Grid Connected Hybrid (PV-Wind-Battery) System with Bidirectional DC-DC Converter

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***Abstract*— The renewable energy sources like sun and wind are the alternate sources of green power generation which can ease the power demand problems. This paper presents the control approach for power flow management of a grid-connected hybrid photovoltaic (PV)–wind-battery-based system with bidirectional dc–dc converter. The main object of the proposed system is to meet the load demand, deal with the power flow from various sources, inject the additional power into the grid, and charge the battery from the grid whenever essential. This can improves the reliability and efficiency of the system. The proposed Hybrid system with the MPPT controlled Bidirectional DC-DC converters and Voltage regulated Inverter for stand-alone application is developed and simulated in MATLAB environment.**

***Index Terms*— Solar Photovoltaic (PV), Wind Energy, Hybrid Energy System, Bidirectional DC-DC Converter, Maximum Power-Point Tracking, Matlab Software.**

I. INTRODUCTION

Rapid depletion of fossil fuels and global warming has necessitated an urgent need for alternative sources of energy to cater the continuously increasing energy demand. The environmental effects and the cost of central power plants are causing a large focus on renewable energies. The power plants are using fossil fuels which result in greenhouse gas emissions. These greenhouse gas emissions have a significant effect on the planet especially with the growth of the population and the corresponding increase of energy consumption. Due to the limitation of conventional resources of fossil fuels, it has compelled the evolution of hybrid power system. Therefore, new ways to balance the load demand is by integrating RES into the system.

Hybrid system enables the incorporation of renewable energy sources and transferable the dependency on fossil fuels, while sustaining the balance between supply and demand. The significant characteristic of hybrid power system includes, system reliability, operational efficiency [1]. The hybrid power system enables to overcome the limitations in wind and photovoltaic resources since their performance characteristics depends upon the unfavorable changes in environmental conditions. It is probable to endorse that hybrid stand-alone electricity generation systems are usually more reliable and less costly than systems that depend on a single source of energy [2]. On other hand one environmental condition can make one type of RES more profitable than other. For example, Photovoltaic (PV) system is ideal for locations having more solar illumination levels and Wind power system is ideal for locations having better wind flow conditions [3].

Thus a PV system consisting of PV array, Maximum Power Point Tracking (MPPT) boost converters, and Wind power system consisting of wind turbine, PMSG, rectifier and MPPT boost converter is integrated into Solar-Wind hybrid power system (SWHPS). The efficiency and reliability of the SWHPS mainly depends upon the control strategy of the MPPT boost converter. The solar and wind power generation cannot operate at Maximum power point (MPP) without proper control logic in the MPPT boost converter. If the MPP is not tracked by the controller the power losses will occur in the system and in spite of wind and solar power availability, the output voltage of the hybrid system will not boost up to the required value [4]. The output voltage of the PV and Wind power generation are quite low as compared with the desired operating level. So, this output voltage is brought to desired operating value of 220V using Boost converter with MPPT controller at each source.

Hybrid PV–wind-based generation of electricity and its interface with the power grid are the important research areas. Chen et al. [5], [6] have proposed a multi-input hybrid PV–wind power generation system which has a buck/buck– boost-fused multi-input dc–dc converter and a full-bridge dc–ac inverter. This system is mainly focused on improving the dc-link voltage regulation. In the six-arm converter topology proposed in [7], the outputs of a PV array and wind generators are fed to a boost converter to match the dc-bus voltage. The steady-state performance of a grid-connected hybrid PV and wind system with battery storage is analyzed in [8]. This paper focuses on system engineering, such as energy production, system reliability, unit sizing, and cost analysis. In [9], a hybrid PV–wind system along with a battery is presented, in which both sources are connected to a common dc-bus through individual power converters. In addition, the dc-bus is connected to the utility grid through an inverter.

The use of multi-input converter for hybrid power systems is attracting increasing attention because of reduced component count, enhanced power density, compactness, and centralized control. Due to these advantages, many topologies are pro-posed, and they can be classified into three groups, namely, non-isolated, fully isolated, and partially isolated multiport topologies.

