Volume : 2 | Issue : 9 | September 2013 • ISSN No 2277 - 8179

A Fuel Cell Based Multilevel Dc-Dc Boost Converter System with Pi and Fuzzy Control

Engineering

KEYWORDS : DC-DC boost converter, Fuel cell, distributed generation systems (DGS), Fuzzy Controller.

B.SHANTHI HAVEELA	M-Tech Scholar, Power Electronics & Electrical Drives Department of Electrical and Electronics Engineering, Gudlavalleru Engineering College, Krishna, (A.P), India
D.KOTESWARA RAJU	Asst. Professor, Department of Electrical and Electronics Engineering, Gudlavalleru Engineering College Krishna, (A.P), India
Dr. P.SANGAMESWARA RAJU	Professor and Head of the Department, Department of Electrical and Electronics Engineering, SVU College of Engineering, Sri Venkateswara University, Tirupati,(A.P),India

ABSTRACT

The distributed generation (DG) systems based on the renewable energy sources have rapidly developed in recent years. These DG systems are powered by micro sources such as fuel cells, photovoltaic (PV) systems, and batteries. Fuel cells are considered to be one of the most promising sources of distributed energy because of their high efficiency, low environmental impact and scalability. Non-isolated high step-up DC-DC converters are required in the industrial applications. Many of these conventional DC–DC converters have the disadvantages of operating at high duty-cycle, high switch voltage stress and high diode peak current. A three-level step up converter is implemented to boost the fuel cell stack voltage of 96V to 340V. The proposed converter consists a system of fuel cell based Multilevel DC-DC converter with PI and Fuzzy controller is modeled and simulated by using Matlab/Simulink.

I. INTRODUCTION

Fuel cells are environmentally sound renewable energy sources that are capable of operating at efficiencies greater than traditional energy production methods. Distributed generation (DG) systems based on renewable energy sources (RES) have experienced a fast development in recent years with more DG units being integrated into the power system. The fuel cells are electrochemical devices that convert chemical energy directly into electrical energy by the reaction of hydrogen from fuel and oxygen from the air without regard to climate conditions, unlike hydro or wind turbines and photovoltaic array.

Fuel cell construction:

In 1839, William Grove discovered that by combining Oxygen and hydrogen in a particular configuration, electricity could be generated. Although this discovery was made more than 160 years ago, the basic operating principle discovered still applies. A basic schematic diagram of a fuel cell is shown in Fig. 1. Hydrogen is applied to the anode where a catalyst separates the hydrogen into electrons and positive hydrogen ions. A membrane separating the anode and cathode allows the positive hydrogen ions to permeate through while rejecting the electrons. This forces the electrons to take the provided electrical path, or circuit, to the cathode. Once the electrons reach the cathode, they recombine with the oxygen and hydrogen ions to form water. The following basic reactions demonstrate the process:

Anode Side : $2H_2 \rightarrow 4H^+ + 4e^-$

Cathode Side : $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

Net Reaction : $2H_2 + O_2 \rightarrow 2H_2O$

When pure hydrogen is used as the fuel, only electricity and water are generated from the fuel cell. This attributes the fuel cell as an environmentally friendly source of energy.

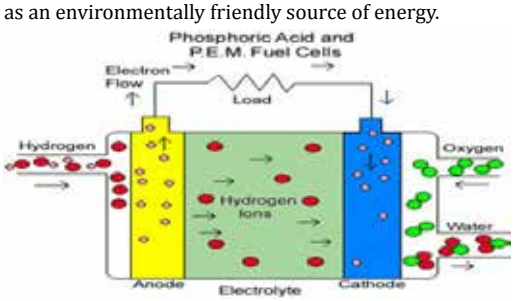


Fig.1. Basic schematic of fuel cell operation

2.2 Converters

2.2.1 DC/DC converter:

In the calculations on the fuel cell stack the number of cells is chosen with respect to that the voltage over the stack should have the same voltage as the grid voltage. If for some reason the number of cells is chosen differently a DC/DC converter can be used to achieve the desired output voltage level [5]. The voltage over the stack is normally not constant and when the current increases there will be a voltage drop. In fuel cells this voltage drop is greater than in normal electrical power generators. In this case there is also need for a DC/DC converter to solve this problem [8].

