The Journal of CPRI,
Vol. 12, No. 2, June 2016 pp. 251-260

Wind - battery hybrid system with maximum power point extraction for residential loads

Siddharth Joshi*, Vivek Pandya** and Bhavesh Bhalja***

This paper proposes a hybrid wind (of 28 kW)generation system for standalone application with battery backup of 4.5 kW. This system is useful where grid connection is not viable and costly; particularly in the remote area. To enhance the performance of the proposed hybrid scheme, maximum power point tracking (MPPT) algorithm is implemented using DC-DC boost converter. The performance of the proposed system has been validated on an equivalent electrical load of the order of 17 kW using permutations and combinations of various types of residential load. Its performance has also been evaluated for extreme operating conditions of radiation levels, wind speeds and load switching events along with variation in climate conditions. The simulation results clearly indicate that the proposed hybrid wind battery satisfy the power demand and regulate the DC bus voltage as per IEEE 1250 standard.

Keywords: *DC-DC converter, hybrid energy system, Maximum Power Point Tracking (MPPT), State of Charge (SoC), Wind energy conversion system (WECS).*

1.0 INTRODUCTION

The burning of fossil fuels and fume of industrial wastes leads to increase an effect of global warming on the surface of the earth. Still, the demand for energy is day by day increasing and cost of the same too. Small-scale renewable energy sources are important alternatives for those locations where grid integration is not possible. For example, such system could be installed at remote villages situated in the desert or hilly areas or sometimes at the roof top itself where wind regime is quite good depends on upon geographical location. Such hybrid wind systems could be installed at small open grounds also to meet the requirement of the energy of the small community. The variation in climatic conditions results in operational issues and introduces limitations in its applications the concept of hybridization of the renewable power source with battery is proposed in the paper. Talking about existing wind power capacity 25.08GW wind power installed in India as on 31st March 2015. However, the wind is also the better alternative for harnessing green energy for a standalone purpose to fulfill the energy demand at remote places.

2.0 LITERATURE REVIEW

The authors proposed voltage based maximum power point tracking for hybrid wind, solar energy systems in [1] which is reliable and profitable. They have used two different blocks of MPPT system for the wind and solar PV system. Authors in [2] and [3] proposed novel technique for MPPT

*Ph.D. Scholar RK University, Rajkot & Lecturer, Electrical Engineering Deparment, School of Technology, Pandit Deendayal Petroleum University, Gandhinagar, Gujarat, India. Email address: siddharth181285@gmail.com Phone no. +91-9427729739
**Associate Professor and Head, Electrical Engineering Deparment, School of Technology, Pandit Deendayal Petroleum University, Gandhinagar, Gujarat, India.
***Associate Professor, Electrical Engineering Deparment, Indian Institute of Technology, Roorkee.

with permanent magnet synchronous generator based standalone wind energy conversion system. They have used direct current as a perturbing variable, and the change in wind speed can be detected indirectly by changing the slope of DC link voltage. They have proposed Perturb and Observe (P&O) technique for a sudden change in wind speed and variable change in the wind (for practical considerations) and from these data next perturbation size is decided in [2]. They have incorporated mode detection feature and stall control for highest wind speed in the same system in [4][5]. The primary objective of such tracking algorithm is to achieve faster and accurate tracking performance as well as the reduction in oscillations around maximum power points.

Power coefficient analysis based MPPT tracking method proposed in [5] with better performance and faster-tracking speed for proposed algorithm. Supervisory control for wind solar hybrid energy conversion system with battery bank is discussed in [7]. The power coefficient of a wind turbine is given by, a ratio of power output from the wind turbine to the power contained in the wind [12,13]. In this paper, they derived an approximate relationship between the optimal value of DC voltage and direct current. Using this relationship they incorporated optimum relationship based control with perturb and observe control method with scaling parameter and controlling parameter. This controlling parameter is fed to ORB control for finding the relation between power coefficient and the different value of same with a change in wind speed. They concluded the improvement in efficiency of 3.6% in simulation and 7.8% in a prototype.

The standalone approach of the wind turbine is discussed connected with PMSG (Permanent Magnet Synchronous Generator) and DFIG (Doubly Fed Induction Generator) in [6], they have used a large rating of battery termed as Remote Area Power Supply (RAPS). They have also proposed one coordinated algorithm of a wind battery hybrid system. They proposed technique with PMSG based wind energy conversion system and DFIG based wind energy conversion system. Some of the authors also suggested the same concept with different permutations and combinations of type and capacity of loads [9,10]. Authors in [10] used an approach of hybridization with 3.5 kW of wind and 3.1 kW of solar PV with battery rating. They have used an approach of the dump load to maintain DC link voltage constant. They proposed dump load power control without using dump load with a flow chart of dump power control.

The authors proposed a novel algorithm in [11] to maintain DC link voltage irrespective of change in load or change in wind speed for PMSG based standalone wind energy conversion system. They have hybridized wind turbine wind turbine, battery and electrolyzer (as a dump load) maintaining DC link voltage constant. So the output voltage will keep constant. They have also proposed a novel control strategy for load management. They have used an electrolyzer as a dump load. They performed simulations in MATLAB™, and its results sound quality of power with THD less than 5% as well voltage profile at the consumer end remains constant under steady state and dynamic conditions. They concluded that the performance of controllers remains satisfactory under varying conditions also.

