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Zeta Converter Driving a PMSM for Electric Boat using Solar PV Array

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Abstract—**The main objective of the proposed system is meant for designing a zeta converter driving a PMSM for electric boat using solar PV array. Solar energy is a renewable energy which can be extract from the nature. In recent days solar PV fed water pumping has increasing largely due to available solar energy. Zeta converter is a DC-DC converter which has variable input voltage and constant output voltage. The ripple in DC output is reduced while using zeta converter. The DC ripple currents are also reduced in Zeta converter. The DC voltage is converted to AC using PWM inverter and then permanent magnet synchronous motor was drived. The peak voltage from the solar cells is detected using IncCond MPPT algorithm. Simulation and experimental results are presented to verify zeta converter fed PMSM motor drive for solar PV array based water pumping using MATLAB-SIMULINK.**

***Keywords*— Zeta-converter, MPPT, PV-array, Permanent Magnet Synchronous Motor**

I. INTRODUCTION

For extracting as much energy as possible from photovoltaic (PV) modules, the energy utilization needs to be improved, as well as power conversion efficiency of converters. Renewable energy sources are becoming an alternative source for cleaned and for generating the sustainable electricity in which photovoltaic (PV) systems have gaining advantages mainly due to increasing efficiency of the modules, cost is reduced and political incitement. PV modules have strong dependence on radiation of solar and temperature of the surface hence it cannot have a specified voltage or current across its terminals.

The Maximum Power Point (MPP) is used as operation point in order to avoid extreme PV output power oscillations and ensure its operation with the highest efficiency (given a solar radiation and temperature condition). For ensuring PV systems operation on the MPP, specific circuits named by Maximum Power Point Trackers (MPPT) are employed.

In most of application, a MPPT is achieved thought hardware block (dc-dc converter), software block (a tracking algorithm) and usually voltage, current or both (external sensors). Perturb and Observe (P&O) and Incremental conductance (IncCond) are the most commonly employed tracking algorithms from the software view point. P&O method is simple, however it failure to track the maximum power point under abrupt changes on radiation of solar and presence of oscillations around the MPP on steady-state.

Inc Cond technique is accurate but implementation is more complex, and it is similar to the P&O method, it needs a sensors (voltage and current sensors) for properly work be capable of meeting the demanding reliability and performance criteria required. On the other hand, a zeta converter has the following advantages over the conventional buck, boost, buck-boost converters and Cuk converter when employed in Solar PV array based applications.

- Belonging to a family of buck-boost converters, the zeta converter may be operated either for increasing or decreasing the output voltage.
- This property offers a boundless region for maximum power point tracking (MPPT) of a SPV array.
- This property also facilitates the soft starting of Permanent magnet synchronous motor unlike a boost converter which will steps up the input voltage level, hence boost converter not ensuring soft starting.
- Unlike a classical buck-boost converter, the zeta converter has a continuous current output.
- The output current in the inductor is continuous and also free from ripple.

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- The zeta converter components and the Cuk converter components numbers are same.
- The zeta converter can be operated as non-inverting buck-boost converter unlike an inverting buck-boost and Cuk converter.
- For reducing the complexity of system responses negative voltage sensing circuits are required. These merits of the zeta converter are favourable for proposed SPV array Electric boat.

II. CONFIGURATION OF PROPOSED SYSTEM

A zeta converter is used here for extracting the maximum power available from a SPV array and speed control of PMS motor coupled with electric boat. Zeta converter offers a boundless region for MPPT and the efficiency is good compared with other converters due to single switch. This converter is operated in continuous conduction mode reduces the stress on its semiconductor devices and components. Furthermore, the switching loss of VSI is reduced by adopting fundamental frequency switching resulting in an additional power saving and hence an enhanced efficiency. The phase currents as well as the DC link voltage sensors are completely eliminated, offering simple and economical system without scarifying its performance. The speed of permanent magnet synchronous motor is controlled, without any additional control, through a variable DC link voltage of VSI. By proper initialization of MPPT algorithm of SPV array the PMSM is started. These are the increased features of proposed system.