2.2.2 DC/AC Converter:

The output of fuel cell stack is a DC current. In Ships, the fuel cells will be used to deliver power to 400/230 volts three phase system and for this purpose an inverter will be needed. When using a DC/AC converter here is no use for a DC/DC converter because it is also capable of regulating the output voltage level [9].

2.3. Fuzzy Logic

2.3.1. Fuzzy Logic Control

Fuzzy logic is a problem solving methodology, just like a Logic control and a Linear Control. This control logic was invented by Professor Lotfi Zadeh of University of California-Berkeley in the mid-1960s and provides a representation scheme as well as a calculus for dealing with vague or uncertain concepts. "Fuzzy Logic deals with those imprecise conditions about which a true/false value cannot be determined" (Introduction to Fuzzy Logic). Pioneered the Japanese, Fuzzy Logic is currently a growing concept in the field of controller design because it provides simple and easy, yet reliable control system. Some of the current applications of Fuzzy Logic in daily devices includes washing machines, camcorders, microwave ovens and dozens more electrical and electronic devices.

II. PROPOSED MODEL

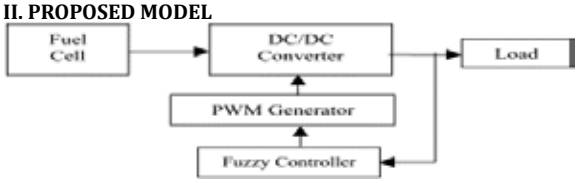


Fig 2. Block diagram of the fuel cell power supply system.

Fig. 2 shows the block diagram of proposed fuel cell based power supply system with fuzzy logic controller. Fuzzy logic, which attempts to combine the easy design of logic with the real-world utility of feedback controls. Specifically, to boost low-output DC voltage of the fuel cell to high DC voltage and to compensate for its slow response during the transient, a multilevel DC- DC boost converter is adopted and an adaptive Fuzzy logic is designed.

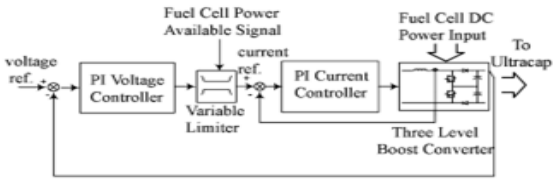


Fig. 3. Block diagram of the three-level boost converter control subsystem.

The control diagram for the boost converter is illustrated in Fig.3. The inner proportional-plus-integral (PI) control loop controls current drawn from the fuel cell, while the outer voltage PI control is used to regulate output voltage delivered to the ultra capacitor to its reference value. The current loop is much faster than the voltage loop to ensure that it keeps up with the variable reference set by the voltage loop. As a rule of thumb, secondary-loop process dynamics must be at least four times as fast as primary-loop process dynamics. The closed loop control of the primary DC–DC converter subsystem was designed using the AC equivalent model and transfer characteristics of the selected converter topology.