The authors presented a review of the different hybrid system used to generate power for the single house or a small community in [12]. They have prepared a table for some standalone systems introduced over the last decade with their outcomes. Similarly, they compare the same for the hybrid solar PV system with their design capacity and its outcome.

Wei Zhou *et al.* reviewed different techniques in [14] for a current status of research of optimum sizing of stand-alone wind solar hybrid system. They different data generation feasibility studies from meteorological data. They have reviewed various modeling techniques for the wind, PV, and battery proposed by various authors. At last, they have discussed criteria for hybrid wind-solar optimizations and optimum sizing methods for wind solar system including meteorological data, geographical construction method, probabilistic approach, iterative techniques, artificial intelligence methods, energy flow and management in the hybrid system.

The authors reviewed different standalone hybrid solar systems for off-grid and rural electrification with design capacity[15]. They have compared various hybrid systems including stand-alone solar PV systems introduced in last twelve years, hybrid solar PV-wind systems, hybrid solar PV-diesel systems, hybrid PV-wind-diesel systems introduced in last twelve years. A renewable mobile house with PV/wind/fuel cell hybrid power system is proposed and demonstrated in [8] by Mehmed Eroglu *et al.* Authors have used different renewable sources simultaneously to power off-grid applications. They have discussed various design aspects and system integration for residential loads.

3.0 PROPOSED WIND BATTERY SYSTEM

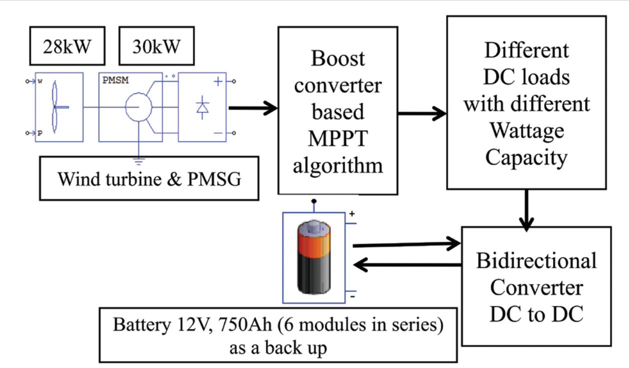

FIG. 1 SYSTEM BLOCK DIAGRAM

The proposed scheme of hybridization has developed from the basic idea discussed in [6] and [8]. In this study, only DC loads are considered. The values of AC loads are represented as equivalent DC resistance. A system of net electrical DC power from the wind of 12 kW at rated wind speed with batteries of (6 nos., 12 V, 750 Ah) are connected in series to form a battery bank. Maximum power point trackers ensure that the renewable energy sources like wind to provide the maximum amount available power (hence current) to the load, at almost all atmospheric conditions. The fixed resistance has considered for analysis with changes in atmospheric conditions in most of the articles. In this paper, we have chosen different loads with different power consumption capacity listed in Table 1. With different combinations of load, wind speed and radiation these load have operated with their given power consumption level itself. The State of Charge (SoC) of the battery is assumed to be 0.8.

A simple bidirectional converter is used for which the value of the inductor is selected as 600 μH [16] to operate in continuous conduction mode. The hysteresis current comparator technique is used to control the state of charge of the battery and also to maintain the DC link voltage.

The reference voltage of 600 V DC is selected. To maintain the state of charge (SoC) of battery range of 0.4(minimum) and 1(maximum) is considered in simulations. These upper and lower limits are coded with simplified C block available in PSIM. The control scheme for selecting the state of charge is taken from [8]in which inner current control and outer voltage control loops are used to control the state of charge of battery. In this paper, hysteresis controller, also known as the bang-bang controller, is used as an inner current control method due to its advantages over other control techniques. Different residential loads are shown in Table 1.

3.1 Wind Energy System with Battery Back up

This hybrid energy system comprises of wind energy conversion system with battery backup. The wind turbine is directly coupled to a permanent magnet synchronous generator (PMSG). They are best suited for standalone wind power applications. The main advantages of PMSG are addressed and compared to different articles and books [12][13]. Permanent magnet synchronous generators are direct drive and self-excited. The diode bridge rectifier is used with the boost converter to realize maximum power point tracking (MPPT) algorithm in [2]. Boost converter comprises of an inductor, power electronic switch, capacitor etc. to which MPPT algorithm is applied. This system is part of hybrid system as shown in the Figure 1. The system is simulated in PSIM® 9.3.4 hard lock.

The mechanical power from available wind is,

$$P_{mech} = \frac{1}{2}\rho A v^3 \quad ....(1)$$

Power captured by the blades of a wind turbine is,

$$P_{net} = P_{mech} \times C_P \quad ....(2)$$

Where,

P_{mech} = Mechanical power from wind turbine in Watt.

