

Design of a PV-Fed BLDC Water Pumping System Using PSO-Based MPPT

P Sowjanya¹, A T S S Gayatri², J B V S M Kumar³

G Veerababu⁴, Ch N P E S Tarun⁵

Asst.Professor, Department of EEE, Srinivasa Inst.of Engg & Technology, Amalapuram, AP, India.¹

B.Tech Students, Department of EEE, Srinivasa Inst.of Engg & Technology, Amalapuram, AP, India.^{2,3,4,5}

ABSTRACT

In present life non conventional energy sources are most powerful in the automotive field sector involve the use of solar photovoltaic (PV)-fed water pumping scheme driven by a brushless DC (BLDC) motor drive. To overcome the difficulty among DC-DC converters and minimize the power processing with employed zeta converter. Duty ratio of zeta converter is controlled to extract the maximum power from the solar system with help of particle swarm optimization (PSO) based maximum power point tracking (MPPT) method. Hybrid energy storage system (HESS) is connected to PV system in order to maintain constant voltage at the input of BLDC motor drive and also mitigate the PV output variations. 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 with help of fuzzy logic controller. The performance of the proposed controller is demonstrated using MATLAB/SIMULINK for variation in atmospheric condition.

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

1. 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 short comings of conventional algorithms. The case of non-uniform solar insulation 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 inspire of having multiple peaks. To maintain the content 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 favorable 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 PVHES system. The real-time operation of the power management controller is validated through simulation.

II. SYSTEM DESCRIPTION

The PV-HES powered BLDC motor driven water pumping system with PSO-based MPPT algorithm, employing zeta converter is shown in Fig.1.

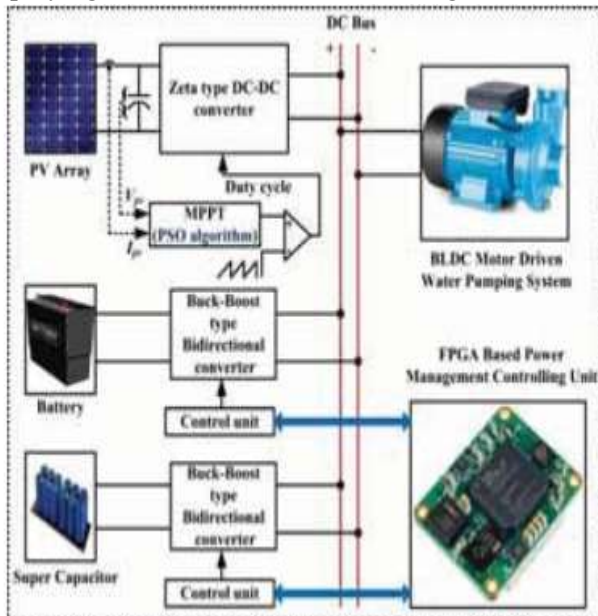


Fig.1 Hybrid PV-ESS fed BLDC motor driven water pumping system.

Solar PV system is utilized as the primary source for BLDC motor driven water pumping system and HES 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 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.

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 for controlling the overall PV-HES system. The real-time operation of the power management controller is validated through fuzzy logic controller. The fuzzy controller is applied to the DC-DC converter and the dynamics of the system have been improved by using fuzzy logic controller.

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 buck boost converter, it produces a non-inverting output voltage resulting in elimination of negative voltage sensors. Fig.2 shows the circuit diagram of zeta converter

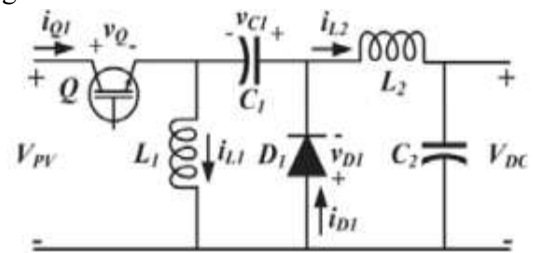


Fig. 2 Zeta converter topology.

