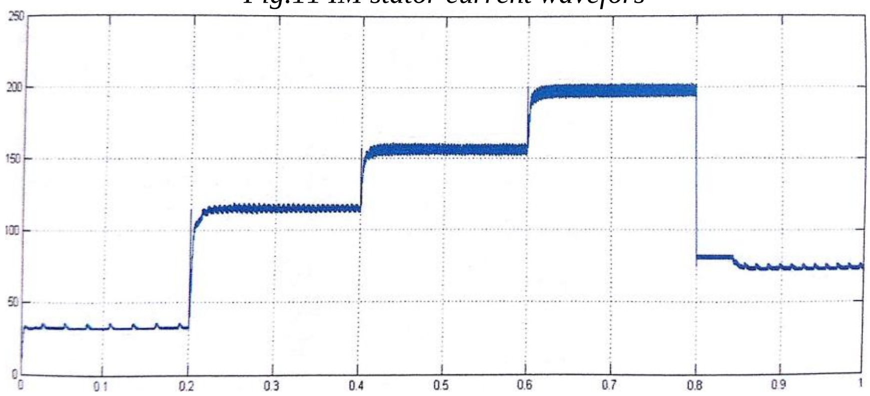

Fig.12 Dynamic performance of Solar PV array voltage waveform

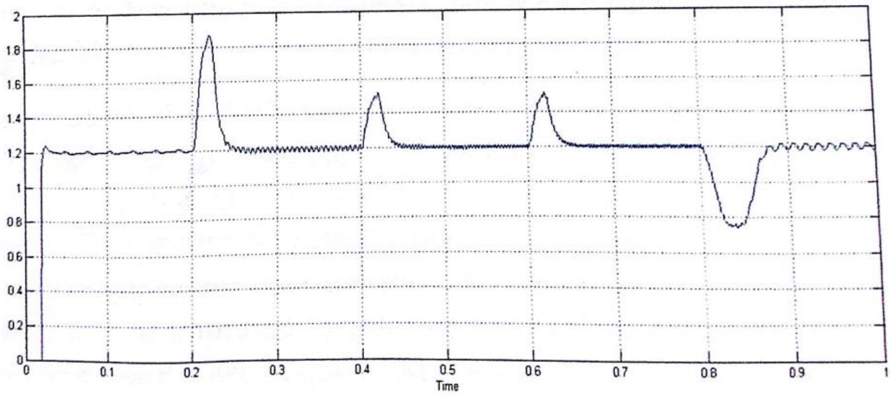

Fig.13 Dynamic performance of Electromagnetic torque waveform of IM

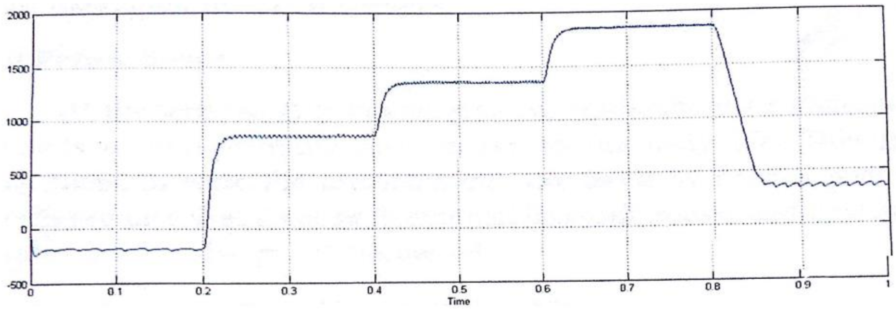

Fig.14 Dynamic performance of speed waveform of IM

VII. CONCLUSION

The subsystems of proposed scheme such as PV array model, ZETA converter and induction motor with filed oriented vector control model have been built and tested individually. And also A maximum power point tracking algorithm has been incorporated. Finally, by Integrating these subsystems, an elaborate Simulink schematic of a solar PV array based zeta converter fed field oriented induction motor drive system, that is capable of simulating typical problems, connected with a high performance digital controlled drive has been proposed. Taking the major advantages of very good and high conversion efficiency of zeta converter, the induction motor and centrifugal pump, a suitable water pumping system based on solar PV array has been developed. The simulation studies of the proposed scheme have been carried out and the results are furnished.