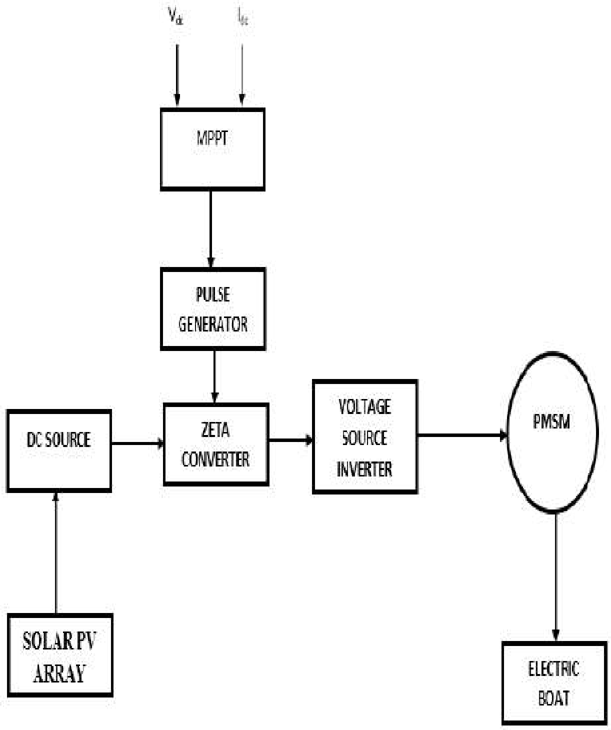

Fig. 1 Block diagram of proposed system

III. OPERATION OF THE PROPOSED SYSTEM

The advantages and desirable features of converter and PMS motor drive is used because it is simple, efficiency is good, cost is economical and it is reliable while using in electric boat which is based on solar PV energy. Simulation results using MATLAB/Simulink and experimental performances are examined to demonstrate the starting, dynamics and steady state behaviour of proposed system subjected to practical operating conditions. The SPV array and PMS motor are designed such that proposed system always exhibits good performance regardless of solar irradiance level

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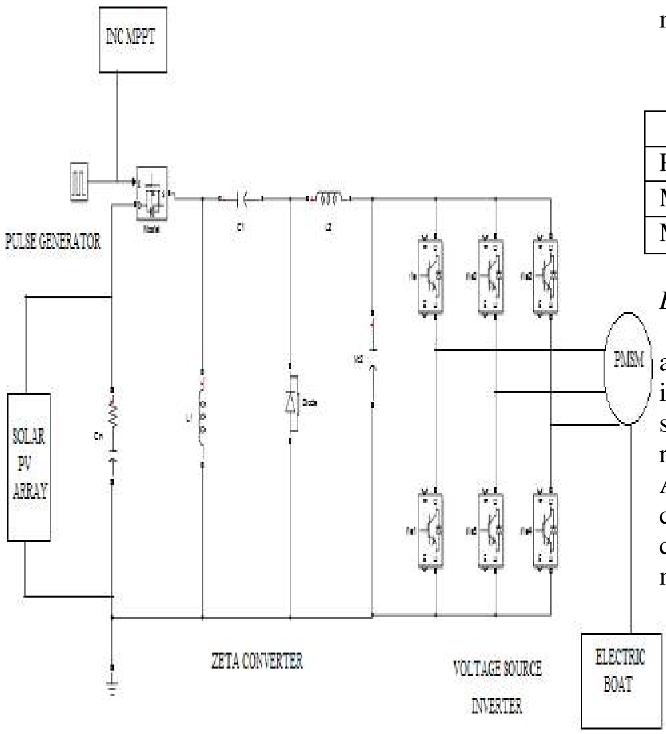

Fig.2. Operation of zeta converter

The VSI, converting DC output from a zeta converter into AC, feeds the PMS motor to drive an electric boat. The VSI is operated in fundamental frequency switching by sensing the speed of the motor.. The high frequency switching losses are thereby eliminated, contributing in an increased efficiency of proposed system.

