

Solar PV Array Fed Zeta Converter Controlled BLDC Motor Based Water Pumping System

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Abstract - This paper proposes a simple, cost effective and efficient brushless DC (BLDC) motor drive for solar photovoltaic (SPV) array fed water pumping system. A zeta converter is utilized in order to extract the maximum available power from the SPV array. The proposed control algorithm eliminates phase current sensors and adapts a fundamental frequency switching of the voltage source inverter (VSI), thus avoiding the power losses due to high frequency switching. No additional control or circuitry is used for speed control of the BLDC motor. The speed is controlled through a variable DC link voltage of VSI. An appropriate control of zeta converter through the proportionate integral maximum power point tracking (PI-MPPT) algorithm offers soft starting of the BLDC motor. The proposed water pumping system is designed and modeled such that the performance is not affected under dynamic conditions. The suitability of proposed system at practical operating conditions is demonstrated through simulation results using power sim followed by an experimental validation.

Keywords: Zeta Converter, BLDC, Motor, Pump, Voltage Source Inverter, Solar, PV array.

I. INTRODUCTION

Drastic reduction in the cost of power electronic devices and annihilation of the fossil fuels in near future invite to use the solar photovoltaic (SPV) generated electrical energy for various applications as far as possible. 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 usage.

Although the several researches have been carried out in the area of SPV array fed water pumping, combining various DC-DC converters and motor drives, the zeta converter in association with the permanent magnet brushless DC (BLDC) motor is still unexplored to develop such kind of system. However, the zeta converter has been used in some other SPV based applications.

II. PROPOSED SYSTEM

Proposed SPV array fed water pumping system with an incremental conductance (INC) MPPT algorithm is used to operate the zeta converter such that the SPV array always operates at its MPP and the BLDC motor experience a reduced current at the starting.

A three phase voltage source inverter (VSI) is operated by fundamental frequency switching for the electronic commutation of BLDC motor. Simulation results using MATLAB/Simulink software is examined to demonstrate the starting, dynamics and steady state behavior of the proposed water pumping system subjected to the random variation in the solar irradiance. The SPV array is designed such that the proposed system always exhibits satisfactory performance regardless of the solar irradiance level or its variation.

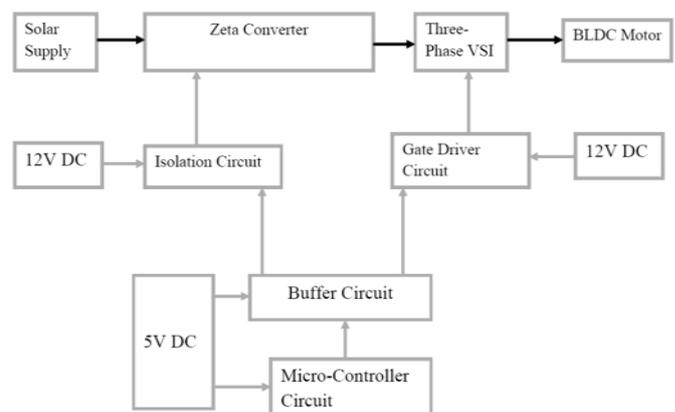


Figure 1: Block Diagram of Proposed System

III. SYSTEM DESIGN

The proposed system consists of (left to right) a SPV array, a zeta converter, a VSI, a BLDC motor and a water pump. The SPV panel converts solar radiation into electrical power that is fed to the ZETA DC-DC converter. The SPV array appears as a power source for the zeta converter. The voltage is boosted and power is transferred from the output of zeta converter which is the input source for the VSI. A maximum power point tracker (MPPT) is used for extracting the

maximum power from the solar PV module and transferring that power to the load. The MPPT algorithm uses voltage and current as feedback from SPV array and generates an optimum

value of duty cycle. The pulse generator generates, through INC-MPPT algorithm, switching pulses for IGBT (Insulated Gate Bipolar Transistor) switch of the zeta converter.

