Stability Analysis with Z-Source Inverter using Solar Energy

Mohana priya P[1], Sasikala N[2], Sandhiya M[3],
Department of Electrical and Electronics Engineering,
N.S.N. College of Engineering and Technology,
Karur, India.

Ms.S.Punitha M.E.,
Assistant Professor
Department of EEE,
N.S.N. College of Engineering and Technology,
Karur , India.

Dr.P.Gomathi M.E.,Ph.D.,
Dean/Professor
Department of EEE,
N.S.N. College of Engineering and Technology,
Karur, India.

Abstract- *This paper presents a new PV power system having a sensorless brushless dc motor (BLDC) driving a water pump. A Z -source inverter (ZSI) is controlled to extract the maximum power from PV array and supplies the BLDC motor instantaneously. The BLDC motor is driven with variable reference speed attend maximum PV power by a hysteresis current control loop. Despite the conventional PV water pumping systems, employing a two stages converter, the proposed system enjoys one stage power conversion. Therefore, less number of power switches, less switching losses and lower cost are obtained. By proper designing of control system parameters and maximum power point tracking (MPPT) method for PV array, good steady state and transient performances have been achieved in response to different operation conditions for PV array. Sensorless drive with low torque ripple is provided for the BLDC motor. The system was simulated by MATLAB software for a PV array of 1 kW.*

I. INTRODUCTION

As the sources of conventional energy are dwindling fast with a corresponding rise in cost, considerable attention is being paid to other alternative energy sources. Solar enerhich is free and abundant in most parts of the world has proven to be a challenging source of energy in many developing and developed countries. The solar energy as PV power systems can be operated as a stand-alone, hybrid or grid connected systems. The first schemes found a wide application in remote regions to meet small, but essential electric power requirement such as water pumping systems [1]-[3]. Photovoltaic (PV) water pumping systems have been increasingly popular in remote areas where grid is not accessible or is too costly to install. These systems are mostly used for agriculture and household purposes. A number of dc motor driven PV pumps are already in use in several parts of the world. But they suffer from maintenance problems due to the presence of the commutator and brushes [4], [5]. Also some pumping system based on induction motor (IM) have proposed where reliability and maintenance-free operations are important. Since most low power motors such as single phase induction motors (IMs) used for residential applications that drive low torque loads need to have a complex control drive system [6], [7]. So it can be more efficient to overcome mentioned problems by choosing a suitable motor instead of a DC or IM one. Having lower power range, simple structure and controllability, BLDC motors can be considered as a suitable alternative. Some early studies based on a BLDC motor have been done for PV water pumping systems [8]. The investigation is based on boost converter which drives a BLDC motor. Because the BLDC motor is not sensorless, the control drive system is relatively complex compare to those use sensorless BLDC motor. In addition the sensorless BLDC motor provides better efficiency and better reliability in the same volume and size. Besides, these systems have employed two power stages converters, a DC/DC boost converter in order to accomplish maximum power point tracking (MPPT) of the PV array and a DC/AC inverter to provide an alternative voltage or current at the output of inverter. But recent papers on PV power systems suggest less numbers of power stage conversions for enhancing the overall system efficiency. In this paper a sensor less BLDC motor has been driven by a three-phase ZSI instead of a two stages power converter. The schematic block diagram of the proposed PV water pumping system is shown in Fig. 1. As it is clear from the figure the system consist of a PV array, a sensor less BLDC motor, a three-phase ZSI and the control system. By generating suitable signals for power switches of ZSI, the system is controlled for different operation conditions such as variations of sun irradiation and temperature levels. The maximum power of PV array is extracted by MPPT control method and then is fed to the sensor less BLDC motor. 1st Power Electronic & Drive Systems & Technologies Conference Considering that the PV power varies to different environment conditions, the sensor less BLDC motor should be driven by variable reference speed. In order to achieve the reference speed for sensor less BLDC motor, the input voltage of inverter is regulated at a constant value (Vinref=300V). The simulation results of the whole system are given to clarify the advantageous of proposed system. The other advantages of the system are less power switches, smaller capacitance and inductance values in comparison with boost converter and fast dynamic response. II. PV ARRAY MODEL AND MPPT The nonlinear Ipv–Vpv and Ppv–Vpv characteristics of solar cells are well known. Using the equivalent circuit of Fig. 2, the nonlinear Vpv–Ipv characteristics of PV module is ln( ) sc pv pvs p v III VR I I λ − + = − (1) where Isc is the cell short-circuit current, I0 is the reverse saturation current, Rs is the series cell resistance, and λ is a constant coefficient and depends upon the cell material. These parameters for the silicon solar panel manufactured by the Iranian Optical Fiber Fabrication Co.

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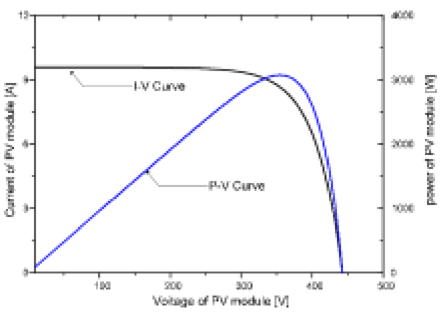