The zeta converter consist of power semiconductor switch Q, Diode D1, the AC coupling capacitor C1, coupled inductors L1, L2, and output capacitor C2. Table I summarizes the design parameters of zeta converter. When switch Q is on, energy will be stored in L1 and L2. So,during this mode L1 and L2 are in charging state. Whereas, when switch Q is off L1 discharges the stored energy into the capacitor C1 and the inductor L2 supplies the stored energy to the output.The DC-link capacitor C2 will be selected based upon the speed of the motor, optimum value should be taken between C2min and C2rated.

TABLE I. DESIGN PARAMETERS OF ZETA CONVERTER

Parameter	Expression	Selected value
Duty cycle (D)	$D = \frac{V_{DC}}{V_{DC} + V_{PV}}$ (2)	0.76
Inductor ($L_1 = L_2$)	$L_1 = L_2 = \frac{DV_{PV}}{f_{SW}\Delta I_L}$ (3)	6 mH
Capacitor (C_1)	$C_1 = \frac{DV_{DC}}{f_{SW}\Delta V_{C1}}$ (4)	20 μ F
DC link capacitor (C_2)	$C_{2min} = \frac{I_{DC}}{6 \times W_{min} \times \Delta V_{DC}}$ (5)	850 μ F
	$C_{2rated} = \frac{I_{DC}}{6 \times W_{rated} \times \Delta V_{DC}}$ (6)	

III. CONTROL STRATEGIES

In this work, the controlling of DC-DC power converters plays a vital role for an effective standalone water pumping system. The zeta converter is controlled by PSO-MPPT algorithm to extract maximum power from PV system whereas the DC-DC bidirectional converters can be controlled by dual loop power management strategy.

3.1 PSO algorithm and application in MPP tracking :

PSO [12] has been found extensively useful in optimization of power system problem, engineering applications, harmonic reduction of power converters [13], etc. Genetic Algorithm, Colonical optimization, and other similar biological evolutionary algorithm need more parametric calculation. Whereas, PSO is easy to execute and less time consuming process as compared to other biological evolutionary algorithms. The particles in PSO moves in the problem space, finds the optimum solution and stores it in the memory. The best fitness in the population and in the overall iteration are termed as personal best value and global best value. Each particle move towards personal and global best values with a certain velocity and modifies it after each iteration. The velocity and position of i th particle in d dimensional space are updated as follows

$$\phi_{id}(k+1) = \phi_{ij}(k) + c_1 r_1 [p_{bij}(k) - \phi_{ij}(k)] + c_2 r_2 [p_{gid}(k) - \phi_{ij}(k)] \quad (7)$$

$$\rho_{ij}(k+1) = \rho_{ij}(k) + \phi_{ij}(k+1) \quad (8)$$

where $i = 1, 2, \dots, n$; $j = 1, 2, \dots, d$; k is the iteration number and $k+1$ index denotes the next iteration. c_1 and c_2 are the acceleration coefficients corresponding to individuality weight and sociality weight respectively (both are taken as 2.05 in this paper), r_1 and r_2 are the uniformly distributed random number between $[0, 1]$. p_{gi} is the personal best experience of each particle, p_{gi} is the best particle in the swarm found so far it denotes the

position and velocity of i th particle respectively. The conventional PSO algorithm has some demerits such as slow convergence when sloving complex function, premature convergence, etc. In order to improve the solution quality and convergence characteristics, there are two modifications in the literature [14, 15]. One is by considering intertia weight (IW) and other is to consider the constriction factor (CF). The CF-PSO has proved to be excellent in solving the optimization problem compared to IW-PSO [16]. Hence, the CF χ is considered as (9) and the velocity update is performed using (10)

$$\chi = \frac{2}{|2 - \varphi - \sqrt{\varphi^2 - 4\varphi}|}, \varphi = c_1 + c_2 \text{ and } \varphi > 4 \quad (9)$$

$$\phi_{id}(k+1) = \chi [\phi_{ij}(k) + c_1 r_1 (p_{bij}(k) - \phi_{ij}(k)) + c_2 r_2 (p_{gid}(k) - \phi_{ij}(k))] \quad (10)$$