All the power ports in non-isolated multiport topologies share a common ground. To derive the multiport dc–dc converters, a series or parallel configuration is employed in the input side [10]–[14]. Some components can be shared by each input port. However, a time-sharing control scheme couples each input port, and the flexibility of the energy delivery is limited. The series or parallel configuration can be extended at the output to derive multiport dc–dc converters [15]. However, the power components cannot be shared. All the topologies in non-isolated multiport are mostly combinations of the basic topology units, such as the buck, the boost, the buck–boost, or the bidirectional buck/boost topology unit. These time-sharing-based multiport topologies promise low cost and easy implementation. However, a common limitation is that power from multiple inputs cannot be simultaneously transferred to the load. Furthermore, matching wide voltage ranges will be difficult in these circuits. This made the researchers to prefer isolated multiport converters compared with non-isolated multiport dc–dc converters.

The proposed system has two renewable power sources, load, grid, and battery. Hence, a power flow management system is essential to balance the power flow among all these sources. The main objectives of this system are as follows.

1) To explore a multi-objective control scheme for optimal charging of the battery using multiple sources.
2) Supplying uninterruptible power to loads.
3) Ensuring the evacuation of surplus power from the renewable sources to the grid, and charging the battery from the grid as and when required.

The grid-connected hybrid PV–wind-battery-based system for household applications is shown in Fig. 1, which can work either in stand-alone or in grid-connected modes. This system is suitable for household applications, where a low-cost, simple and compact topology capable of autonomous operation is desirable. Furthermore, a control scheme for effective power flow management to provide uninterrupted power supply to the loads while injecting excess power into the grid is proposed. Thus, the proposed configuration and control scheme provide an elegant integration of PV and wind energy source.

This paper deals with the simulation and control of (PV/wind) hybrid systems including energy storage battery connected to the grid. Study of modeling and simulation on the entire PV/wind/battery hybrid system is carried out under Matlab/Simulink environment.

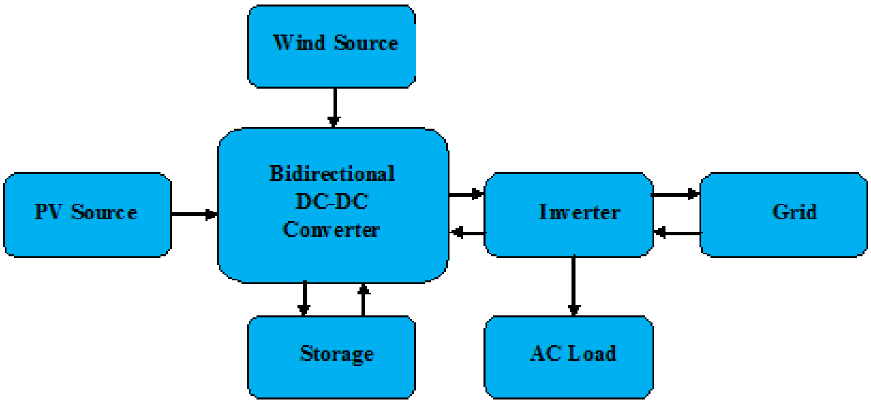

Figure 1. Block diagram of Proposed System

II. MODELLING AND CONTROL OF HYBRID SYSTEM

A. Photovoltaic Power System

Fig. 2 shows a simplified scheme of a standalone PV system with DC–DC buck converter. This section is devoted to PV module modeling which is a matrix of elementary cells that are the heart of PV systems.

The modeling of PV systems starts from the model of the elementary PV cell that is derived from that of the P–N junction [16].