III. THREE LEVEL BOOST CONVERTER

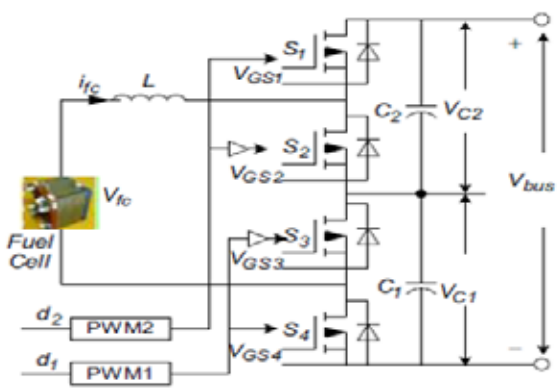


Fig. 4: Three-level DC-DC boost converter In conventional boost converter, the boost ratio is limited by the inductor's equivalent series resistance (ESR).The voltage gain of the boost converter is limited owing to the losses associated with the inductor filter, capacitor, main power switch and rectifier diode. In this converter, the boost factor is quasi-linear when the duty cycle is from [0-0.5] the boost factor becomes non-linear for high duty cycles [8]. This behavior complicates the boost converter control in renewable energy generation systems. The necessary boost factor for renewable generation systems is from 4-6. But the maximum boost factor obtained from this converter is around 2 when operated in linear region. Therefore, three-level DC/DC boost converters are a well-adopted solution in applications with high input voltage and high switching frequency. The switches are stressed on half of the total dc bus voltage. This allows us to use lower voltage rated switches, having better switching and conduction performance compared to the switches rated on the full blocking voltage [6]. Therefore, the converter's overall performance, including cost and efficiency, can significantly be better compared to conventional converters, particularly when the switching frequency is above 20 kHz or metal–oxide semiconductor field-effect transistors (MOSFETS) are used. In three-level boost converter, by cascading the output voltage *VC1* and the output voltage *VC2* high output voltage *Vbus* is easily obtained [4] as shown in Fig. 4. The output voltage obtained here is (N-1) times the voltage obtained from the conventional boost converter where N=3, the number of levels. A smaller size of the inductor is needed to achieve comparably low ripple. The inductor volume is one-fourth of that of the conventional one. In addition, it reduces the required semiconductor device voltage rating by a factor of two [7].

When multi-level boost converter is employed in open loop mode, it exhibits poor voltage regulation and unsatisfactory dynamic response, and hence, this converter is generally provided with closed loop control for output voltage regulation. In turn, the DC link bus voltage which is fed to the voltage source inverter should be almost constant. In order to maintain the DC link bus voltage constant, the control signals d1 and d2 have to be controlled. For different values of duty cycles, we get different values of DC link bus voltages. A feedback control loop is provided through comparator, gain block, PI controller. The output of the PI controller is nothing but the duty cycles d1 and d2 which varies the switching functions generated by the pulse width modulators PWM1 and PWM2. The DC link reference voltage is taken as 340V.

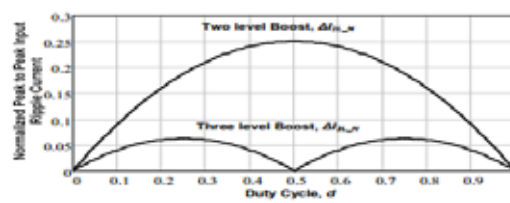


Fig. 5. Input current ripple of two and three level DC-DC converters Referring to Fig. 5, under the same operating conditions, the three level boost converter clearly offers significant ripple current reduction when compared to the conventional boost converter. It is also observed that when the duty cycle has a value of 50%, the ripple current is zero. IV FUZZY LOGIC CONTROLLER The fuzzy controller is characterized as follows. Five fuzzy sets for each input and outputs: NB, NS, ZO, PS, and PB.

1 Triangular membership functions for simplicity.
2 Fuzzification using continuous universe of discourse.
3 Implication using Mamdani's 'min' operator.
4 Defuzzification using the height method.

Fig.6 shows the normalized triangular membership functions used in Fuzzification. Fig. 6(a) for error Fig.6 (b) for change in error Fig. 6(c) for output.