The PSO-based MPPT technique is successfully realized in MATLAB 2014b environment to calculate optimum duty cycle in such a way that power can be maximized. The MPPT controller measures the V_{pv} and I_{pv} through sensors and computes the output power. The algorithm starts with random initialization of velocities and particles (duty cycle of zeta converter) are initialized in the range of minimum to maximum duty cycle. The fitness function (FF) of MPPT is defined as

$$FF = \max_{D} P_{pv}(D) \quad (11)$$

The optimum duty cycle. Duty cycle is varied in the range of 0 to 1. The initial duty cycle and minimum fitness values after final iteration are assigned as local and global best positions respectively. In the next stage of the algorithm, particles in the swarm follow a velocity and position update rule according to (10) and (8). The updated position of the particle may not be very close to the previous position due to the stochastic nature of PSO. In such case the sudden change in D will result in large voltage stress on the switch Q .

Hence, the duty cycle is sorted according to the last obtained value and the nearest duty cycle is considered to reduce the switch stress. Iteration process continues in the same way until the counter reaches the maximum set value and the best solutions are chosen after the maximum number of iterations. Otherwise, increase the iteration counter and the fitness value is re-evaluated. The particles in the swarm will be reinitialized when any change in the shading pattern is noticed. Maximum iteration count is set to 50 and number of particles is set to 5 in the algorithm. During both uniform and partial

shading of PV array, the proposed MPPT controller successfully tracks the global maximum power.

3.2. Power management control strategy :

The controlling of bidirectional DC-DC converters is done to maintain constant DC voltage across the BLDC drive even at various atmospheric conditions. The power management algorithm utilized in this work consists of two loops to generate the reference current (I_{ref}) that needed to maintain constant DC voltage. A proportional-integral (PI) controller is employed to generate the I_{ref} for the HESS system. Further it is divided for battery and super capacitor to individual control the expression for reference current is as given below

$$I_{ref} = \left(K_p + \frac{K_i}{s} \right) * V_{error} \quad (12)$$

K_p are the proportional and integral gains respectively. The value of the K_p , K_i can be estimated using Ziegler-Nicholas method [17]. The obtained reference current is separated using low pass filter to provide reference current to the battery and super capacitor. The error obtained by comparing reference and actual current is given to the reset pin of SR flip-flop.

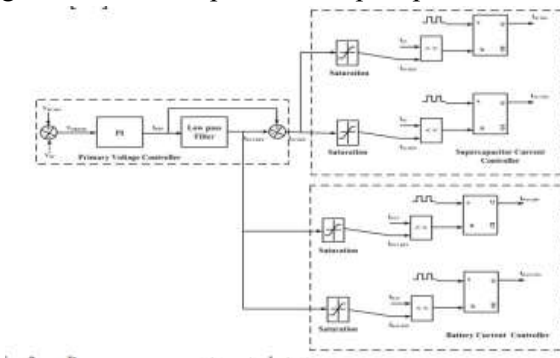


Fig. 3. Power management control strategy.

If the actual current is greater than the reference current, battery & super capacitor will be switched to discharging mode and will be in charging mode when actual current is less than the reference value. Fig. 3 gives the detail description of power management control strategy.

IV FUZZY CONTROLLER

The word fuzzy is defined by Lotfi and Zahid above the vagueness and that occurs when the boundary of the piece solves the problem. In 1965 this process is used for improving the effectiveness and exhibits immense at fuzzy set theory at uncertainty in the system.

Fuzzy set theory is a major tool to improve excellent at mathematically that handle certain data due to vagueness. That understanding human speech and improve the handwritten to recognizing to the instance at various characters in fuzziness manifests. Fuzzy set

theory is an extension that helps in setting the classical theory where elements are part of improving the varying degrees of membership. Fuzzy logic uses the whole interval between 0 and 1 to describe human reasoning. This process will balance the input variable at mapped by the sets in membership to improve the functions and that also known as FUZZY SETS.

The fuzzy set comprises a membership function which could be defined as a variable parameter. The value between 0 and 1 to change the values at membership in the fuzzy set. The methods will be converting the crisp input with increasing solve at fuzzy value is known as fuzzification. The result of the Fuzzier module will be interfaced with various rules. That are basic on varies operation of FLC is need to improve the construction from the fuzzy control rules utilizing at fuzzy sets, in general, to reduce the error and change the error to control the actions. That is based on the fuzzy module in the below figure. The output is a combination with giving the crisp as a result of controlling the variable with in-process and also known as DEFUZZIFICATION.

