Operation and Control of Wind/Fuel Cell BasedHybrid Microgrid in Grid Connected Mode

B.Rohith kumar[1], N.Narasimhulu[2]

[1]M.Tech, Department of electrical Engineering , SKD Engineering college,gooty, A.P, India
[2] M.Tech , Associate Professor & Head of Electrical & Electronics Engineering department , Department of electrical Engineering , SKD Engineering college, gooty,A.P, India

---***---

Abstract - ***A microgrid is a collection of loads and micro sources that operate as a single controllable system to provide both heat and power to a small area. A hybrid grid consists of both AC and DC grid. AC power sources and loads are connected to the AC grid whereas DC power sources and loads are connected to the DC grid and both the grids are connected together by a bidirectional converter. In this paper, a hybrid microgrid consisting a wind turbine and fuel cell stack is proposed to reduce the process of multiple AC-DC-AC and DC-AC-DC conversions which are commonly seen in an individual AC grid or DC grid. The proposed hybrid grid is operating in grid connected mode. The various control mechanisms are implemented for the power electronic converters for smooth power exchange between AC and DC grids and for stable operation of the proposed hybrid microgrid under various resource conditions. A small hybrid grid is considered and simulated using the MATLAB/SIMULINK environment.***

Keywords—Hybrid grid; Fuel cell; Wind turbine generator; Grid connected mode; Bidirectional converter

I. INTRODUCTION

For the past hundred years, the electrical power system is dominated mainly by the three phase AC power system due to various reasons such as efficient transformation of AC power at various voltage levels, for long distance transmission and for inherent characteristic from fossil fuel driven rotating machines for electric power generation. The basic structure of the present day power system is the integration of generation, transmission and distribution system. In conventional power plants, electricity is produced from fossil fuels such as coal, oil and natural gas and these generating stations will be located far away from the load centers due to safety concern and due to the availability of energy sources. Power generated from these stations are then transmitted over long distance at high voltage levels to the load centers and then delivered to the customer load points with the help of sub-transmission networks and distribution networks. This leads to the higher transmission losses and also the complexity of the system increases. Also, the environmental effects caused by these fossil fuels are high due to their high carbon emission. As a result, renewable energy resources such as wind, tidal, solar, small hydropower and biomass are becoming the best option for generating electric power due to their low environmental effects. The current power system is undergoing considerable amount of changes, because more renewable energy based power conversion systems are connected to the low voltage distribution systems as distributed generators due to their environment friendliness and reliability. On the other hand, dc loads such as LED lights, refrigerators and electric vehicles are increasing to save electric energy and to reduce emissions. In the present system, these loads are supplied by means of AC power sources along with the help of power electronics converters. This further increases the cost of the system and appliances as it requires additional converters. When power can be supplied by renewable energy based distributed generators, there is no need for high voltage transmission and also transmission losses can be reduced. AC microgrids have been developed to enable the connection of renewable energy based power generating sources to the present AC system [2]- [5]. As stated earlier, due to increasing amount of DC loads in residential, industrial and commercial buildings the power system loads are becoming DC dominated. In many industries DC power is required for the speed control purpose. If these loads are supplied by means of AC grid, then it requires embedded AC/DC converters and DC/DC converters to supply different DC voltages. As a result, DC grids are resurging due to the various advantages of renewable energy sources and their inherent advantage of supplying DC loads [6], [7].

The multiple reverse conversions associated with an individual ac or dc grid leads to additional costs and losses and hence reduces the overall efficiency of the system. A hybrid AC/DC microgrid helps to minimize these multiple reverse conversion problem which normally associated with individual AC grids or DC grids [1]. In this hybrid system AC loads are connected to the AC grid and DC loads are connected to the DC grid and the AC and DC grids are connected through a bidirectional converter. The proposed architecture, operation and control of the hybrid microgrid are more complicated than those of individual DC grid or AC grid. The various control mechanisms for controlling the converters [14] and to maintain the stable system operation in grid connected mode is explained in the following sections.