P_{net} = Net power from wind turbine after Betz limit and multiplication of power coefficient.

ρ = Air density (1.225 kg/m^3).

A = Swept area of wind turbine in m^2.

C_P = Power coefficient of wind turbine

v = Velocity of wind or wind speed in m/s.

λ = Tip speed ratio of wind turbine.

β = Blade pitch angle.

C_P is a power coefficient and it is a function of tip speed ratio (λ)and blade pitch angle (β). TSR can be defined as ratio of wind speed at the tip of the blade divided by the wind speed.

$$TSR = \frac{\omega R}{v} \quad ....(3)$$

Where, R is the radius of wind turbine and ω is the angular speed of wind turbine.

In practice, as per betz limit C_P cannot be exceeded from their theoretical limit i.e. 0.59. For low-speed wind machines, C_P ranges from 0.2 to 0.4 and for large wind machines up to 0.5 is observed. Graph between TSR and power coefficient is discussed in many articles and books.

4.0 SIMULATION RESULTS AND ANALYSIS

Figure 2 is showing the input given the-the wind turbine at 0° pitch angle. Figure 3 shows the response of the system by maintaining DC link voltage constant with change in wind speed as well as switching of load. Figure 4 and Figure 5 are showing simulation results under dynamic performance for the hybrid system under variable wind speeds, showing the power consumption for various residential loads connected with the system. Equivalent DC load is considered for particular equipment in this study. To make a system, dynamic switching ON and OFF the loads have made. Initially, all the loads except two, three star AC all other loads are ON. After t=2 second one of the three Star AC (Air Conditioner) is ON and similarly after t=4 second other three star AC will be made ON as shown in Figure 4. (power rating has indicated in Table 1) and after t=6 second cloth iron is disconnected from the system which is shown in Figure 4.

Wind speed variation is perturbed from t=0 second the wind speed is 11.5 m/s and it will maintain at 11.5 m/s up to t=4 second. At t=4 second the wind speed is decreased from 11.5 m/s to 10.5 m/s and at t=6 second wind speed is again increased at 11.5 m/s.

I total is total current drawn by the load. In this case 22 A. L-C tank circuit of 200 μH and 1000 μF is used after combining both the source powers and battery power for smoothing the DC voltage and current waveform. The simulation results are satisfied for hybridization of the system with change in atmospheric conditions and load. The basic calculations of battery backup time is shown in Table 2, considering 12 hours back up.

TABLE 1 DESCRIPTION OF LOAD IN WATT AND V ALUE OF THE RESISTANCE USED AT 600V DC [12]				
Sl. No.	**Load**	**Total No. of Units**	**Power Consu-mption in Watt**	**Value of resistance at 600V DC**
1	Refrigerator	1	300 W	1200 Ω
2	Dishwasher	1	1450 W	250 Ω
3	Large Burner	1	2100 W	175 Ω
4	Ceiling Fans	4	100x4= 400 W	900 Ω
5	Cloth Iron	1	1000 W	360 Ω
6	Tube lights	4	60x4= 240 W	1500 Ω
7	Window Air Conditioner	2	1200x2= 2400 W	300 Ω each
8	3 Star Air Conditioner	2	3000x2= 6000 W	120 Ω each
9	Televi-sion	2	150x2= 300 W	1200 Ω each
10	Laptop/ desktop	4	450 W	800 Ω
11	Water Pump	1	450 W	260 Ω
	Total power drawn by the load		16.44 kW	

Figure 6 shows the average current shared by battery and wind generator with the dynamic behavior of the wind turbine with the change in wind speed. In this study the blade pitch angle beta (β) is considered as 0° because this wind turbine has rated wind speed of 11.5 m/s. It also shows the direct current shared by wind source and battery at dynamic behaveiour of load and atmospheric conditions.

Figure 7 shows the power shared by wind source as well as battery. Figure 8 shows SoC of the battery and battery voltage after bidirectional converter at DC bus. The battery voltage remains constant and equals to reference voltage selected.

The standalone wind generation system with battery backup satisfied the load demand. Some issues of overcharging of the battery bank are still to be addressed. Nowadays the dump load is used to avoid the overcharging of the battery. It will also be helpful to maintain or regulate DC link voltage of DC bus when the sudden change in wind speed below cut out level as well as to protect the battery bank from overcharging if there is no load demand still the wind is blowing.