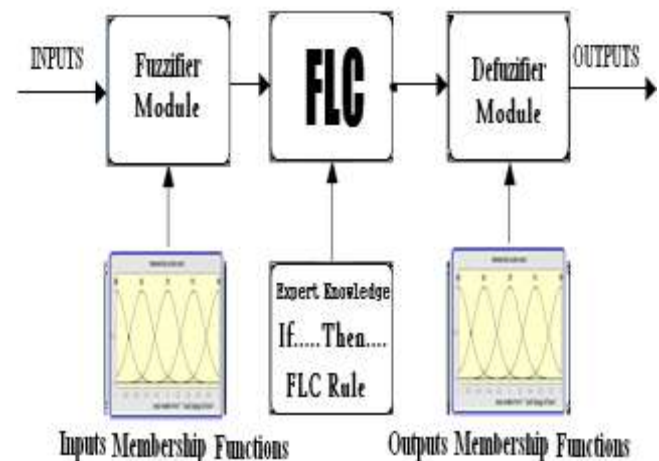


Fig 4: Block diagram fuzzy logic

4.1 Fuzzy rules:

In this fuzzy control the system with input and output variable to maintaining the size at various forms to determine the words. That selects the special vocabulary to determine the variables. In generally are used at big medium and small. These three words are need for the controller's input and output variable states. That need for maintain the plus among the positive and negative directions and improve the system at varies of zero at seven words: { negative big, negative medium, negative small, zero, positive small, middle, CT }, the general terms used in the English abbreviation prefix: {NB, NM, NS, ZE, PS, PM, PB}.

V SIMULATION DESIGN AND RESULTS:

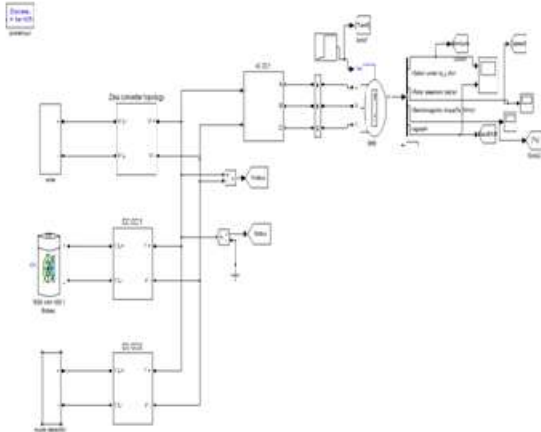


Fig5.1: Simulation Block Diagram

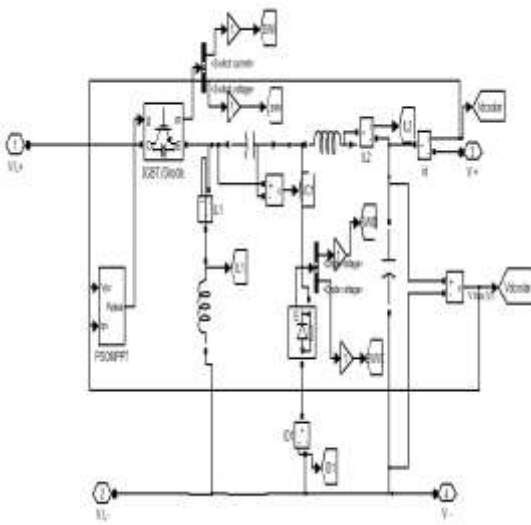


Fig 5.2: Simulation of Zeta Converter

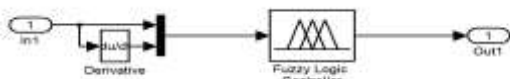


Fig5.3: Fuzzy Logic Controller

Simulation Results:

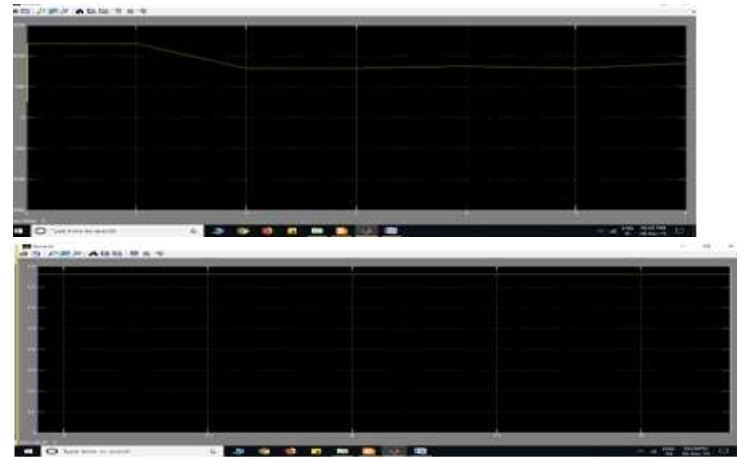
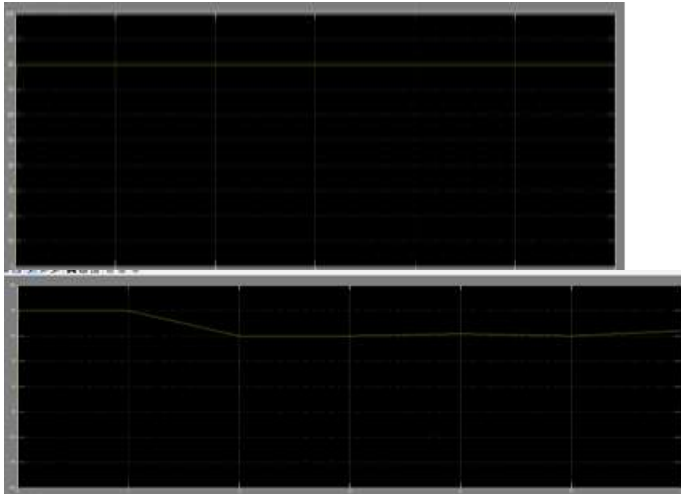