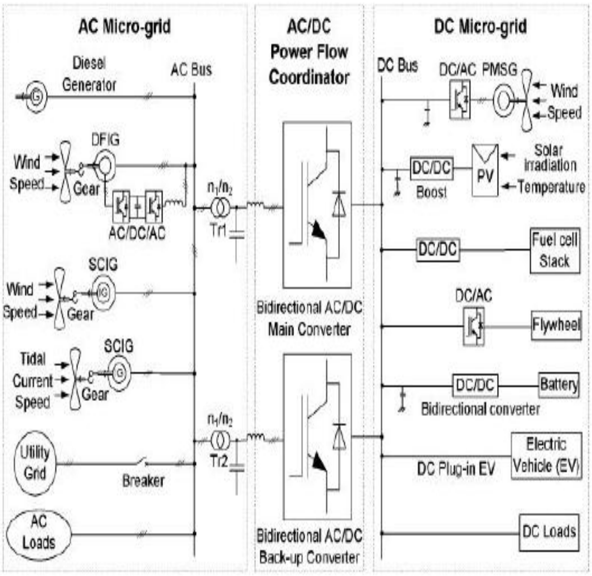

Fig -1: A typical hybrid AC/DC microgrid

2. A TYPICAL HYBRID AC/DC MICROGRID

Fig. 1 shows the typical structure of a hybrid AC/DC microgrid [1]. It consists of AC grid and DC grid and they are interconnected with the help of three phase bidirectional AC/DC converter (main converter) and a transformer. The three phase AC network of the hybrid grid is connected to the utility grid through a transformer and a circuit breaker. AC power sources such as tidal power plant, small diesel generator and wind turbine generator (WTG) are connected to the AC grid. AC energy storage devices such as flywheels are connected to the AC grid through converters. All types of AC loads can be connected to the AC network whereas DC power sources such as solar panels, fuel cell stacks are connected on the DC grid through DC/DC power converters. DC loads and energy storage devices such as batteries and super capacitors and electric vehicles can be connected to the DC grid through DC/DC converters.

3. HYBRID GRID CONFIGURATION AND NETWORK MODELING

3.1 Grid Configuration

Fig. 2 shows the compact representation of the proposed hybrid microgrid. The proposed system is modeled using Matlab/Simulink environment to simulate the system operation and control. In this system, 50 kW fuel cells stacks are used as a DC power source and it is connected to the DC grid through a DC/DC boost converter. The capacitor is used to reduce the ripples if the fuel cell output voltage. A 20 kW Doubly Fed Induction Generator (DFIG) WTG system is taken as AC power source and it is connected to the AC grid through a back to back AC/DC/AC converter. A battery is connected to the DC network as an energy storage device through a bidirectional DC/DC converter. AC loads and DC loads are connected correspondingly to AC and DC grids. The network equations are given in [1].

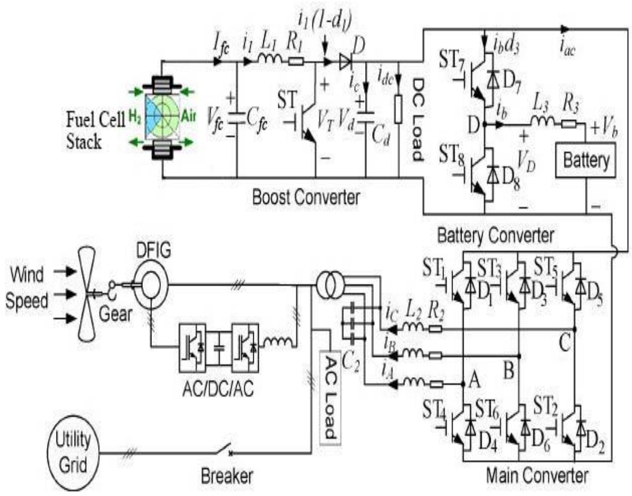

Fig -2: Compact representation of the proposed hybrid grid

3.2 Modeling of the Fuel Cell

A fuel cell is a device that converts chemical energy from fuels into electric energy with the help of anode, cathode and an electrolyte. In this paper, Solid Oxide Fuel Cell (SOFC) is used and it uses solid oxide or ceramic as an electrolyte. The output voltage of the fuel cell is given by the equation (1).