Fig.1. Solar output Waveform

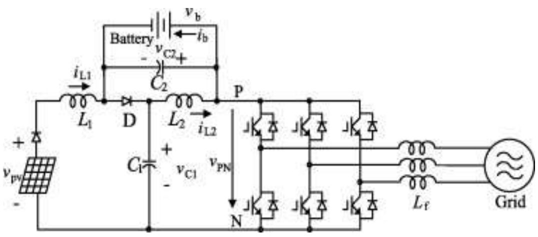
In order to achieve more PV power, Ns numbers of PV modules are serried as a PV string and then Np numbers of PV strings are paralleled as a PV array. As the voltage and current of a PV array vary in respect to insolation and temperature levels, the equation (1) has been computed for several insolation levels (G=600, 800, 1000 W/m2) for the same temperature level (T=25oC). The Vpv-Ipv and Ppv-Vpv characteristics of the PV array have been shown in Fig. 3. These figures illustrate the nonlinear variations of the PV maximum power point respect to irradiation levels. In this paper PV system is modeled in the PSCAD program as a DC voltage source based on equation (1). According to Fig. 3 there is only one operating point on every Ppv-Vpv characteristic that the maximum PV power can be extracted. Providing this operating point for PV array is called as Maximum Power Point Tracking (MPPT) performance employed by MPPT controller. There are several methods to accomplish MPPT for PV array [10]-[12].

III. BLDC MOTOR DRIVE

Permanent magnet DC motors use mechanical commutator and brushes to achieve the commutation. However, BLDC motors adopt Hall Effect sensors in place of mechanical commutator and brushes. The stators of BLDC motors are the coils, and the rotors are the permanent magnets. The stators develop the magnetic fields to make the rotor rotating. Hall Effect sensors detect the rotor position as the commutating signals. Therefore, the BLDC motors use permanent magnets instead of coils in the armature and so do not need brushes. As the rotor position is detected by incremental encoder then the Hall Effect sensors can be removed. So a motor without Hall Effect sensors is called as a sensorless BLDC motor. In this paper, a three-phase and two pole sensorless BLDC motor is used. For the three phases BLDC motor the back EMF and phase current waveforms with 120° conduction mode are shown in Fig. 5 [14]-[16].

BASIC OPERATION PRINCIPLES OF ZSI The impedance network which is made of an X shape LC network can boost the dc input voltage (Vo) in respect to the interval of shoot-through zero state (T0) during a switching cycle (T). In conventional VSI there are eight permissible switching states: six active and two zero states, while during the zero states there is no difference for the load if the upper three, the lower three or all the six switches are gated on (all the states short the output terminal of the inverter and produce zero voltage to the load). As discussed in [17] in ZSI, during the zero states all the switches are gated on (shoot-through state) and this state is used to achieve boosting dc input voltage. Therefore in ZSI, there are six active states and two zero states which are the same as conventional inverter and an addition shoot-through state (it is forbidden in conventional inverters) which is utilized advantageously to boost the dc-bus voltage. Two basic operation mode of ZSI are illustrated in Fig. 6.

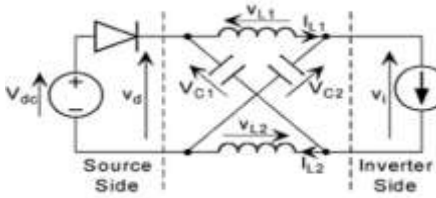
CONTROL SYSTEM DESCRIPTION Fig. 7 describes the basic building blocks of PV array MPPT control and the sensorless BLDC motor drive. The drive system consists of the PI speed controller, reference current generator, hysteresis current controller, three-phase ZSI and the motor-load unit. First the reference voltage of PV array is determined by the IC MPPT controller and compared with the PV array voltage. Then the error signal is processed by a PI controller to obtain the shoot through interval time of ZSI (T0). The shoot through state can be performed through the ZSI regulating the input dc voltage of inverter (Vin).



The voltage error (e=Vref-Vin) is considered by a PI controller to utilize as reference speed for BLDC motor. Then the speed of the motor is compared with its reference value, and the speed error is processed in the PI speed controller. The output of this controller is considered as the reference torque. A limit is put on the speed controller output depending on the permissible maximum winding currents. The reference current generator block generates the three phase reference currents using the limited peak current magnitude decided by the controller and the position sensor. The motor currents are compared with the reference currents and the hysteresis current controller regulates the winding currents (ia, ib, ic) within the small band around the reference currents. These switching commands and the Z-Source switching commands are ORed to drive inverter switches.

IV. SIMULATION RESULTS

The proposed system was simulated by PSCAD/EMTDC to evaluate the system capability in response to different operation conditions. The PV array output power range is about 0.5kW to 1kW. The other simulation parameters related to BLDC motor, load torque constant (K), ZSI and LC filter are presented in Table II. Three different operating conditions are indicated by Fig. 8 showing the simulated results for motor phase currents, rotor speed electromagnetic and load torques and PV output power for the following stages respectively. In Fig. 9 simulation results for phase currents of BLDC motor are shown for all stages at one operating cycle respectively. In this stage the system starts to operate, while BLDC motor is at the stationery state. Also the irradiation level of sun is about G=600W/m2, and the temperature level is about T=10oC. At first the MPPT controller regulates the shoot-through time (T0) of ZSI, so the PV output power is adjusted to its maximum value (Pmpp=520W) and the capacitors are being charged simultaneously. This situation continues until the input dc voltage of inverter (Vin) boosts to its reference value at t=0.14sec. At this time the reference speed increases from zero to its nominal value, i.e. 1433r.p.m. and once Vin increases to track Vref. Considering that the load torque is in proportion to the square of speed (i.e. 2 Lr TK ω =). As shown in Fig. 8 (a), the three-phase starting currents for BLDC motor smoothly increase to reach their steady state values, i.e. 3.65A at t=0.8sec. In this state the maximum power of PV array is drawn to supply the motor. The steady state values are; N=1433rpm, TL=2.6N.m and Te=2.9N.m. Once back emf should be provided the current of the motor should be reversed.



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