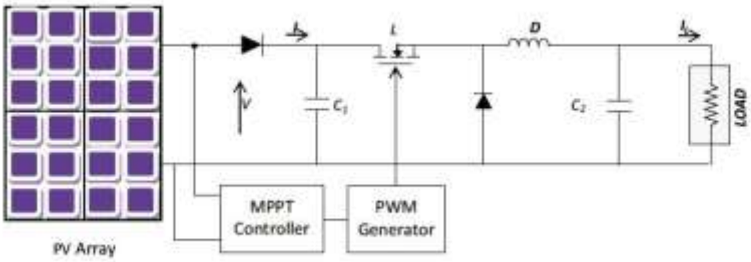

Figure 2. A PV system with a DC–DC buck converter

The PV cell combines the behavior of either voltage or current sources according to the operating point. This behavior can be obtained by connecting a sunlight-sensitive current source with a P–N junction of a semiconductor material being sensitive to sunlight and temperature. The dot-line square in Fig. 3 shows the model of the ideal PV cell. The DC current generated by the PV cell is expressed as follows.

$$I = I_{PV,\,cell} - I_{s,\,cell}\,(e^{V/aVT} - 1) \qquad (1)$$

The first term in Eq. (1), that is Ipv, cell, is proportional to the irradiance intensity whereas the second term, the diode current, expresses the non-linear relationship between the PV cell current and voltage. A practical PV cell, shown in Fig. 3, includes series and parallel resistances [17]. The series resistance represents the contact resistance of the elements constituting the PV cell while the parallel resistance models the leakage current of the P–N junction. This model is known as the single diode equivalent circuit of the PV cell. The larger number of diodes the equivalent circuit contains, the more accurate is the modeling of the PV cell behavior, however, at the expense of more computation complexity. The single diode model shown in Fig. 3 is adopted for this study, due to its simplicity.

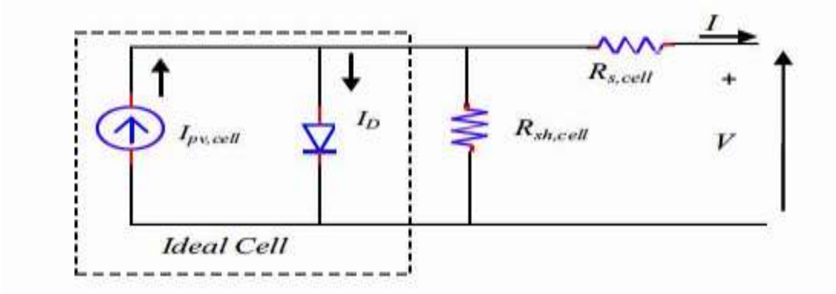

Figure 3. Equivalent circuit of an ideal and practical PV cell

Commercially photovoltaic devices are available as sets of series and/or parallel-connected PV cells combined into one item, the PV module, to produce higher voltage, current and power, as shown in Fig. 4.

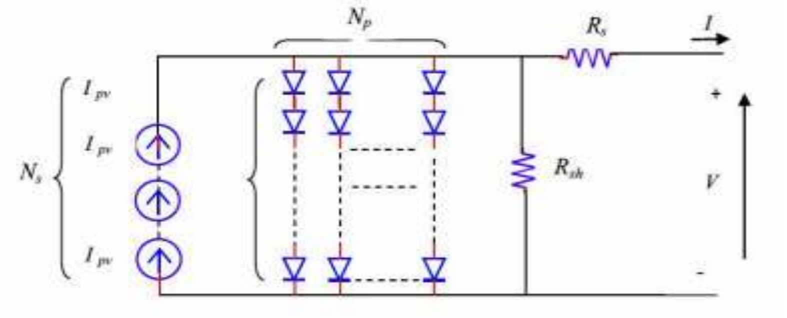

Figure 4. Equivalent circuit of PV module

The equation of the I–V characteristic of the PV module is obtained from Eq. (1) by including the equivalent module series resistance, shunt resistance and the number of cells connected in series and in parallel.

A PV module can be modeled as a current source that is dependent on the solar irradiance and temperature. The complex relationship between the temperature and irradiation results in a non-linear current–voltage characteristics. A typical I–V and P–V curve for the variations of irradiance and temperature is shown in Fig. 5 and 6, respectively. As can be observed, the MPP is not a fixed point; it fluctuates continuously as the temperature or the irradiance does. Due to this dynamics, the controller needs to track the MPP by updating the duty cycle of the converter at every control sample. A quicker response from the controller (to match the MPP) will result in better extraction of the PV energy and vice versa [18].