$$V_{fc}=E_{fc}-V_{act,fc}-V_{ohm,fc}-V_{conc,fc} \quad (1)$$

Where V_{fc} and E_{fc} are the fuel cell output voltage and Internal voltage. $V_{act,fc}$, $V_{ohm,fc}$ and $V_{conc,fc}$ are activation, ohmic and concentration voltage drops inside the fuel cell [12]. The total power generated by the fuel cell stack is represented as:

$$P_{fc}=N_0V_{fc}I_{fc} \quad (2)$$

Where P_{fc} is the total power generated by the fuel cell stack. N_0 is the number of cells in the stack series, I_{fc} is the stack current [13].

3.3 Modeling of Wind Turbine Generator

There are different types of wind turbine generator and one of the commonly used WTG is the DFIG. The voltage equations of an induction motor are given by [10], [11] and the power output from the WTG is represented as:

$$P_m = 0.5\rho A C_p(\lambda,\beta)\bar{V}_w^3 \quad (3)$$

Where P_m is the output power, ȡ is the air density, A is the rotor swept area, $Cp(\lambda,\ddot{u})$ is the power coefficient and it is function of speed ratio (λ) and pitch angle (ȕ).and V_W is the wind speed.

The voltage equations of the induction motor in rotating d-q coordinates and the parameters used to simulate DFIG wind turbine is given in [1].

3.4. Modeling of Battery

The battery is modeled based on nonlinear voltage source in series with the internal resistance and the output voltage mainly depends on the current and state of charge (SOC) of the battery, which is a nonlinear function of current and time [8], [9]. State of a battery is represented by two parameters i.e., terminal voltage and state of charge. Terminal voltage is represented by equation (4).

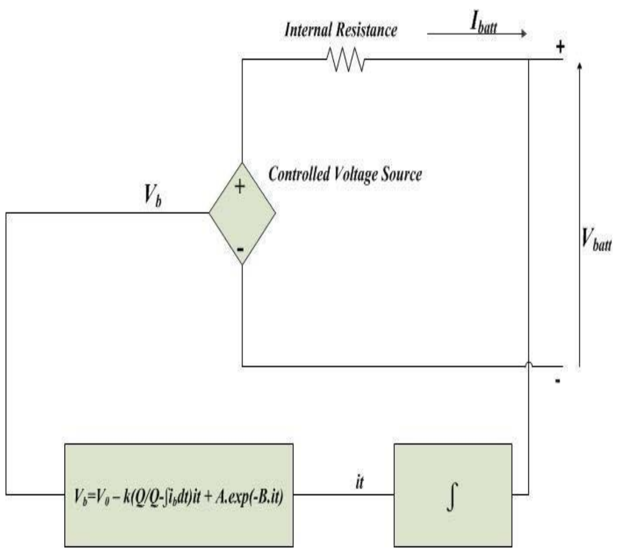

Fig -3: Model of a battery

$$V_b = V_o + R_b i_b - K\frac{Q}{Q-\int i_b\,dt} + A * \exp(B\int i_b\,dt) \quad (4)$$

SOC of a battery is represented as:

$$SOC = 100\left(1+\frac{\int i_b\,dt}{Q}\right) \quad (5)$$

Where R_b is the internal resistance of the battery, i_b is the battery charging current, V_O is the open circuit voltage of the battery, Q is the battery capacity, K is the polarization voltage, A is the exponential voltage and B is the exponential capacity. Fig. 3 shows the basic model of a battery [9].

The term $KQ\ /(Q-\int i_b dt)$ in equation (4) represents the non-linear voltage which changes with the magnitude of current and state of charge of battery.