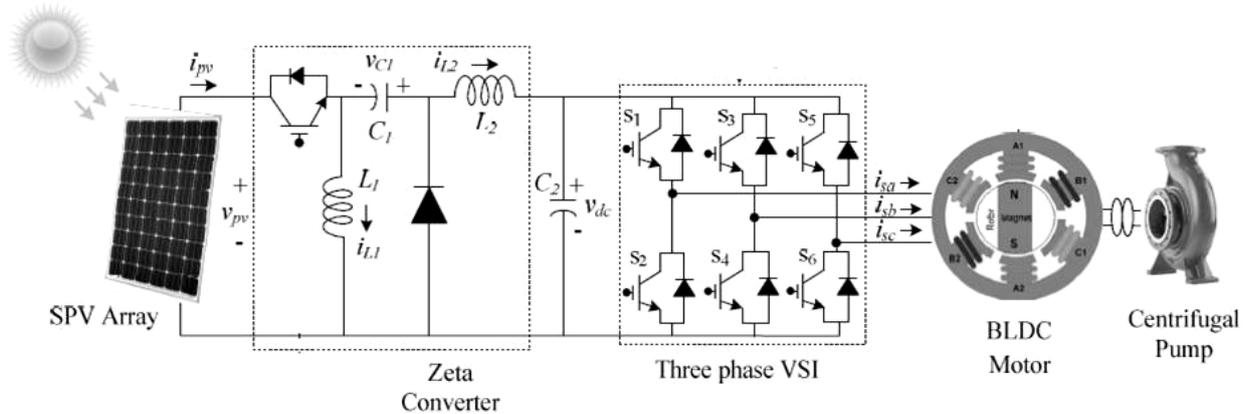


Figure 2: Circuit Diagram of Proposed System

The gate pulses used to operate the zeta converter is supplied by a microcontroller. Further, it generates actual switching pulse by comparing the duty cycle with a high frequency carrier wave. The VSI is operated in fundamental frequency switching by sensing the speed of the BLDC motor with an inbuilt encoder. The high frequency switching losses are thereby eliminated, contributing in an increased efficiency of proposed water pumping system. The VSI, converting DC output from a zeta converter into AC, feeds the BLDC motor to drive a water pump coupled to its shaft.

The input voltage to zeta converter is DC voltage from solar PV array. The input voltage of zeta converter is 12V. The input voltage of zeta converter is variable and the output voltage is constant. The output voltage of the zeta converter is 24V. The input voltage from the SPV array is boosted and the output is increased. The VSI converts 24 DC voltages to 3-phase 24 AC supply for driving the BLDC Motor.

A zeta converter is utilized in order to extract the maximum power available from a SPV array, soft starting and speed control of BLDC motor coupled to a water pump. Due to a single switch, this converter has very good efficiency and offers boundless region for MPPT. This converter is operated in continuous conduction mode (CCM) resulting in a reduced stress on its power 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 BLDC motor is controlled, without any additional control, through a variable DC link voltage of VSI.

Moreover, a soft starting of BLDC motor is achieved by proper initialization of MPPT algorithm of SPV array. These features offer an increased simplicity of proposed system. The SPV array and BLDC motor are designed such that proposed system always exhibits good performance regardless of solar irradiance level.

3.1 Control Methodology

The proposed system is controlled at two stages. These two control techniques namely; MPPT and electronic commutation are discussed in brief as follows.

3.1.1 INC-MPPT Algorithm

An efficient and commonly used INC-MPPT technique in various SPV array based applications is utilized in order to optimize the power available from the SPV array and to facilitate the soft starting of the BLDC motor. Selecting an optimum value of perturbation size ($DD = 0.001$) not only avoids the oscillations around the MPP but provides the soft starting of the BLDC motor also. An intellectual agreement between the tracking time and the perturbation size is held to fulfill the objectives.

3.1.2 Electronic Commutation

The BLDC motor is controlled by the VSI operated through the electronic commutation of BLDC motor. 6 switching pulses are generated as per the various possible combinations of 3 Hall-effect signals. These 3 Hall-effect signals are produced by the inbuilt encoder according to the rotor position. A particular combination of the Hall-effect signal is produced for specific range of rotor position. The electronic commutation provides fundamental frequency

switching of the VSI, hence the losses associated with the high frequency switching is completely eliminated.

IV. RESULT & DISCUSSIONS

The PV array fed zeta converter fed VSI-BLDC motor-pump has been proposed and its suitability has been demonstrated through practical validation. The proposed system has been designed and modeled appropriately to

accomplish the desired objectives and validated to examine various performances under starting, dynamic and steady state conditions. The zeta converter quickly changes its mode of operation following the validated to examine various performances under starting, dynamic and steady state conditions. The performance evaluation has justified the combination of zeta converter and BLDC motor for SPV array based water pumping.