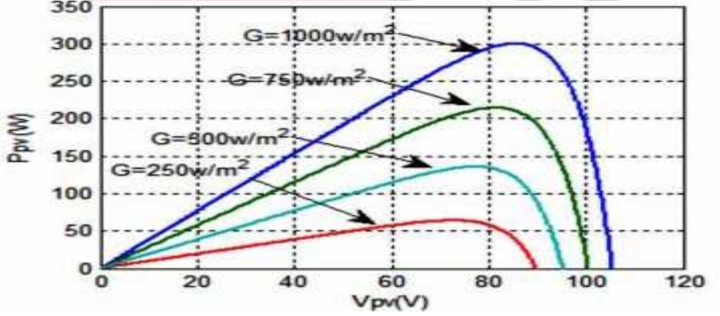

Figure 5. Solar cell voltage-current characteristics

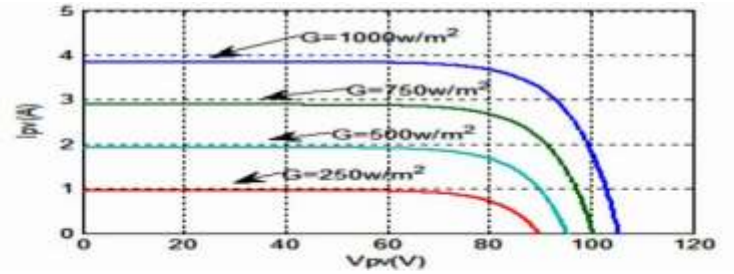

Figure 6. Voltage-power characteristics

B. Wind turbine power system

Depending on the aerodynamic characteristics, the wind power captured by the wind turbine can be expressed

$$P = \frac{1}{2} Cp (\lambda, \beta) \rho \pi R^2 V^3 \qquad (2)$$

Where Cp (λ, β) is the wind turbine power coefficient which is a function of λ and β, ρ is the air density, R is the radius of wind turbine blade, V is the wind speed, β is the blade pitch angle, and λ is the tip speed ratio:

$$\lambda = w R / V \qquad (3)$$

Where w is the wind turbine rotational speed. There exits an optimal tip speed ratio λopt that can maximize Cp and P. Then, the maximum wind power Pmax captured by wind turbine can be described as,

$$P \max = \frac{1}{2} \rho \pi R^5 (Cp, \max / \lambda^2_{opt}) w3 \qquad (4)$$

The output mechanical power versus rotational speed characteristic of wind turbine for different wind speeds is shown in Fig. 6, in which the dotted line shows the maximum power points for different wind turbine rotational speed w and different wind speed V. Each P–w curve is characterized by a unique turbine s peed corresponding to the maximum power point for that wind velocity. The peak power points in the P–w curves correspond to dP / dw = 0 [19].The mechanical power generated by turbine speed under different wind speeds and the target optimum power is shown in Fig.6. The objective of any MPPT controller is to keep the operating of the turbine on this curve [20].

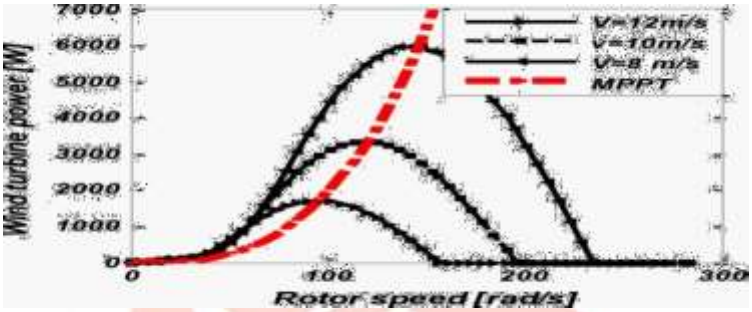

Figure 7. Mechanical power generated by turbine speed under different wind speeds

C. Storage power system

There are three types of battery models reported in the literature, specifically: experimental, electrochemical and electric circuit-based. Experimental and electrochemical models are not well suited to represent cell dynamics for the purpose of state-of-charge (SOC) estimations of battery packs. However, electric circuit-based models can be useful to represent electrical characteristics of batteries. The simplest electric model consists of an ideal voltage source in series with an internal resistance.