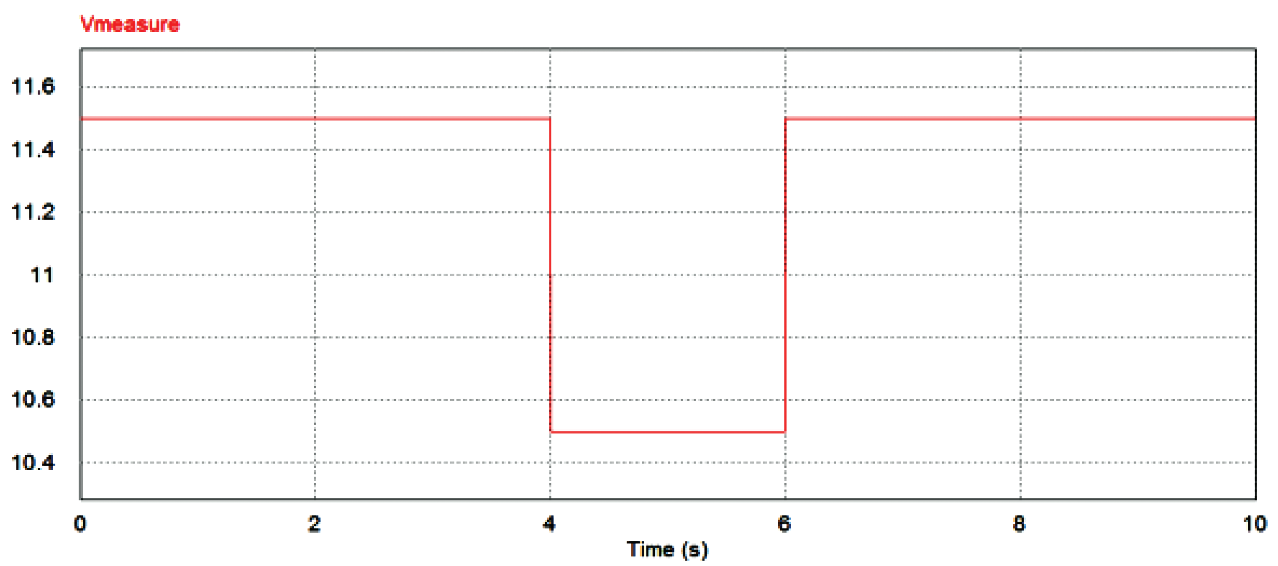

FIG. 2 INPUT WINDSPEED TO WIND TURBINE AT 0° PITCH ANGLE.

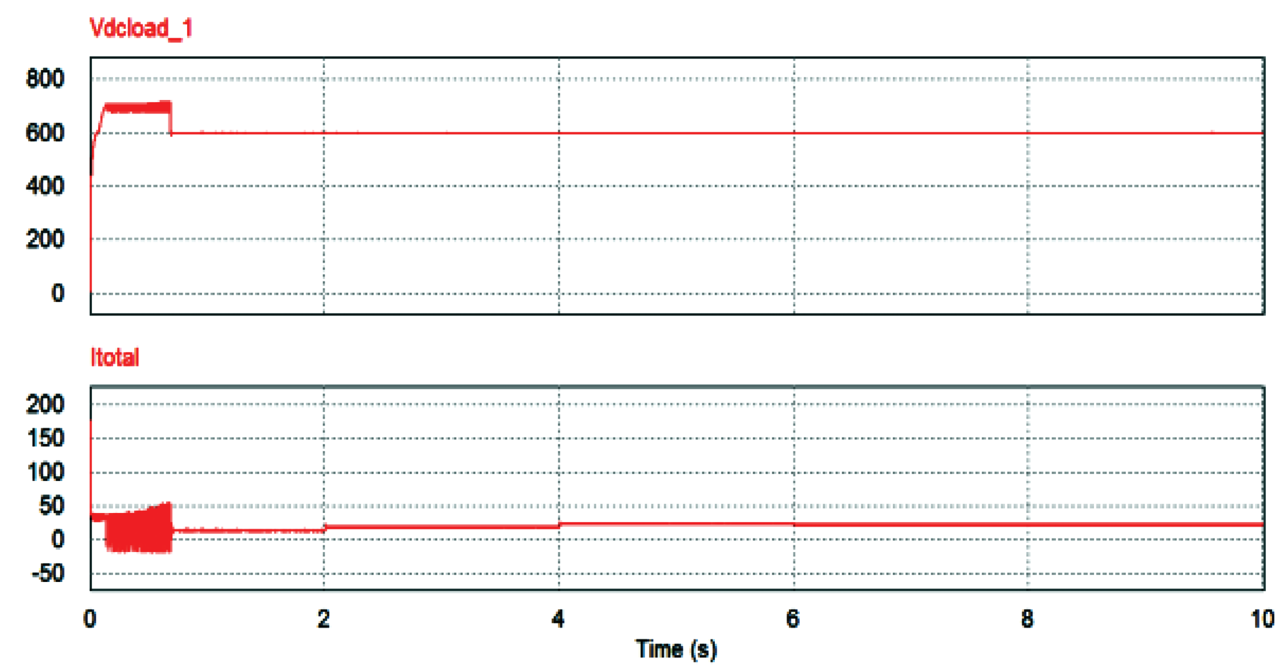

FIG. 3 DC LINK VOLTAGE AND TOTAL DIRECT CURRENT DRAWN BY SYSTEM.

