PV-HESS fed BLDC Driven Water Pumping System with PSO-based MPP Tracking Employing Zeta Converter

Mohammad Saif Ali
Department of Electrical Engineering
BIT SINDRI

Prof. Vandan Raj Kamal Aluri
Department of Electrical Engineering
BIT SINDRI

***Abstract*—The increased importance of renewable sources in the field of automotive sector entails the use of solar photovoltaic (PV)-fed water pumping system driven by a brushless DC (BLDC) motor drive. To overcome the drawback associated with the conventional DC-DC converters, a zeta converter is employed to optimize the power processing. The maximum power is extracted from the solar array by controlling the duty cycle of zeta converter through particle swam optimization (PSO) based maximum power point tracking (MPPT) algorithm. To mitigate the PV output variation, hybrid energy storage system (HESS) is integrated to the PV system which inturn maintains the constant voltage at the input of BLDC motor drive. A robust power management algorithm is employed for proper control of PV-HESS system. The overall MPPT with power management control facilitates the zeta converter to meet smooth performance of the water pumping system. The performance of the proposed controller is demonstrated using MATLAB/Simulink for variation in atmospheric condition and Xilinx system generator control platform interfaced with Zynq ZC-702 FPGA kit.**

Keywords—Brushless DC (BLDC) motor; hybrid energy storage system (HESS), maximum power point tracking (MPPT), particle swarm optimization (PSO), photovoltaic (PV) system, zeta converter.

I.INTRODUCTION

The increasing electrical demand in the world draws the researcher’s interest towards the effective use of renewable energy sources. Solar energy system is most popular among the different renewable energy sources as it is clean and eco friendly. As solar energy is intermittent in nature, so to increase the efficiency of the solar energy system it necessitates tracking the maximum power point. Many MPPT algorithms are mentioned in the literature [1] to track the maximum power from the solar PV system. Perturb & observe (P&O), incremental conductance (INC), short circuit current and open circuit voltage are the some traditional MPPT algorithms. Continuous research is going on for improvement in the MPPT technology [2] to overcome the shortcomings of conventional algorithms. The case of non-uniform solar insolation to the PV array due to the clouds, shadows of trees and buildings is considered as partial shaded condition (PSC). PSC can cause the multiple peaks in *PV* characteristics. The conventional MPPT algorithms may bound to the local peak that may not be the true MPP of the *P-V* characteristics. PSO-based MPPT algorithm [3] is one of the improved & efficient MPPT technique for optimal extraction of maximum power from the solar PV system which has the ability to track the global MPP in spite of having multiple peaks.

To maintain the constant supply the solar PV source needs backup such as energy storage system. The hybrid energy storage system is most popular now a days is a combination of battery and super capacitor. Steady state power backup can be supplied by the battery where as super capacitor will be acting as backup for transient case. The HESS can be charged or discharged through a bidirectional DC-DC converter. Switching pulses for the bidirectional DC-DC converter can be generated based on the proper power management algorithm. A buck-boost type bidirectional converter is traditionally used for this purpose.

The voltage from PV source is boosted using the DC-DC converter. There are several DC-DC converter topologies presented in the literature, among which zeta converter grabs the attention of the researcher’s to employ in various applications like MPPT, power factor correction (PFC) and power quality improvement [4]-[6]. Different advantages of using zeta converter are: a) boundless region of MPPT can be achieved unlike conventional buck and boost converters [7], b) presence of inductor in output side makes output current continuous and ripple free, c) negative voltage sensing elements are not necessary with zeta converter as it produce non inverting output voltage. Application of zeta converter in BLDC motor drive gives the advantage of soft starting [8] and is favourable for effective water pumping system. In this work, solution of an effective and standalone water pumping system is proposed, i.e., PSO-based MPPT algorithm is employed to generate switching pulses for the zeta converter and dual loop power management algorithm is employed [9, 10] for controlling the overall PVHESS system. The real-time operation of the power management
controller is validated through Xilinx system generator [11] control platform interfaced with Zynq ZC-702 FPGA kit. Finally, the conclusions are drawn.