4. GRID OPERATION AND CONTROL

There are five types of converters used in the hybrid grid and these converters have to be coordinately controlled for supplying reliable power to AC and DC loads under variable resource conditions. Hybrid microgrid can be operated in two modes namely grid-tied mode and isolated (autonomous) mode. In this paper, grid tied mode of operation is analyzed and simulated for the proposed system. The AC/DC/AC converter in the WTG is used to regulate the rotor side current to extract maximum power from wind turbine and to synchronize with the AC grid. In this mode, the hybrid grid is connected to the utility grid and here the utility grid will acts as a swing bus and any power demand will be balanced by the utility grid.In case, if there is any power surplus on the DC side, the excess power will be transferred to the utility grid. In this case the main converter will acts as inverter. In grid-tied mode, the function of the energy storage system is to prevent the frequent power transfer between DC and other grids. So, the role of energy storage device is not much important and can be neglected. The main function of the bidirectional main converter is to maintain smooth power exchange between AC and DC grids and to provide stable DC link voltage. The basic control mechanisms for the WTG [11] and for the operation of battery converter [8], [9] have been studied and used here to control the overall operation of the hybridmicrogrid.Fig. 4 shows the control scheme for controlling the main converter during grid tied mode of operation. For smooth power exchange between the AC and DC grids and to supply the necessary reactive power, PQ control is used for controlling the main converter. The DC bus voltage is maintained to constant value through PI controller. Output of the DC-link voltage loop through a PI controller is set as an active current reference (id*) and the reactive current reference (iq*) is set to zero.