In this work, a generic battery model suitable for dynamic simulation presented in [21] is considered. This model assumes that the battery is composed of a controlled-voltage source and a series resistance, as shown in Fig.8.

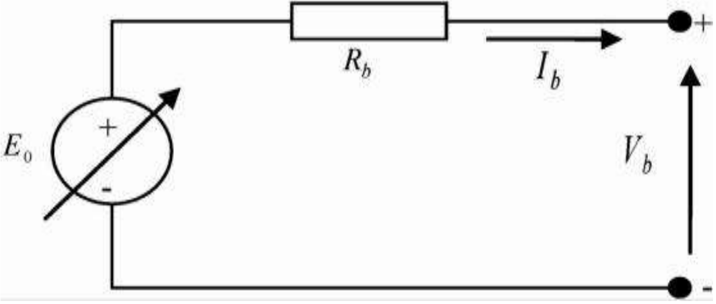

Figure 8. A generic battery model

III. PROPOSED CONTROL SCHEME

A grid-connected hybrid PV–wind-battery-based system consisting of four power sources (grid, PV, wind source, and battery), and three power sinks (grid, battery, and load) requires a control scheme for power flow management to balance the power flow among these sources.

The control philosophy for power flow management of the multisource system is developed based on the power balance principle. In the stand-alone case, PV and wind source generate their corresponding MPP power, and load takes the required power. In this case, the power balance is achieved by charging the battery until it reaches its maximum charging current limit I_b max. Upon reaching this limit, to ensure power balance, one of the sources or both have to deviate from their MPP power based on the load demand. In the grid-connected system, both the sources always operate at their MPP. In the absence of both the sources, the power is drawn from the grid to charge the battery as and when required. The equation for the power balance of the system is given by

$$Vpv\ Ipv + Vw\ Iw = Vb\ Ib + Vg\ Ig \qquad (5)$$

The peak value of the output voltage for a single-phase full-bridge inverter is,

$$V = ma\ Vdc \qquad (6)$$

and the dc-link voltage is,.

$$Vdc = n\ (Vpv + Vb) \qquad (7)$$

Hence, substituting for Vdc in (4) gives

$$Vg = 1/\sqrt{}\,2\ ma\ n\ (VPV + Vb) \qquad (8)$$

In the boost half-bridge converter,

$$Vw = (1 - Dw)\ (Vpv + Vb) \qquad (9)$$

Now, substituting Vw and Vg in (3),

$$Vpv\ Ipv + (Vpv + Vb)\ (1 - Dw)\ Iw = Vb\ Ib + 1/\sqrt{}\,2\ ma\ n\ (VPV + Vb)\ Ig \qquad (10)$$

From equation (10), it is evident that if there is a change in power extracted from either PV or wind source, the battery current can be regulated by controlling the grid current I_g. To ensure the supply of uninterrupted power to critical loads, priority is given to charge the batteries. After reaching the maximum battery charging current limit I_b max, the surplus power from renewable sources is fed to the grid. In the absence of these sources, battery is charged from the grid.

IV. SIMULATION RESULTS AND DISCUSSIONS

Detailed simulations studies are carried out on the MATLAB/Simulink platform are shown in figure 9. The results obtained for various operating conditions are presented in this section.