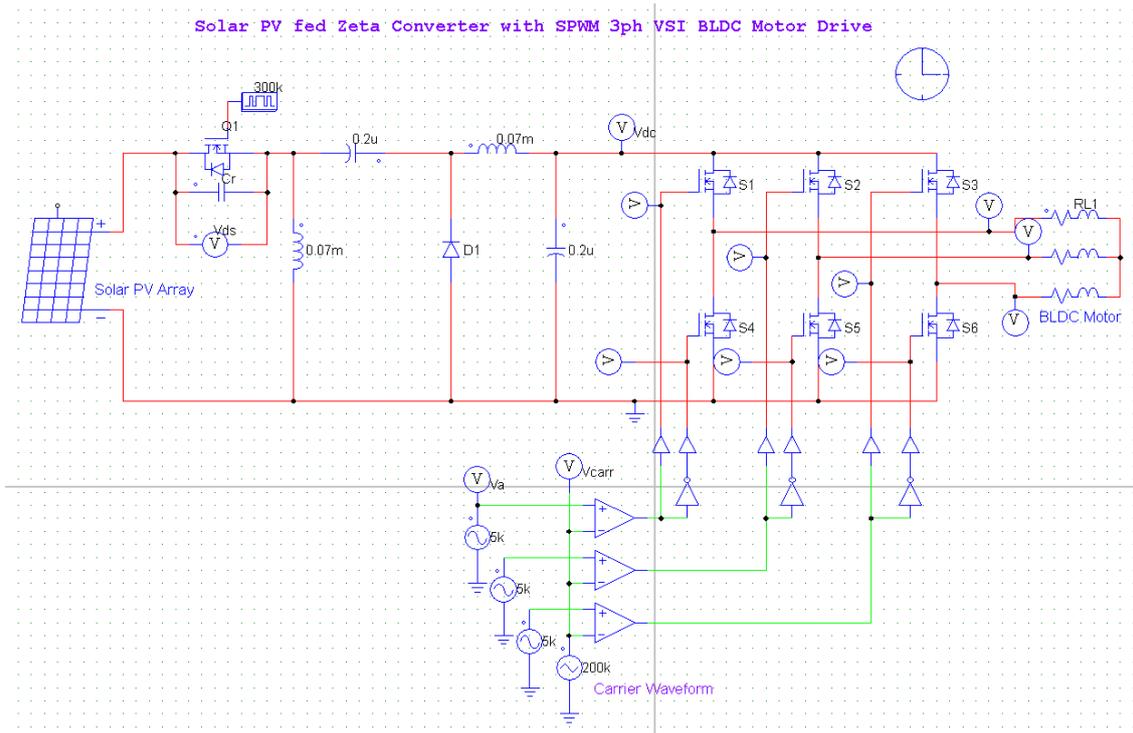


Figure 3: Solar PV Zeta Converter BLDC Motor Drive Circuit

4.1 Outputs of the Three Phase Sinusoidal PWM

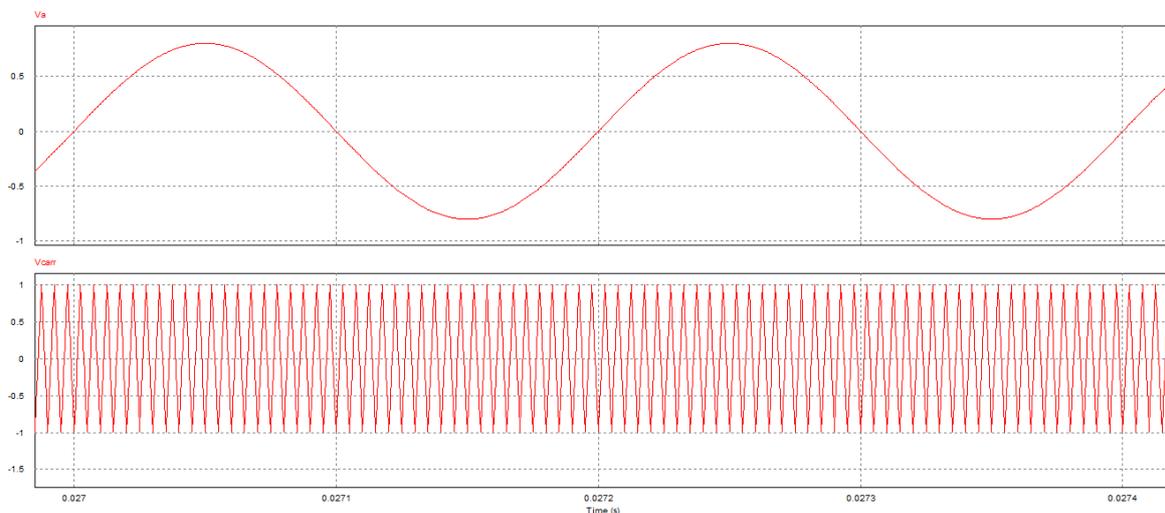


Figure 4: Carrier Generation

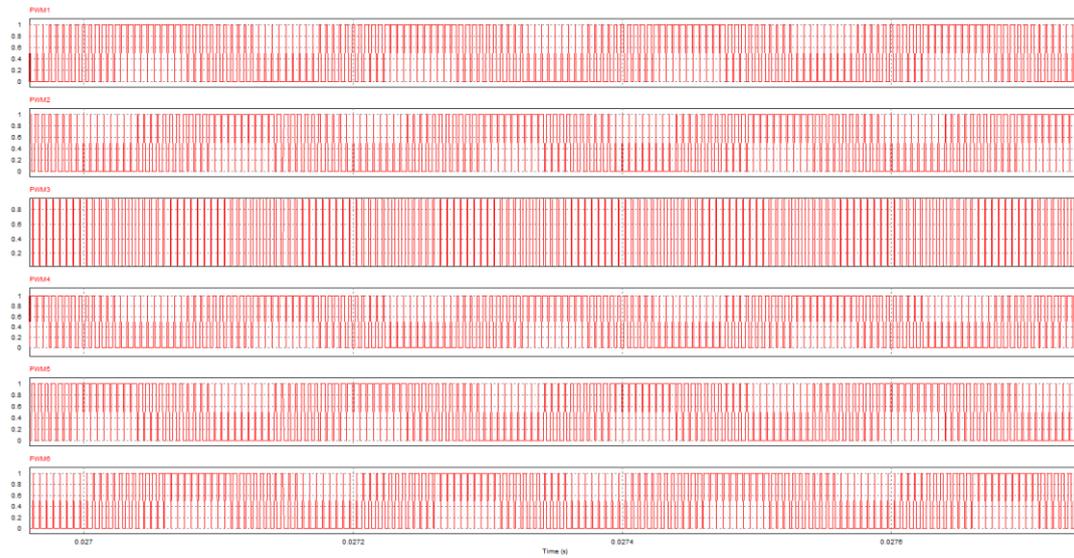


Figure 5: Gate Signals



Figure 6: Three Phase Output Voltage

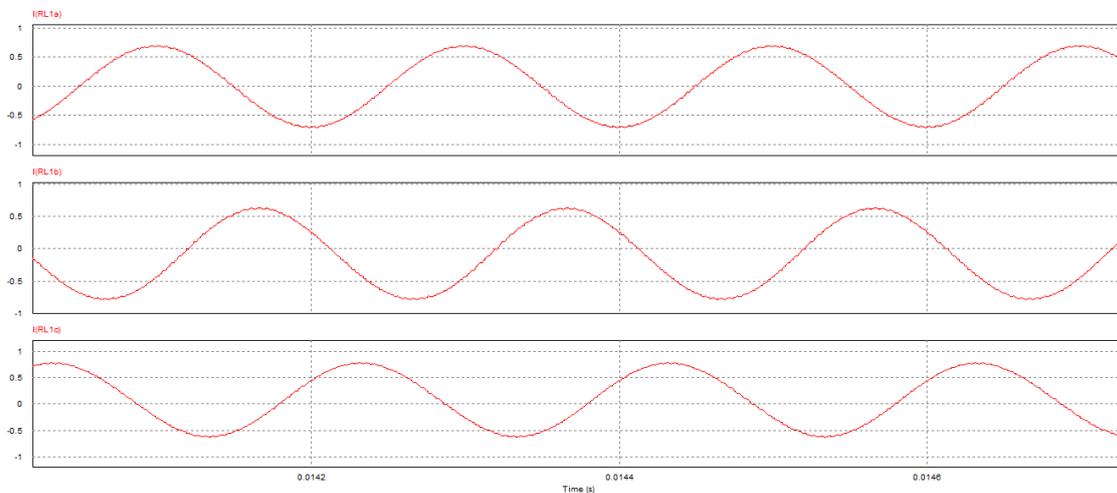


Figure 7: Three Phase Output Current

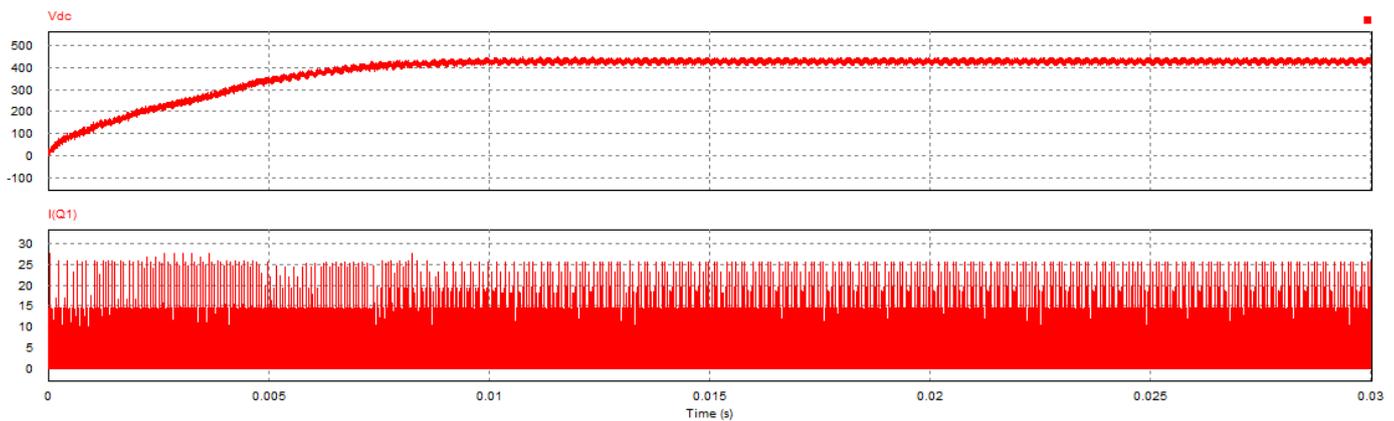


Figure 8: Zeta Converter Output

The solar photovoltaic arrangement zeta converter supplied voltage source inverter-BLDC motor pump for water pumping has been proposed. The system will avail the various desired functions such as MPP extraction of the SPV array, soft starting of the BLDC motor, fundamental frequency switching of the VSI resulting in a reduced switching losses, reduced stress on IGBT switch and the components of zeta converter by operating it in continuous conduction mode and stable operation. Moreover, the proposed system has operated successfully even under the