IV. DESIGN OF THE PROPOSED SYSTEM

The various operating stages of the configuration are shown in fig. 1 such as the solar PV array, the zeta converter, the VSI and the PMSM are designed such that a satisfactory operation is always accomplished under any kind of change in solar insulation level. An Induction motor of 4 kW rated power is selected for a centrifugal water pump of 1 kW power rating. According to the selected power ratings, each stages of the proposed system are designed as follows.

A. Design of Solar PV array

The practical converters are associated with various power losses. The motor pump set also introduces the electrical and mechanical losses. To compensate these losses, the size of SV array is selected with slightly more peak power capacity to ensure the satisfactory operation regardless of power losses. A solar PV array of 1 kW peak power capacity, somewhat more than required by the motor, is selected so that the performance of the system is not affected by the losses associated with the converters and the motor.

TABLE – I

Design Of Solar PV Array	
PV array Input voltage	96.87 V
MPPT voltage (V)	96.87 V
MPPT current (I)	2.1 A

B. Design of Zeta Converter

The Zeta converter is the next design process consists of an estimation of input inductor, *L1*, output inductor, *L2* and intermediate capacitor, *C1*. These components are designed such that the zeta converter always operates in CCM 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, the duty cycle of the zeta converter is calculated using dc input voltage and the maximum voltage from the MPPT and the value of D is

$$D = \frac{Vdc}{Vdc + Vm} = \frac{560}{560 + 96.87} = 0.853$$

Table-II

Zeta Converter	
Input voltage (V)	96.87 (V)
Output voltage (V)	552 (V)

The components used in the zeta converter are two inductors, two capacitors, two resistors and their values are tabulated below in the table.

Table-III

Zeta converter components value	
C_{in}	R=0.001 Ω C=0.02 mF
L_1	0.0013 mH
L_2	0.0013 mH
C_1	0.1 mF
VC_1	0.2 mF
VC_2	100 Ω

C. Design of voltage source inverter

The voltage source inverter is designed next to zeta converter. A new design approach for estimation of DC link capacitor of VSI is presented here. This approach is based on the fact that 6th harmonic component of the supply (AC) voltage is reflected on the DC side as a dominant harmonic in the three phase supply system [3].Here, the fundamental frequencies of output voltage of the VSI are estimated corresponding to the rated speed and the minimum speed of Induction motor essentially required to pump the water. These two frequencies are further used to estimate the values of their corresponding capacitors. Out of these two estimated capacitors, larger one is selected to assure a satisfactory operation of proposed system even under the minimum solar irradiance level. The fundamental output frequency of VSI corresponding to the rated speed of PMS motor is estimated as is given as:

$$\omega_{rated} = 2\Pi f_{rated} = 2\Pi \frac{N_{rated} * P}{120} = 2\Pi \frac{5000}{120} = 262\ rad/sec$$

D. Design of PMS motor

The induction motor designed for coupling with the pump. The power rating, voltage, speed, frequency of the PMS motor as shown in Table –IV. The 1kw PMS motor is used for coupling with the electric boat. The torque value of the motor is 7.14 NM. The frequency of the motor is 262 rad/sec. PMS motor RPM is given as 5000 rpm and the number of phases is 3. The rated frequency is 50 Hz.

TABLE-IV

PMS Motor Rating	
Phase	3
Voltage	560 V
Speed	5000 RPM
Frequency	50 Hz

V. SIMULATION AND RESULTS

The FIG. (3) Below, shows the simulated schematic diagram of the complete designing of PMSM Driven Solar PV Array Fed Electric Boat Employing Zeta Converter. The modeling and simulation of the whole system has been done in MATLAB-SIMULINK.

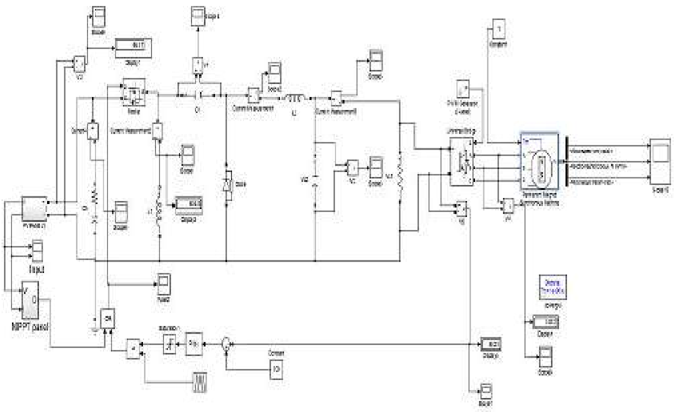

Fig.3. Simulink model of PMSM Driven solar PV array fed electric boat employing zeta converter.