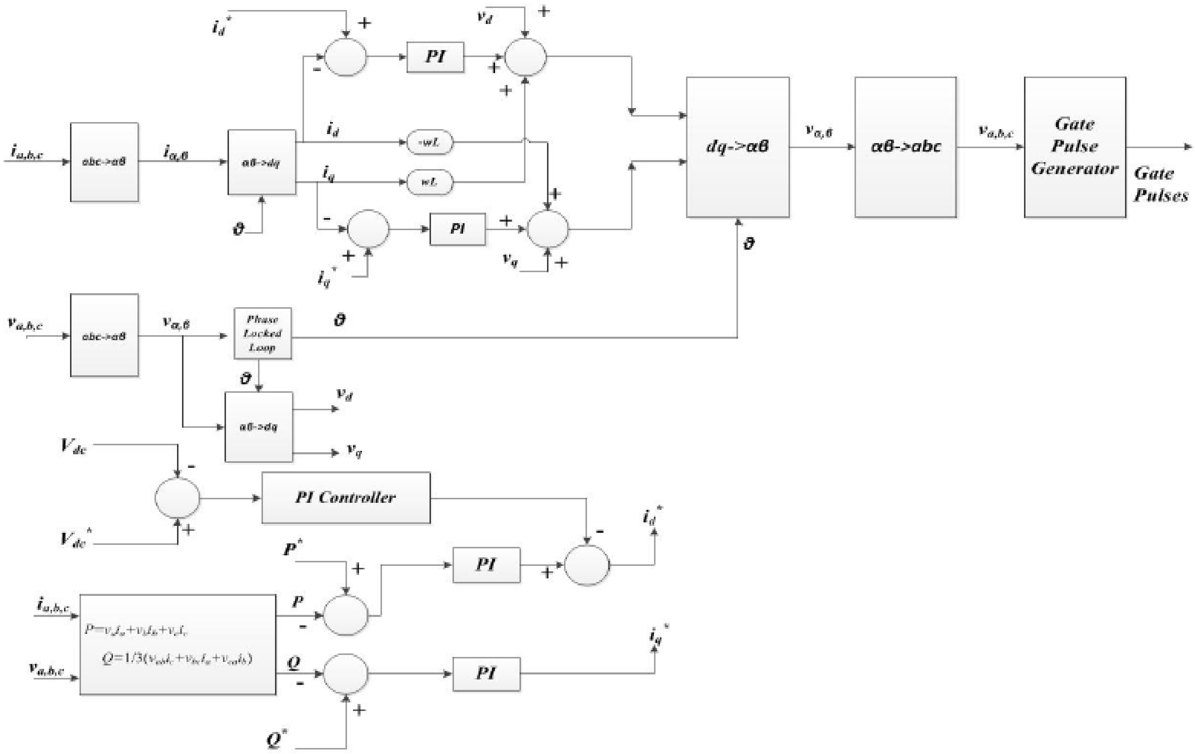

Fig -4: PQ control scheme for controlling the main converter

The active current (id) and the reactive current (iq) is calculated from the line current through Clarke and Park transformation. When there is an excess power on the DC grid, the main controller is controlled to transfer the power from DC grid to AC grid. In this situation, the sign of active current (id) and its reference (id*) are both positive. If there is any sudden increase in DC loads, there will be a power shortage on the DC grid and so the main converter is controlled to supply power from AC grid to DC grid. In this situation, the sign of active current (id) and its reference (id*) are both negative.

5. SIMULATION RESULTS AND DISCUSSION

The proposed hybrid microgrid system is simulated using MATLAB/SIMULINK environment A 50 kW fuel cell stack and 20 kW WTG is taken and the component parameters for the hybrid grid are given in [1] and it is used to simulate the operation of the hybrid grid. The proposed system is controlled to operate in grid-tied mode and the battery is assumed to be fully charged.

In the grid tied mode, main converter is controlled through PQ control and the following results were obtained. Fig. 5 shows the output voltage of the fuel cell stack and then this voltage is boosted to 500 V through a DC/DC boost converter and the corresponding waveform is shown in the Fig. 6. The output power obtained from the fuel cell stack is shown in Fig. 7. When the AC side is loaded heavily, then there will be a power demand on the AC side and so the excess power on the DC grid will be transferred to AC grid. Fig. 8 shows the power flow on the AC side and Fig. 9 shows the corresponding active current and its reference value. It is observed that both id and i * are positive and so the power flow is from DC side to AC side.