minimum solar irradiance. So using these types of projects, we can supply the power with low cost low energy consumption motor with high speed response of the system.

V. CONCLUSIONS

A zeta converter with solar photovoltaic supply input that feeds a voltage source inverter which drives a BLDC motor pump for water pumping has been proposed and the hardware is designed. The system will avail the various desired functions such as MPP extraction of the SPV array, soft starting of the BLDC motor, fundamental frequency switching of the VSI resulting in a reduced switching losses, reduced stress on IGBT switch and the components of zeta converter by operating it in continuous conduction mode and stable operation. The hardware implementation of the converter is done and the performance is tested. Moreover, the proposed system has operated successfully even under the minimum solar irradiance. The BLDC motor fed by zeta converter operates with high backup capacity with low power wastage for water pumping. So using these types of projects, we can supply the power with low cost low energy consumption motor with high speed response of the system. Thus this system can be suitable to be implemented practically. The performance evaluation has justified the combination of zeta converter and BLDC motor for SPV array based water pumping.

VI. FUTURE SCOPE

Two phase currents are sensed along with Hall signals feedback for control of BLDC motor, resulting in an increased cost. The additional control scheme causes increased cost and complexity, which is required to control the speed of BLDC motor. Moreover, usually a voltage-source inverter (VSI) is operated with high-frequency PWM pulses, resulting in an increased switching loss and hence the reduced efficiency. Contrary to it, ZSI also necessitates phase current and dc link voltage sensing resulting in the complex control and increased cost. Furthermore, the switching loss of VSI can be 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 sacrificing its performance.

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