References

[1] Sachin Jain and Vivek Agarwal,A Single-Stage Grid Connected Inverter Topology for Solar PV Systems With Maximum Power Point Tracking IEEE Transactions On Power Electronics, Vol. 22, No. 5, September 2007.
[2] Utkarsh Sharma, Shailendra Dwivedi, Chinmay Jain, Bhim Singh, “Single Stage Solar PV Array Fed Field Oriented Controlled Induction Motor Drive for Water Pump”, IEEE 1st International Conference on Power Electronics, Intiligent Control and Energy systems (ICPEICES), 2016.
[3] B. K.Bose, “Modern Power Electronics and AC Drives,” Prentice Hall, 2002.
[4] R. Krishnan, “Electrical Motor Drives Modelling, Analysis and Control,” Prentice Hall, 2006.
[5] Adrian Szabo, Mohan Kansara, Edward Stephen Warda, “A General Approach For the Study Of Dc-Dc Converters” Proceeding of the 6th International Conference on optimization of Electrical and Electronic Equipment.vol.2 pp. 325-330, year 1998.
[6] S.Karthika,S.Vijay Shankar , “A Zeta Converter Fed Induction Motor Drive For Solar PV Array Based Water Pumping”, International Conference on Emerging trends in Engineering, Science and Sustainable Technology (ICETSST-2017), E-ISSN: 2348 – 8379.
[7] Rajan Kumar, Bhim Singh, Ambrish Chandra, Kamal Al-Haddad, “Solar PV Array Fed Water Pumping Using BLDC Motor Drive with Boost-Buck Converter”, IEEE Energy Conversion Congress and Exposition (ECCE), 978-1-4673-7151-3/15/$31.00 ©2015 IEEE
[8] Abhishek Jain, M.Sai Ganesh, “BLDC Motor Driven Solar PV Array Fed Water Pumping System Employing Zeta Converter”, International Journal & Magazine of Engineering, Technology, Management and research, march-2017, ISSN No: 2348-4845.
[9] Kim, L.H., Hahm, N.k., Lee, W.C., et al. ‘Analysis of a new PWM method for conducted EMI reduction in a field oriented controlled induction motor’. Applied Power Electronics Conf. and Exposition, 2006. APEC ’06, 2006, pp. 204–210
[10] Renge, M.M., Suryawanshi, H.M.: ‘Three-dimensional space-vector modulation to reduce common-mode voltage for multilevel inverter,” IEEE Trans. Ind. Electron., 2010, 57, (7), pp. 2324–2331.
[11] M.Abu-Aligah, “Design of Photovoltaic Water Pumping System and Compare it with Diesel Powered Pump”, Jordan Journal of Mechanical and Industrial Engineering (JJMIE), Volume 5, Number 3, June 2011 ISSN 1995-6665 Pages 273 - 280
[12] N. Sowmya Smitha Raj, Smt. B. Urmila, “PV fed Zeta converter”, International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com Vol. 3, Issue 4, Jul-Aug 2013, pp.2692-2696

[13] F. Blaschke, "The principle of field orientation as applied to the new transvector closed loop system for rotating field machines," Siemens Review, vol. 34, pp. 217-220, May 1972.
[14] P. C. Krause, "Analysis of Electrical Machinery," McGraw-Hill Book Company, 1986.
[15] Rajan Kumar, Bhim Singh, "Buck-Boost Converter Fed BLDC Motor Drive for Solar PV Array Based Water Pumping", 2014 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), 978-1-4799-6373-7/14/$31.00 ©2014 IEEE
[16] Saurabh Shukla, Bhim Singh "Single Stage SPV Array Fed Speed Sensorless Vector Control of Induction Motor Drive for Water Pumping" 1st IEEE International Conference on Power Electronics. Intelligent Control and Energy Systems (ICPEICES-2016).