II.SYSTEM DESCRIPTION

The PV-HESS powered BLDC motor driven water pumping system with PSO-based MPPT algorithm, employing zeta converter.

Solar PV system is utilized as the primary source for BLDC motor driven water pumping system and HESS will be the backup to handle intermittence due to variation in atmospheric conditions. The switching of zeta converter is done by pulses generated from the PSO-based MPPT controller. The power management of the system for varying

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atmospheric conditions will be carried out by the battery and super capacitor. The battery will manage the power variations during steady state where as super capacitor will operate during the transient condition. Ultimate aim here is to maintain the constant voltage across the BLDC motor even at varying atmospheric condition which is achieved by the suitable power management algorithm. The power balance equation will be as given below

$$P_M = P_{PV} + P_{SC} + P_B \quad (1)$$

where P_{PV} is the generated power of the solar energy system; $P_M$is the power demanded by BLDC motor drive; P_{SC} and $P_B$are the instantaneous powers of the super capacitor and battery bank respectively.

Power balance control strategy using SR flip-flops is employed in this system and validated using Zynq ZC 702 FPGA kit.

A. Design and operation of zeta converter

The zeta converter can boost or reduce the output voltage by proper switching like a buck-boost converter. Unlike the buckboost converter, it produces a non-inverting output voltage resulting in elimination of negative voltage sensors. Fig. 2 shows the circuit diagram of zeta converter.

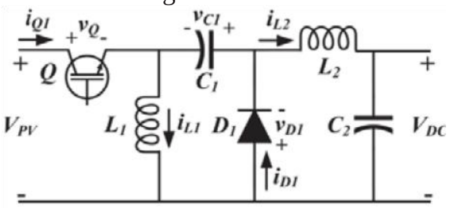

Fig. 1. Zetta converter topology.

The zeta converter consist of power semiconductor switch Q, Diode D_1, the AC coupling capacitor C_1, coupled inductors L_1, L_2, and output capacitor C_2. Table I summarizes the design parameters of zeta converter.

When switch Q is on, energy will be stored in $L_1$and L_2. So, during this mode L_1 and L_2 are in charging state. Whereas, when switch Q is off L_1 discharges the stored energy into the capacitor C_1 and the inductor L_2 supplies the stored energy to the output. The DC-link capacitor C_2 will be selected based upon the speed of the motor, optimum value should be taken between C_{2min} and
C2rated.

TABLE I. DESIGN PARAMETERS OF ZETA CONVERTER

Parameter	Selected value
Duty cycle (*D*)	0.76
Inductor (L_1=L_2)	6 mH
Capacitor (C_1)	20 F
DC link capacitor (C_2)	850 F

CONCLUSION

The PV fed BLDC drive using zeta converter assisted by HESS has been validated as an effective solution for replacing the usage of conventional energy sources. The zeta converter employed has the better performance in terms of MPPT implementation, smooth operation of motor drive for water pumping. Also, the power management algorithm used for the HESS system is capable of maintaining constant voltage to BLDC motor. Various desired performances such as PSO-based MPPT under varying atmospheric condition, operation of zeta converter, dynamic performance of overall system has been demonstrated using MATLAB/Simulink platform. The results shown in this study confirm the accuracy of the control algorithm. Further, the controller reliability is tested by using hardware-in-loop co-simulation platform employing ZYNQ ZC702 FPGA evaluation kit.

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APPENDIXES

PV Source Parameters (Simulated Data)

Open circuit voltage, V_{oc} = 105 V; short circuit current, I_{sc} = 18 A; maximum power, P_{mpp} = 1440 W; voltage at maximum power point, V_{mpp} =84 V; current at maximum power point, I_{mpp}=17 A. *Parameters for BLDC Motor (Simulated Data)* Stator resistance, R_s = 0.36 ȍ; stator inductance, L_s = 1.3 mH; torque constant, K_t = 0.49 Nm/A; voltage constant, K_e = 51 V_{LL}/k_r/min; speed, N_{rated} = 3000 rpm; no. of poles, P = 6.

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