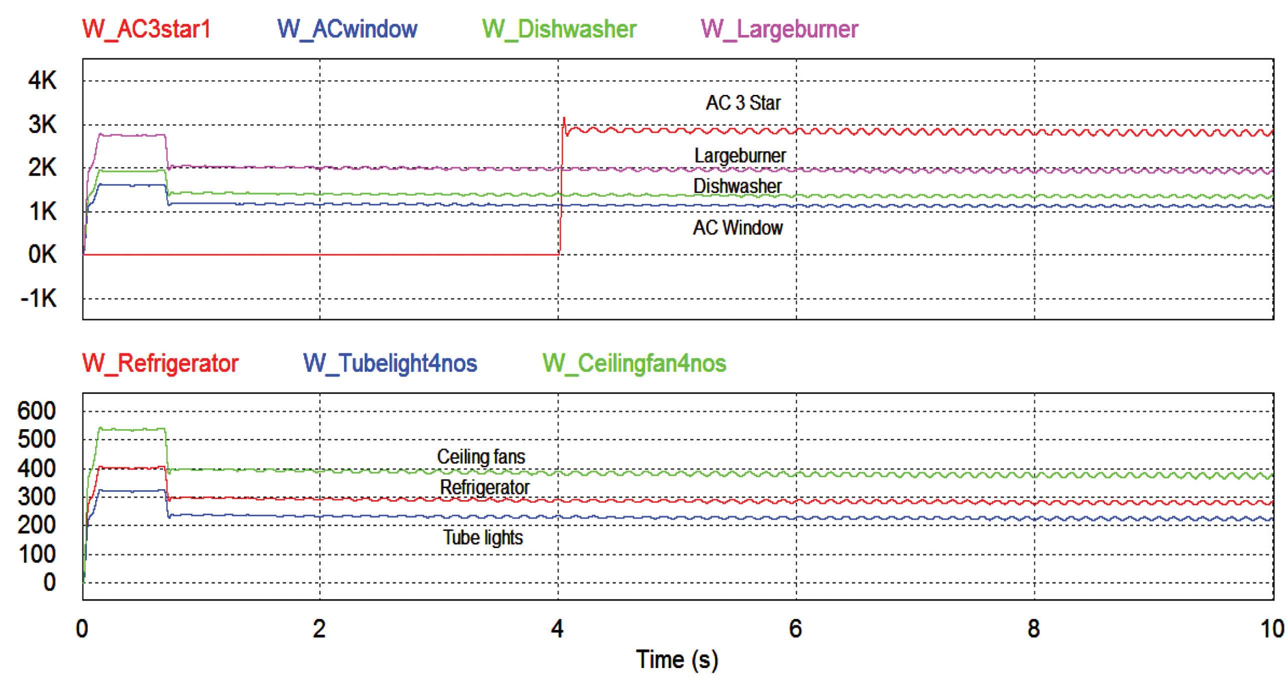

FIG. 4 POWER CONSUMED BY VARIOUS ELECTRICAL APPARATUS

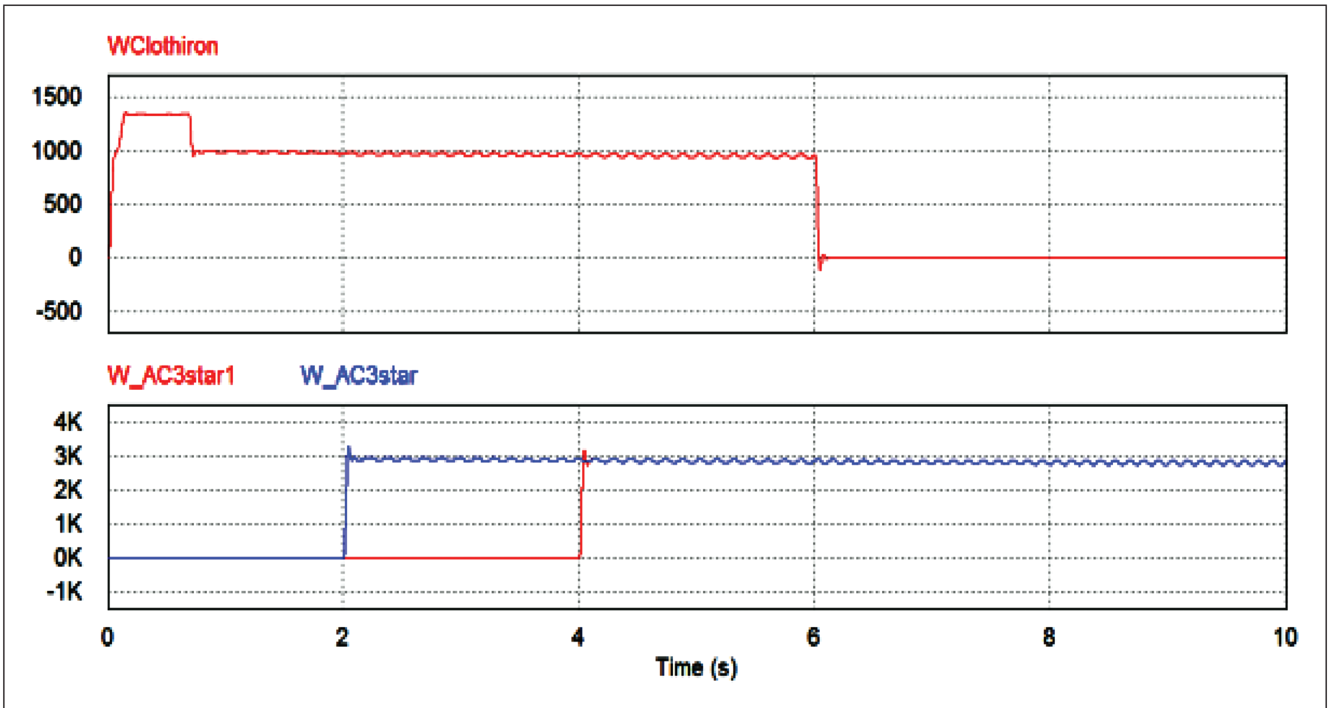

FIG. 5 SWITCHING OF LOADS (TWO NOS. OF THREE STAR AC AND CLOTH IRON)