A. Input voltage of zeta coverter

The input voltage to zeta converter is DC voltage from solar PV array. The input voltage of zeta converter is 96.87 V. The input voltage of zeta converter is variable and the output voltage is constant.

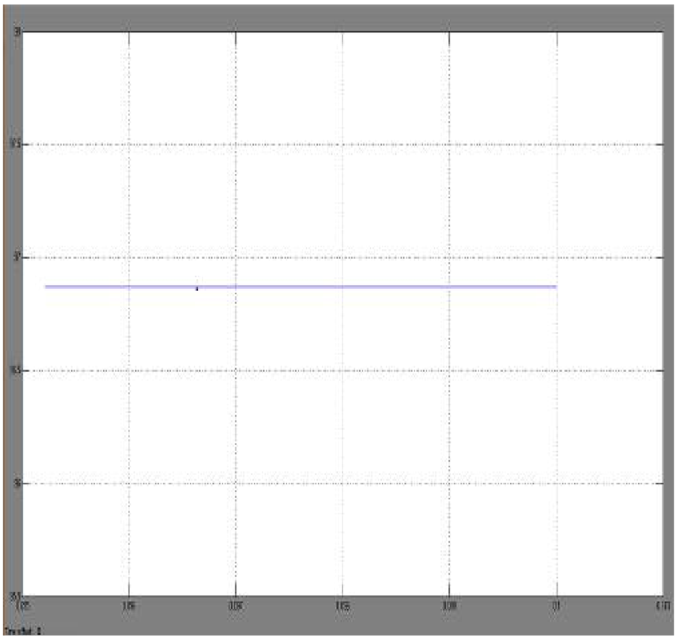

Fig.4. Input voltage to zeta converter

B. Output voltage of zeta coverter

The output voltage of the zeta converter is 415 V. The input voltage from the SPV array is boosted and the output is increased.

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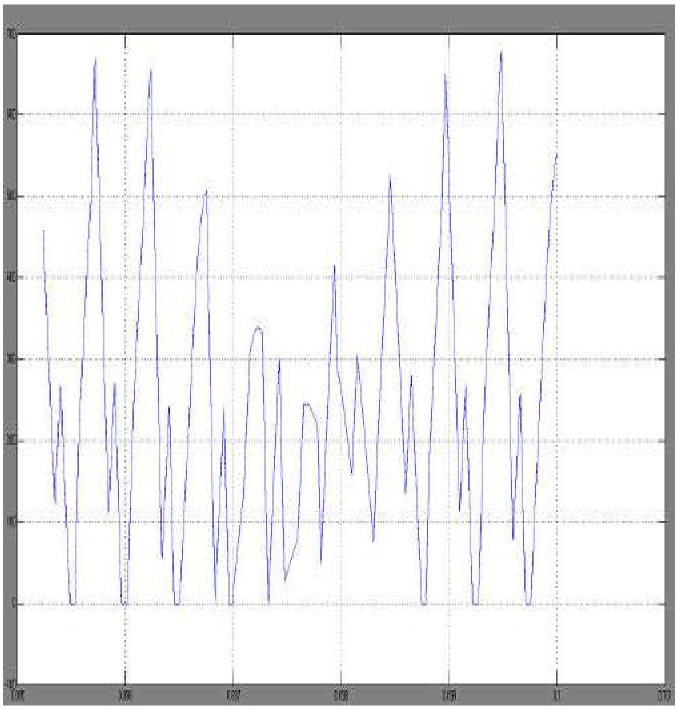

Fig.5. output voltage of zeta converter

C. voltage source inverter output

The VSI converts 552 DC voltage to 552 AC supply for driving the PMS Motor. PWM signals are given to gate terminal for PWM output voltage.