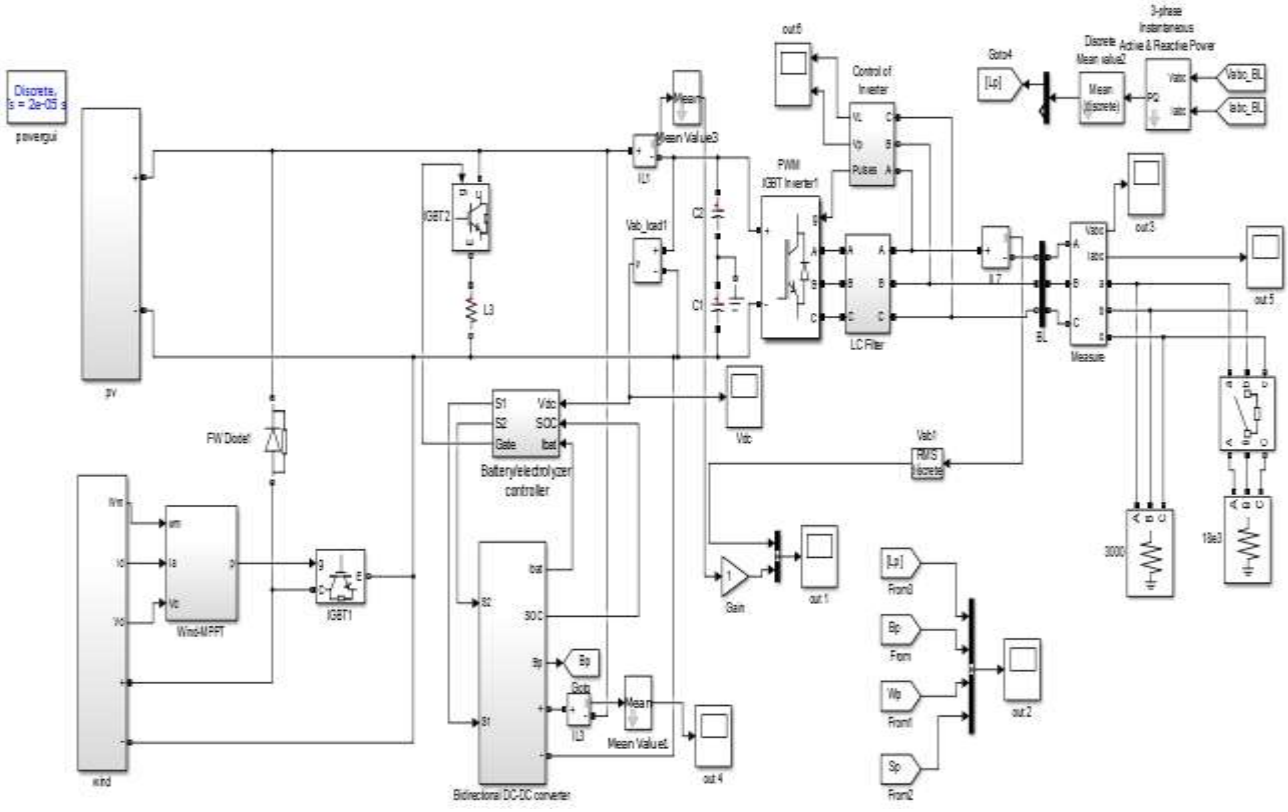

Figure 9: Proposed grid-connected hybrid system with Bidirectional DC-DC converter using MATLAB

The values for source-1 (PV source) is set at 35.4 V (Vmpp) and 14.8 A (Impp), and for source-2 (wind source) is set at 37.5 V (Vmpp) and 8 A (Impp). It can be seen that Vpv and Ipv of source-1, and Vw and Iw of source-2 attain set values required for MPP operation. The battery charged with the constant magnitude of current, and the remaining power is fed to the grid.

The system response for step changes in the source-1 insolation level while operating in the MPPT mode is shown in Fig. 10. Until 2 s, both the sources are operating at MPPT and charging the battery with constant current and the remaining power is fed to the grid. At instant 2 s, the source-1 insolation level is increased. As a result, the source-1 power increases, and both the sources continue to operate at MPPT. Though the source-1 power has increased, the battery is still charged with the same magnitude of current, and power balance is achieved by increasing the power supplied to the grid. At instant 4 s, the insolation of source-1 is brought to the same level as before 2 s.

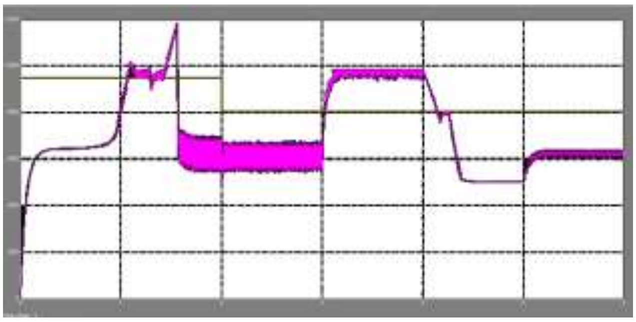

Figure 10. Solar output Power

The power supplied by source-1 decreases. Battery continues to get charged at the same magnitude of current, and power injected into the grid decreases. The same results are obtained for step changes in the source-2 wind speed level. These results are shown in Fig. 11.