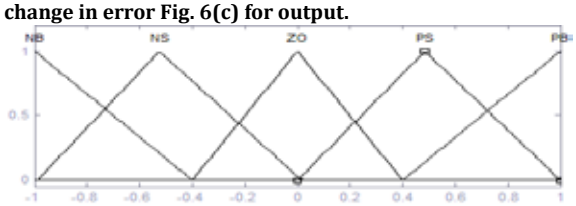
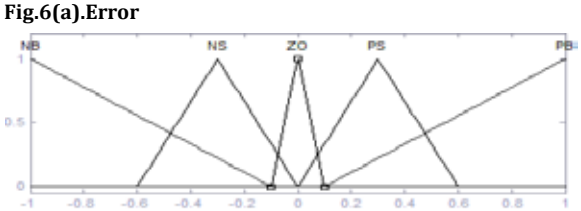


Fig.6(a).Error



Volume : 2 | Issue : 9 | September 2013 • ISSN No 2277 - 8179

Fig6 (b) Change in error

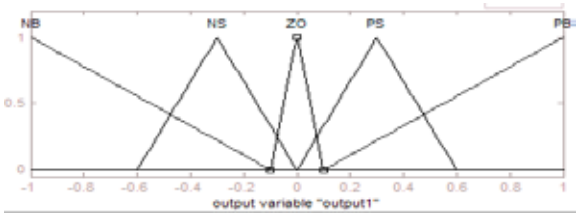


Fig6(c) output
Fig.6 Normalized triangular membership functions used in Fuzzification

(de) \ (e)	NB	NS	ZO	PS	PB
NB	NB	NB	NB	NS	ZO
NS	NB	NB	NS	ZO	PS
ZO	NB	NS	ZO	PS	PB
PS	NS	ZO	PS	PB	PB
PB	ZO	PS	PB	PB	PB

Fig 7.Table Rules for error and change in error
TABLE I. SYSTEM DESIGN

Parameters	Range
Input voltage, Vfc	96v
Output voltage, Vdc	340 V
Inductor	500 µH
Capacitor C1, C2	1000 µF
MOSFETs S1=S2=S3=S4	IRPF264N; 250 V, 38 A
Series resistance, rl	10 Ω
Filter Inductor, Lf	2 mH
Filter Capacitor, Cf	2 mH

V.MATLAB/SIMULINK MODELLING AND SIMULATION RESULTS

Here the simulation is carried out by Two Cases. I. A Multilevel DC-DC Boost Converter with closed loop PI control II. A Multilevel DC-DC Boost Converter with closed loop Fuzzy control Case I: A Multilevel DC-DC Boost Converter with closed loop PI control Fig.8 Implementation of the proposed system in MATLAB/SIMULINK

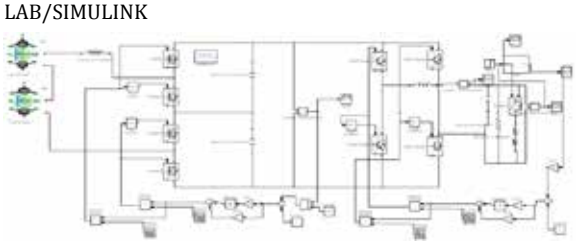


Fig.8 Implementation of the proposed system in MATLAB/SIMULINK

Figure.8 shows the simulation model of proposed DC-DC Boost converter with fuel cell is connected to the input with PI controller. The waveforms are almost close to a sine wave. It can be seen that the load voltage remains constant irrespective of the load changes, but the load current changes with respect to the load. The rms voltage remains constant at 230V for the entire simulation time as seen.