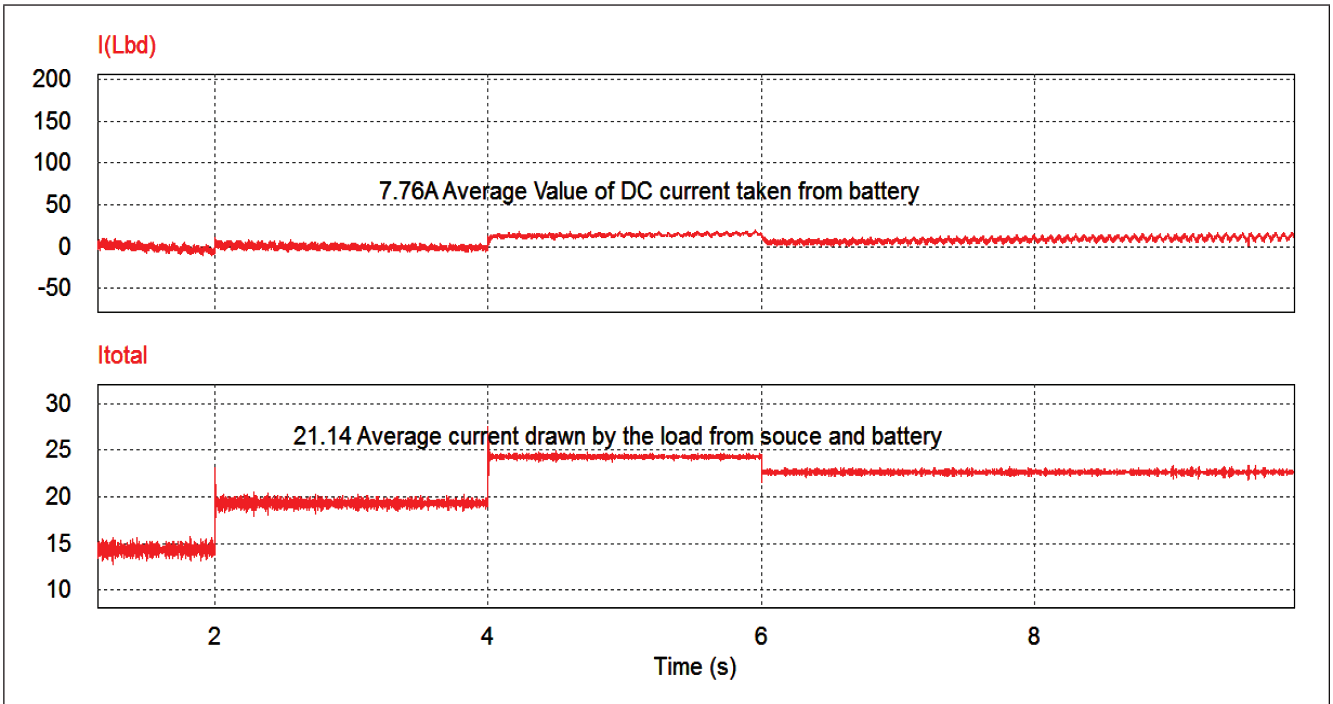

FIG. 6 CURRENT SHARED BY BATTERY AND TOTAL CURRENT DRAWN BY LOAD

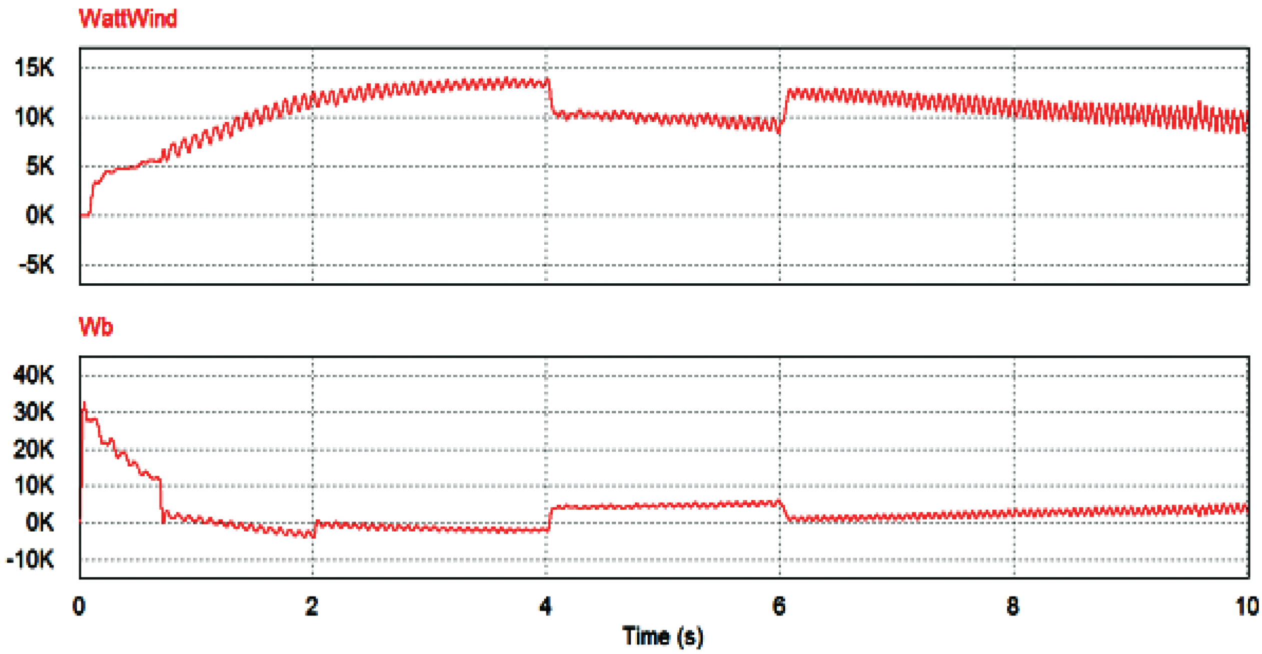