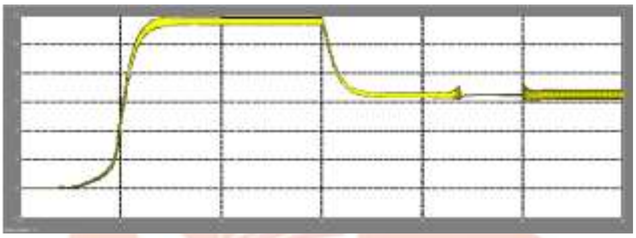

Figure 11. Wind output Power

The response of the system in the absence of source-1 is shown in Fig. 11. Until time 2s, both the sources are generating the power by operating at their corresponding MPPT and charging the battery at constant magnitude of current, and the remaining power is being fed to the grid. At 2 s, source-1 is disconnected from the system. The charging current of the battery remains constant, while the injected power to the grid reduces. At instant 4 s, source-1 is brought back into the system. There is no change in the charging rate of the battery. The additional power is fed to the grid. The same results are obtained in the absence of source-2. Fig. 12 shows the results in the absence of both PV and wind power, battery is charged from the grid.

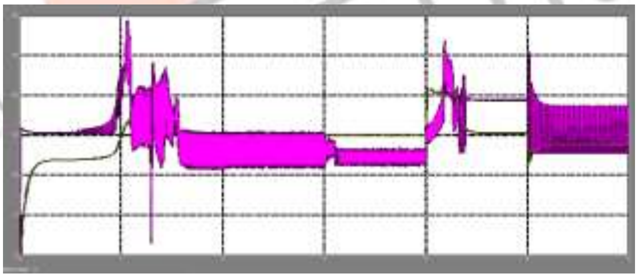

Figure 12. Battery output Power

V. CONCLUSION

To make best use of renewable energy sources nature has provided abundant opportunities. In this paper grid-connected hybrid PV–wind-battery-based power transfer scheme feeding ac loads is presented. To extract maximum energy from the proposed hybrid system provides a smart integration of PV and wind sources. It produces a compact converter system with reduced cost. A flexible control approach which attains a better utilization of PV, wind power, battery capacities without affecting the battery life. Detailed simulation studies are carried out to ascertain the viability of the scheme. The proposed design is capable of supplying continuous power to ac loads, and ensures the evacuation of surplus PV and wind power into the grid.

REFERENCES

[1] Natsheh, E.M.; Albarbar, A.; Yazdani, J., "Modeling and control for smart grid integration of solar/wind energy conversion system," 2nd IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies (ISGT Europe),pp.1-8, 5-7 Dec. 2011.

[2] Bagen; Billinton, R., "Evaluation of Different Operating Strategies in Small Stand-Alone Power Systems," IEEE Transactions on Energy Conversion, vol.20, no.3, pp. 654-660, Sept. 2005.

[3] S. M. Shaahid and M. A. Elhadidy, “Opportunities for utilization of stand-alone hybrid (photovoltaic + diesel + battery) power systems in hot climates,” Renewable Energy, vol. 28, no. 11, pp. 1741–1753, 2003.

[4] Yuncong Jiang; Qahouq, J.A.A.; Orabi, M., "AC PV solar system distributed architecture with maximum power point tracking," IEEE 34th International Telecommunications Energy Conference (INTELEC), pp.1-5, Sept. 30 2012-Oct. 4 2012.

[5] Y.-M. Chen, C.-S. Cheng and H.-C. Wu, “Grid-connected hybrid PV/wind power generation system with improved DC bus voltage regulation strategy,” in Proc. 21st Annu. IEEE Appl. Power Electron. Conf. Expo. (APEC), Texas, USA, Mar. 2006, pp. 1088–1094.