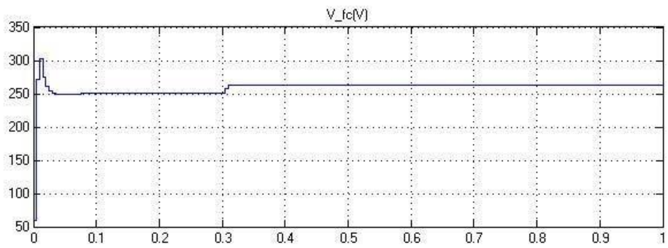

Fig -5: Output voltage of Fuel cell stack

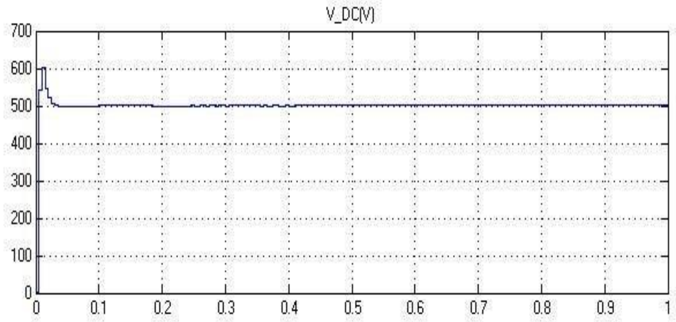

Fig -6: Output voltage across the DC load

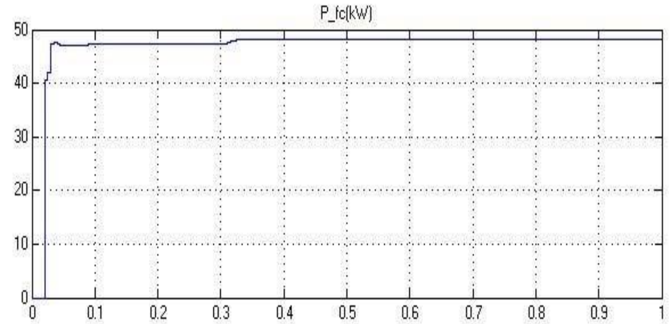

Fig -7: Output power from fuel cell stack

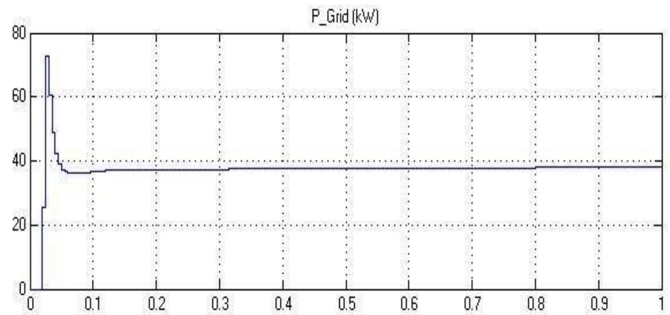

Fig -8: Power flow on AC side

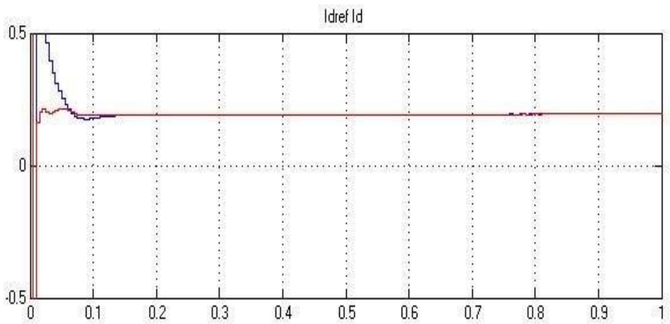

Fig -9: Active current and its reference when power demand on AC side

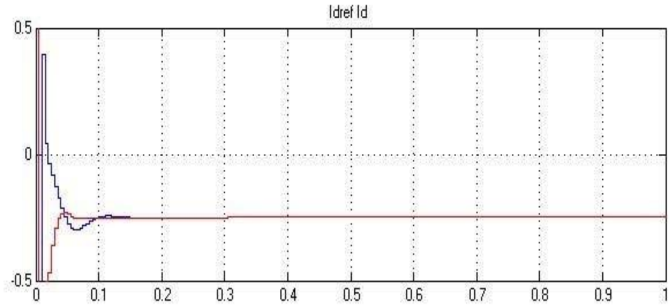

Fig -10: Active current and its reference when power demand on DC side

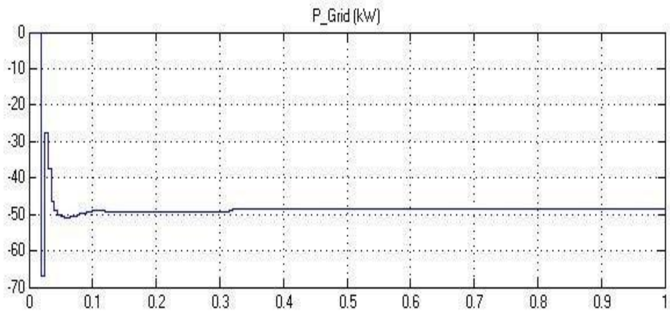

Fig -11: Power flow on AC side

When DC grid is loaded heavily, then there will be power demand on the DC grid. Fig. 10 shows the active current and its reference value when there is a power demand on the DC grid. It is seen that both the values are negative and so the power flow will be from AC to DC grid and the corresponding power flow on the AC grid is shown in the Fig. 11. As fuel cells are the constant DC power source, it can be effectively used along with the WTG to manage heavier loads on the AC side especially during low wind speed.

6. CONCLUSION

The proposed architecture, operation and control of the hybrid microgrid consisting of fuel cell stack and DFIG wind turbine generator is studied and simulated using Matlab/Simulink environment. Converters are coordinately controlled for smooth power exchange between AC and DC grids. Although the hybrid grid can reduce the process of multiple reverse conversions in an AC or DC grid, there are so many technical challenges lies for the implementation of the hybrid grid. As power rating of the SOFC is high, it can be effectively used along with WTG to supply the loads without any interruption. The hybrid microgrid is one of the best options for small isolated industrial plants as the major power supply.