Fig. 5.4 Tracking curves obtained during uniform shading

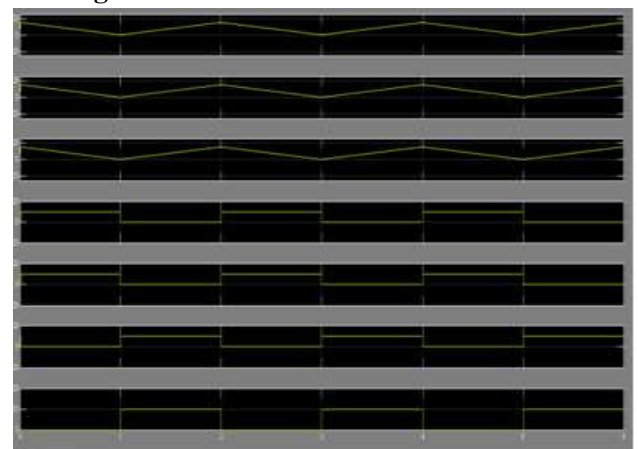


Fig. 5.5. Zeta converter variables during steady state

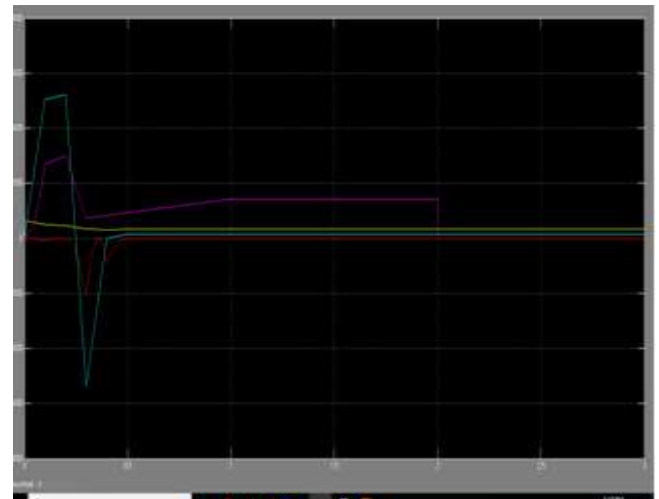
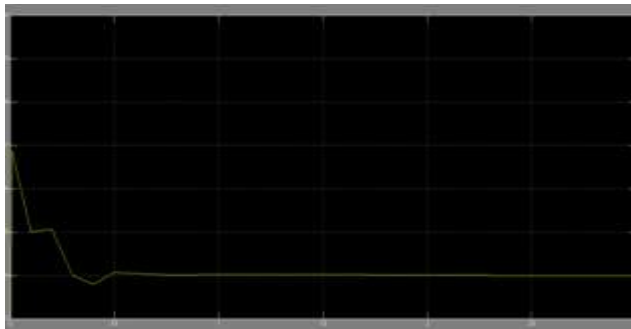
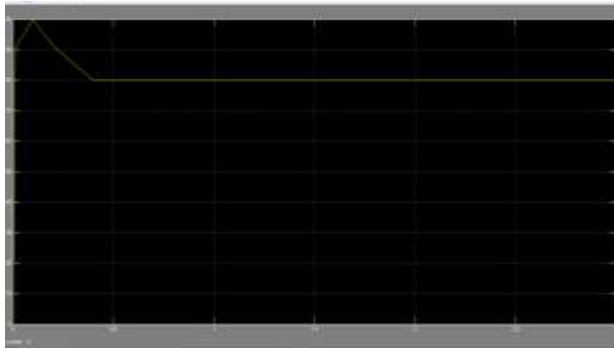


Fig. 5.6. Power management curves for a step change of 1000 W/m2 to 0 W/m2 at 2 s



(a)



(b)

Fig.5.7. Load parameters (a) Current, (b) Voltage



Fig 5.8. (a) Speed, (b) Torque of BLDC motor

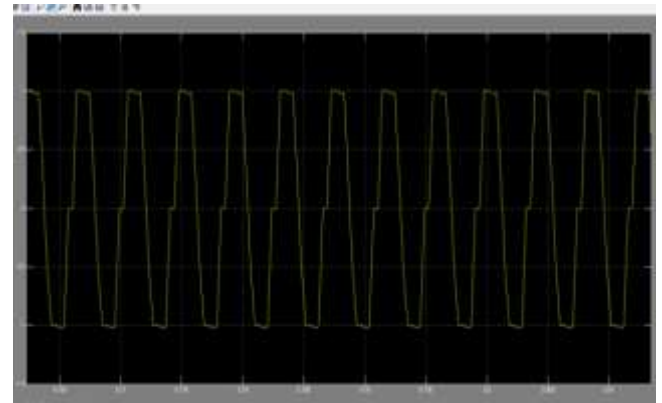
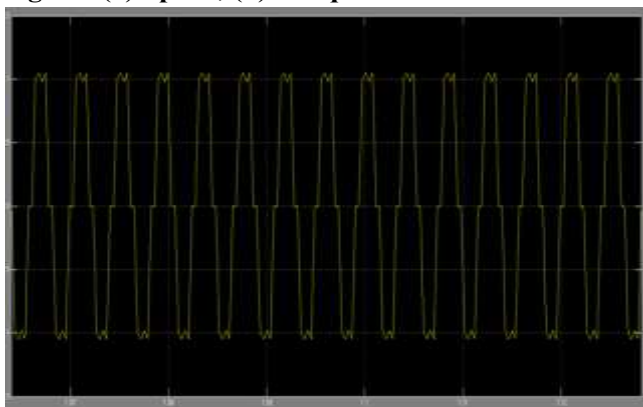


Fig. 5.9. (a) Stator current, (b) Back EMF of BLDC motor.

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 HSS system is capable of maintaining constant voltage to BLDC motor. In this paper fuzzy logic controller is stabilize the system response fast. 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.