FIG. 7 POWER SHARED BY LOAD AND BATTERY BANK,

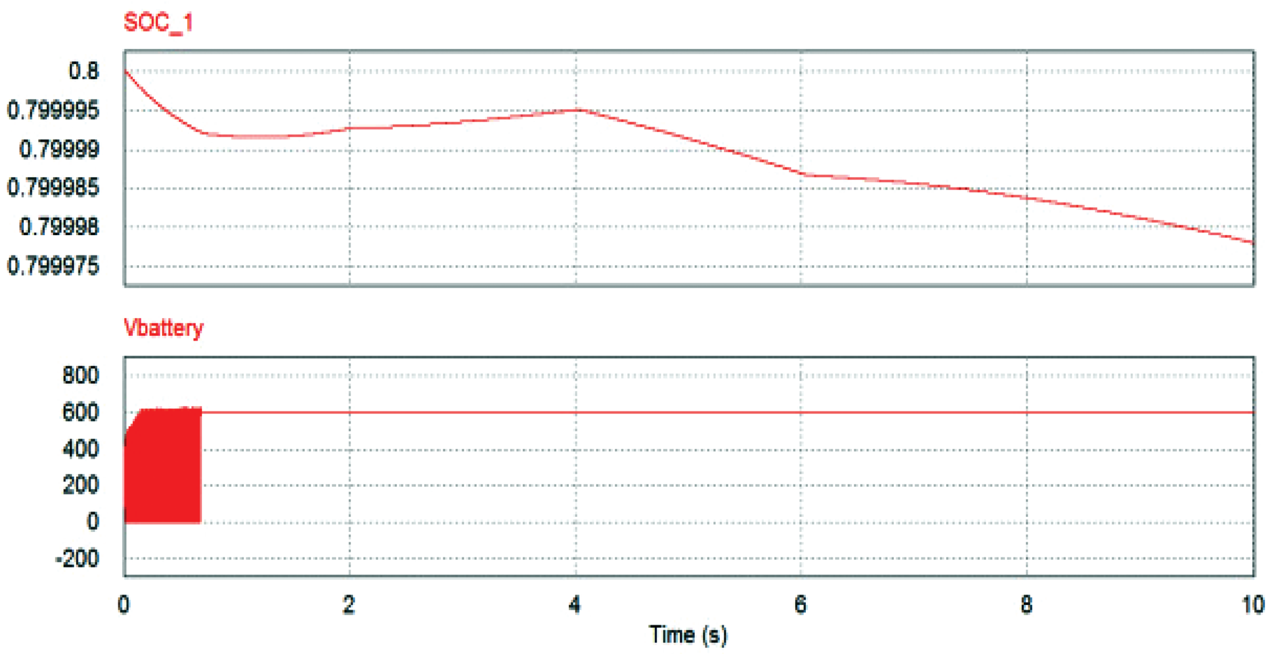

FIG. 8 STATE OF CHARGE OF BATTERY BANK AND VOLTAGE ACROSS DC BUS FROM BATTERY END.