[6] Y.-M. Chen, Y.-C. Liu, S.-C. Hung, and C.-S. Cheng, “Multi-input inverter for grid-connected hybrid PV/wind power system,” IEEE Trans. Power Electron., vol. 22, no. 3, pp. 1070–1077, May 2007.

[7] H. C. Chiang, T. T. Ma, Y. H. Cheng, J. M. Chang, and W. N. Chang, “Design and implementation of a hybrid regenerative power system combining grid-tie and uninterruptible power supply functions,” IET Renew. Power Generate, vol. 4, no. 1, pp. 85–99, Jan. 2010.

[8] F. Giraud and Z. M. Salameh, “Steady-state performance of a grid-connected rooftop hybrid wind-photovoltaic power system with battery storage,” IEEE Trans. Energy Convers., vol. 16, no. 1, pp. 1–7, Mar. 2001.

[9] S.-K. Kim, J.-H. Jeon, C.-H. Cho, J.-B. Ahn, and S.-H. Kwon, “Dynamic modeling and control of a grid-connected hybrid generation system with versatile power transfer,” IEEE Trans. Ind. Electron., vol. 55, no. 4, pp. 1677–1688, Apr. 2008.

[10] A. Khaligh, J. Cao, and Y. J. Lee, “A multiple-input DC–DC converter topology,” IEEE Trans. Power Electron., vol. 24, no. 3, pp. 862–868, Mar. 2009.

[11] R.-J. Wai, C.-Y. Lin, J.-J. Liaw, and Y.-R. Chang, “Newly designed ZVS multi-input converter,” IEEE Trans. Ind. Electron., vol. 58, no. 2,pp. 555–566, Feb. 2011.

[12] R.-J. Wai, C.-Y. Lin, and Y.-R. Chang, “High step-up bidirectional isolated converter with two input power sources,” IEEE Trans. Ind. Electron., vol. 56, no. 7, pp. 2629–2643, Jul. 2009.

[13] S.-Y. Yu and A. Kwasinski, “Analysis of soft-switching isolated time-sharing multiple-input converters for DC distribution systems,” IEEE Trans. Power Electron., vol. 28, no. 4, pp. 1783–1794, Apr. 2013.

[14] L. Kumar and S. Jain, “A multiple input dc-dc converter for interfacing of battery/ultra-capacitor in EVs/HEVs/FCVs,” in Proc. IEEE 5th IICPE, Dec. 2012, pp. 1–6.

[15] H. Wu, K. Sun, S. Ding, and Y. Xing, “Topology derivation of non-isolated three-port DC–DC converters from DIC and DOC,” IEEE Trans. Power Electron., vol. 28, no. 7, pp. 3297–3307, Jul. 2013.

[16] Paul C. P. Chao, Wei-Dar Chen, Chih-Kuo Chang. Maximum power tracking of a generic photovoltaic system via a fuzzy controller and a two-stage DC–DC converter. 30 September 2011 / Accepted: 23 April 2012 / Published online: 9 May 2012.

[17] Villalva MG, Gazoli JR. Comprehensive approach to modeling and simulation of photovoltaic arrays. IEEE Trans Power Electron 2009; 24:1198–208.

[18] Zainal Salam, Jubaer Ahmed, Benny S. Merugu “The application of soft computing methods for MPPT of PV system: A technological and status review” ELSEVIER Applied Energy 107 (2013) 135–148.

[19] Nur Atharah Kamarzamana, Chee Wei Tan, “A comprehensive review of maximum power point tracking algorithms for photovoltaic systems,” Renewable and Sustainable Energy Reviews, vol.37, pp-585-598, Sep 2014.

[20] Ridha BENADU', Brahim KHIARI’, Anis SELLAMI “Predictive Current Control Strategy for a Three-Phase Grid Connected Photovoltaic Wind Hybrid System” 978-1-4673-9768-1/16/$31.00 ©2016 IEEE.

[21] Dong-Min Miao; Jian-Xin Shen, "Comparative study on permanent magnet synchronous generator systems with various power conversion topologies," 2013 Fourth International Conference on Power Engineering, Energy and Electrical Drives (POWERENG), pp.1738-1743, 13-17, May 2013.