REFERENCES

- [1] Sariki Murali, Kaibalya Prasad Panda, Gayadhar Panda "PV-HESS fed BLDC Driven Water Pumping System with PSO-based MPP Tracking Employing Zeta Converter" 2018 IEEE
- [2] B. Bendib, H. Belmili and F. Krim, "A survey of the most used MPPT methods: conventional and advanced algorithms applied for photovoltaic systems," *Renew Sustain Energy Rev*, vol. 45, pp. 637–648, 2015.
- [3] R. B. A. Koad, A. F. Zobaa and A. El-Shahat, "A novel MPPT algorithm based on particle swarm optimization for photovoltaic systems," *IEEE Trans. Sustain. Energy*, vol. 8, no. 2, pp. 468–476, Apr. 2017.
- [4] V. K. A. Shankar, S. Umashankar, S. Padmanaban, M. S. Bhaskar, V. K. Ramachandramurthy and V. Fedák, "Comparative study of photovoltaic based power converter topologies for pumping applications," *IEEE Conference on Energy Conversion (CENCON)*, Kuala Lumpur, Malaysia, pp. 174-179, 2017.

- [5] B. Singh and V. Bist, "Power quality improvements in a zeta converter for brushless dc motor drives," *IET Sci. Meas. Technol.*, vol. 9, no. 3, pp. 351–361, May 2015.
- [6] V. Bist and B. Singh, "A brushless DC motor drive with power factor correction using isolated zeta converter," *IEEE Transactions on Industrial Informatics*, vol. 10, no. 4, pp. 2064–2072, Nov. 2014.
- [7] M. H. Thagvee, M. A. M. Radzi, S. M. Moosavain, H. Hizam and M. Hamiruce, "A current and future study on non isolated DC-DC converters for photovoltaic application," *Renew Sustain Energy Rev*, vol. 17, pp. 216–227, Jan. 2013.
- [8] R. Kumar and B. Singh, "BLDC motor-driven solar PV array-fed water pumping system employing zeta converter," *IEEE Transactions on Industry Applications*, vol. 52, no. 3, pp. 2315–2322, May–June 2016.
- [9] S. K. Kollimalla, M. K. Mishra, A. Ukil and H. B. Gooi, "DC grid voltage regulation using new HESS control strategy," *IEEE Transactions on Sustainable Energy*, vol. 8, no. 2, pp. 772–781, April 2017.
- [10] S. Kotra and M. K. Mishra, "A supervisory power management system for a hybrid microgrid with HESS," *IEEE Transactions on Industrial Electronics*, vol. 64, no. 5, pp. 3640–3649, May 2017.
- [11] S. K. Dash, G. Panda, P. K. Ray and S. S. Pujari, "Realization of active power filter based on indirect current control algorithm using Xilinx system generator for harmonic elimination," *International Journal of Electrical Power & Energy Systems*, vol. 74, pp. 420–428, 2016.
- [12] J. Kennedy and R. Eberhart, "Particle swarm optimization," *Proc. IEEE Int. Conf. on Neural Networks*, pp. 1942–1948, April 1995.
- [13] K. P. Panda, and S. K. Mohapatra, "Anti-predatory PSO technique-based solutions for selected harmonic elimination in cascaded multilevel inverters," *Int. J. Industrial Electronics and Drives*, vol. 3, no. 2, pp. 78–88, 2016.
- [14] Y. Shi and R. C. Eberhart, "Empirical study of particle swarm optimization," *Proc. Congress on Evolutionary Computation*, 1999, pp. 1950–1955.
- [15] M. Clerc and J. Kennedy, "The particle swarm—explosion, stability, and convergence in a multidimensional complex space," *IEEE Trans. Evol. Comput.*, vol. 6, no. 1, pp. 58–73, 2002.
- [16] R. C. Eberhart and Y. Shi, "Comparing inertia weights and constriction factors in particle swarm optimization," in *Proc. Congr. Evol. Comput. (CEC)*, pp. 84–88, 2000.
- [17] P. M. Meshram and R. G. Kanojiya, "Tuning of PID controller using Ziegler-Nichols method for speed control of DC motor," in *IEEE International Conference On Advances In Engineering, Science And Management (ICAESM)*, Nagapattinam, Tamil Nadu, pp. 117–122, 2012.
- [18] S. Kochannek, I. Mauser, B. Bohnet, S. Hubschneider, H. Schmeck, M. Braun, and T. Leibfried, "Establishing a hardware-in-the-loop research environment with a hybrid energy storage system," in *IEEE Innovative Smart Grid Technologies-Asia (ISGT-Asia)*, 2016.