REFERENCES

[1] Xiong Liu, Peng Wang, and Poh Chiang Loh, "A hybrid AC/DC microgrid and its coordination control," IEEE Trans. Smart Grid, vol. 2, pp. 278-286 June. 2011.
[2] F. D. Kanellos, A. I. Tsouchnikas, N. D. Hatziargyriou, "Micro-Grid simulation during grid-connected and islanded modes of operation", International Conference on Power Systems Transients (IPST 05) in Montreal, Canada on June 19-23, 2005.
[3] Ramon Zamora, Anurag K. Srivastava, "Controls for microgrids with storage: Review, challenges, and research needs", Renewable and Sustainable Energy Reviews, Volume 14, Issue 7, pp. 2009–2018 September 2010.
[4] A. Arulampalam, N. Mithulananthan, R.C. Bansal, and T.K. Saba, "Micro-grid control of PV-Wind-Diesel hybrid system with islanded and grid connected operations," in Proc. IEEE Int. Conf. Sustainable Energy Technologies, pp. 1-5, Dec. 2010.
[5] M. Barnes, J. Kondoh, H. Asano, and J. Oyarzabal, "Real-World microGrids- An overview," in IEEE Int. Conf. Systems of Systems Engineering, pp.1-8, April 2007.
[6] Lee, B.Han, Y.Seo, "Operational analysis of DC Micro-grid using detailed model of distributed generation," Energy Conversion Congress and Exposition (ECCE), pp.3153-3160, 12-16 Sept. 2010
[7] Guiting Xue, Yan Zhang, Dakang Zhu, "A distributed control strategy for an isolated residential DC microgrid," Research Journal of Applied Sciences, Engineering and Technology vol.4, Issue 20 pp. 4138-4144, Oct. 2012.
[8] Yinjiao Xing, Eden W.M.Ma, Kwok L.Tsui and Michael Pecht, "Battery management systems in electric and hybrid vehicles," Energies, vol. 4, Issue 11, pp. 1840-1857, Oct. 2011.
[9] Tremblay O, Dessaint L.A, Dekkiche A.I, "A Generic Battery Model for the Dynamic Simulation of Hybrid Electric Vehicles," Vehicle Power and Propulsion Conference, pp.284-289, Sept. 2007.
[10] Adrea Junyent, Oriol Gomis-Bellmunt, Andreas Sumper, Marc Sala, "Modeling and control of the doubly fed induction generator wind turbine," Simulation modeling practive and theory, vol. 18, Issue 9, pp. 1365–1381 October 2010.
[11] Balasubramaniam Babypriya and Rajapalan Anita, "Modeling, simulation and analysis of doubly fed induction generator for wind turbines," Journal of Electrical Engineering, Vol.60, No.2, pp. 79-85, 2009.
[12] M. H. Nehrir and C. Wang, "Modeling and control of fuel cells: distributed generation applications," Wiley-IEEE Press, February 2009.
[13] C. Boccaletti, G. Duni, G. Fabbri, E. Santini, "Simulation models of fuel cell systems," ICEM 2006 - 17th Int. Conf. on Electrical Machines, Chania (Greece), 2006

BIOGRAPHIES

Mr.B. Rohith Kumar is pursuing his M.Tech in the stream of Electrical Power System from Srikrishna Devaraya Engineering College, Gooty of Anantapuramu district (A.P). He completed his B.Tech in the stream of Electrical & Electronics Engineering, from Sir Vishveswaraiah Iinstitute of Science and Technology, Madanapalle. His areas of interest are Electrical Power System, Control Systems.

Mr. N. Narasimhulu (Namala Narasimhulu) has completed his professional career of education in B.Tech (EEE) from JNTU Hyderabad in the year 2003. He obtained M.Tech degree from JNTU, HYDERABAD, in the year 2008. He is pursuing PHD in the area of Power System in JNTUA, Anantapuramu. He has worked as Assistant Professor from 2003-2008 and at present working as an Associate Professor and Head of the EEE Department in Srikrishna Devaraya Engineering College, Gooty of Anantapuramu district (A.P). He has published eight papers and attempts for further progress in technical field. He is a life Member of Indian Society for Technical Education (India). His areas of interests include Electrical Power Systems, Network Analysis & Electrical Machines.