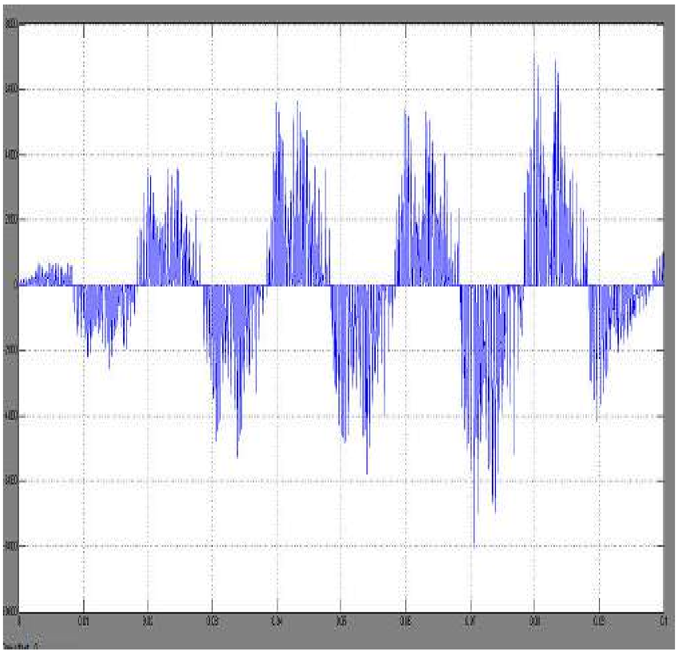

Fig.6. output waveform for VSI

D. Output waveforms for induction motor

The output waveforms of induction motor are given below (a) Rotor Speed, (b) Electromagnetic Torque, (c) Rotor angle.

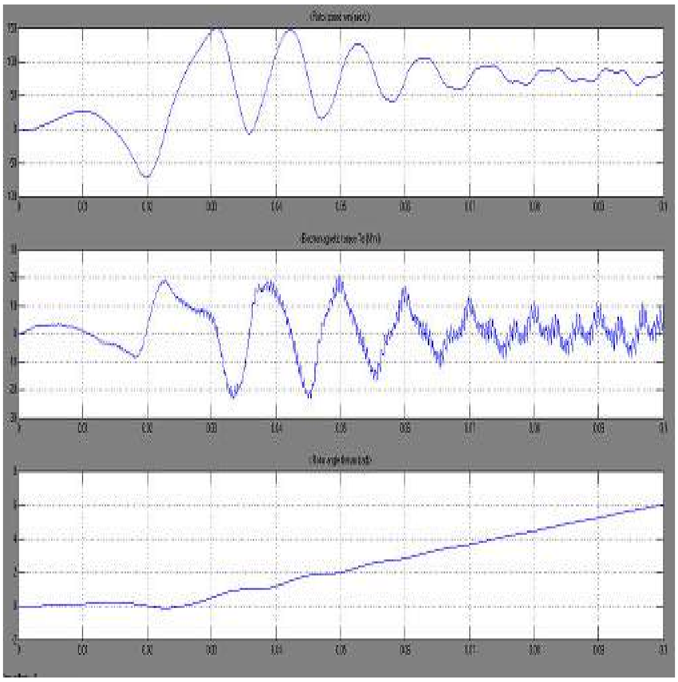

Fig.7. output waveforms of PMSM

VI. CONCLUSION

The transient, dynamic and steady state behaviors of the proposed Zeta Converter Driving a PMSM for Electric Boat using Solar PV Array have been evaluated. The proposed system has been modeled, designed and simulated in MATLAB/Simulink environment. The flexibility of increasing and decreasing the voltage level and hence does not possess a limited region of MPPT was provided by the DC-DC zeta converter. Taking the advantages of very good conversion efficiency of zeta converter, the PMS motor based on solar PV array for electric boat has been developed. The proposed system is designed brightly, such that the performance is not affected by the weather condition and efficiency limitations of the converters and motors. Using the simulated results, a zeta converter with the PMS motor drive is proved as a suitable combination for solar PV based electric boat.

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