5.0 CONCLUSION

The concept of hybridization with battery is successfully simulated to meet load demand. The MPPT algorithm ensures about its operating point closer to maximum power point during the change in atmospheric condition. Battery bank regulates DC link voltage with change in wind speed as well as load maintains DC link voltage constant. From simulation we can observe 70% load can be shared by the wind and 30% can be shared by battery bank on an average. The performance of hybrid system increases the system reliability. Therefore this system can play a vital role as the eco-friendly power solution. This will become a fruitful way to produce electrical energy where grid connections are not available especially in rural areas where open grounds are available for installing a small windmill at 20 metre to 30 metre hub height.

TABLE 2

ESTIMATION OF POWER OF ARRAY OF BATTERIES FOR SERIES CONNECTION

No. of series connected batteries	6
Voltage rating of battery V_{batt} (V)	12V each
Capacity of battery (Ah)	750 Ah
Rating hours as a backup (h)	12 hours
Current of battery I (A)	62.5 A
Total voltage from array	72 V
Total power from array (kW)	4.5 kW

REFERENCES

[1] N A Ahmed, M Miyatake, and A K Al-Othman, Hybrid solar photovoltaic/wind turbine energy generation system with voltage-based maximum power point tracking, Electric power components and systems, Vol. 37, No.1, pp. 43-60, December 2008.

[2] Z M Dalala, Z U Zahid, W Yu, Y Cho and JLai, Design and analysis of an MPPT technique for small-scale wind energy conversion systems, IEEE transactions on energy conversion, Vol. 28, No. 3, pp. 756-767, September 2013.

[3] Z M Dalala, Z U Zahid and J J Lai, New overall control strategy for small-scale WECS in MPPT and stall regions with mode transfer control, IEEE transactions on energy conversion, Vol. 28, No. 4, pp. 1082-1092, December 2013.

[4] Y Xia, K H Ahmed and B W Willams, A new maximum power point tracking technique for permanent magnet synchronous generator based wind energy conversion system, IEEE transections on power electronics, Vol. 26, No. 12, pp. 3069-3620, December 2011.

[5] Y Xia, K H Ahmed and B W Willams, Wind turbine power coeffiecient analysis of a new maximum power point tracking technique, IEEE transactions on industrial electronics, Vol. 60, No. 3, pp. 1122-1132, March 2013.

[6] N Mendis, K M Muttaqi, S Sayeef and S. Perera, Standalone operation of wind turbine-based variable speed generators with maximum power extaction capability, IEEE transactions on energy conversion, Vol. 27, No. 4, pp. 822-834, December 2012.

[7] F Valenciaga and P F Puleston, Supervisor Control for a Stand-alone hybrid generation system using wind and photovoltaic energy, IEEE transections on energy conversion, Vol. 20, No. 2, pp. 398-405, June 2005.

[8] M Eroglu, E Dursun, S Sevencan, J Song, S Yazici and O Kilic, A mobile renewable house using PV/wind/fuel cell hybrid power system, International journal of hydrogen energy, Vol. 36, No. 13, pp 7985-7992, July 2011.

[9] M H Nehrir, B J La Meres, G Venkataramanan, V Gerez and L A Alvarado, An approach to evaluate the general performance of stand-alone wind/ photovoltaic generating systems, IEEE Transections on energy conversion, Vol. 20, No. 2, pp. 433-439, June 2005.

[10] T Hirose and H Matsuo, Standalone hybrid wind-solar power generation system applying dump power control without dump load, IEEE transections on industrial electronics, Vol. 59, No. 2, pp. 988-997, February 2012.

[11] C N Bhende, S Mishra and S G Malla, Permanent magnet synchronous generator-based standalone wind energy supply system, IEEE transactions on sustainable energy, Vol. 2, No. 4, pp. 361-373, June 2011.

[12] G M Masters, Renewable and efficient electric power systems, Willey intersciene publication, 2013.

[13] M R Patel, Wind and solar power systems design, analysis and operation, 2nd edition taylor and francis, crc press, 2005, chapter 3, 4,8.

[14] W Zhou, C Hou, Z Li, L Lu and H Yang, Current status of resarch on optimum sizing of stand-alone hybrid solar-wind power generation systems, Journal of applied energy, Vol. 87, No. 2, pp. 380-389, February 2010.

[15] R K Akikur, R Saidur, H W Ping and K R Ullah, Comparative study of stand-alone and hybrid solar energy systems suitable for off-grid rural electrification: A review, Renewable and sustainable energy reviews, Vol. 27, pp. 738-752, June 2013.

[16] Roger Gules, Juliano De Pellegrin Pacheco, Hélio Leães Hey and Johninson Imhoff, A maximum power point tracking system with parallel connection for PV stand-alone applications, IEEE transactions on industrial electronics, Vol. 55, No. 7, pp. 2674-2683, July 2008.

[17] PSIM® 9.0 software user manual and hardlock kit.

[18] Hummer20kWsmallwindturbine, datasheet. http://www.hummerwindgenerator.com/20kw-projects.

[19] Tutorials of PSIM, for battery bank. http://powersimtech.com/wp-content/uploads/2013/04/Tutorial-How-to-use-Lithium-Ion-battery-model.pdf (also available with hardlock).

[20] Energy statistics 2016, Report, 23rd issue, by central statistics office, ministry of statistics and programme implementation government of India, New Delhi.