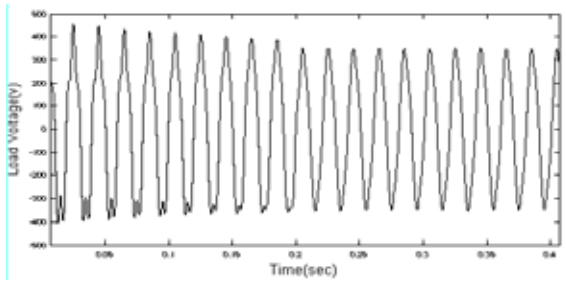


Fig.9.Load voltage waveform during the load variations

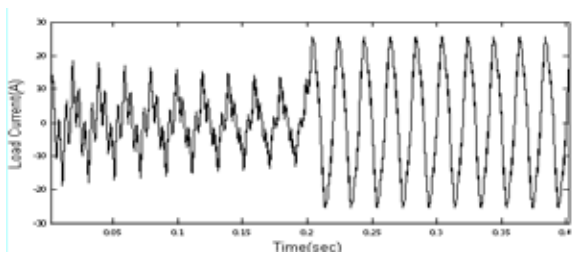


Fig10. Load current waveform during the load variations

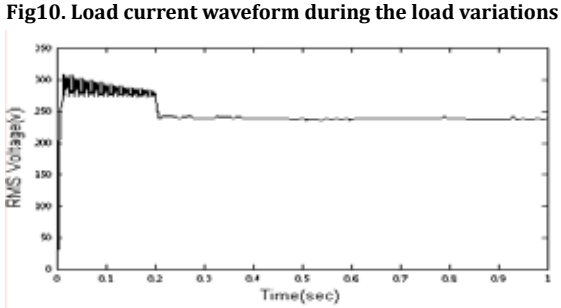


Fig.11. Inverter output voltage waveform during the load variations

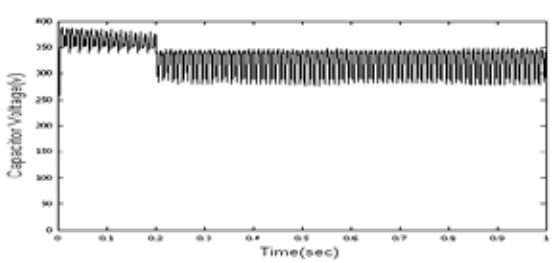


Fig.12. The DC link bus voltage

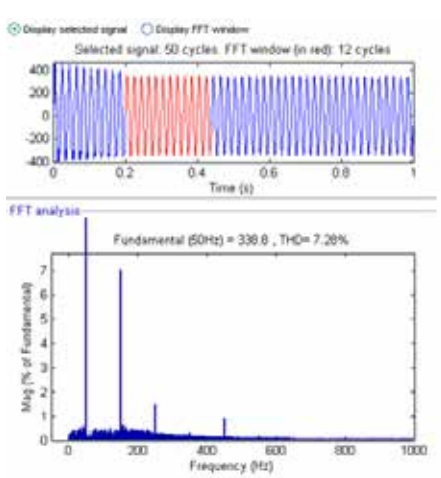


Fig.13. THD waveform of output voltage waveform using PI controller

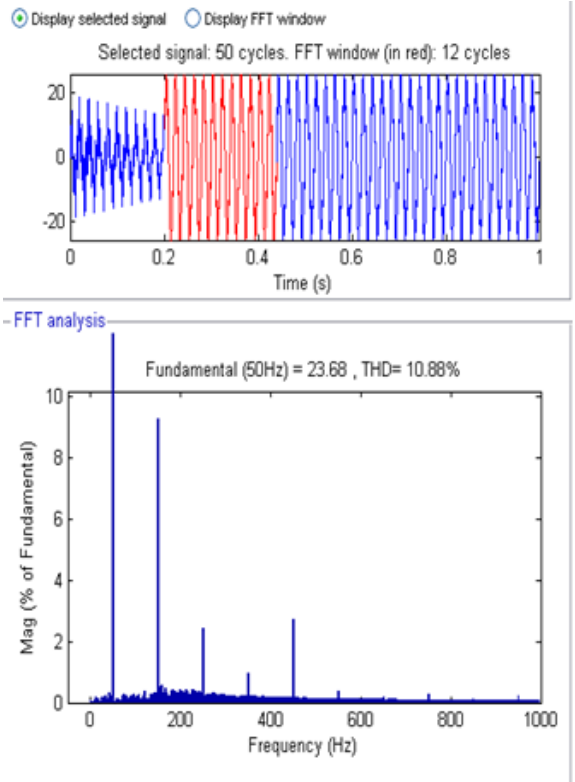


Fig.14. THD waveform of output current waveform using PI controller

Case II: A Multilevel DC-DC Boost Converter with closed loop Fuzzy control

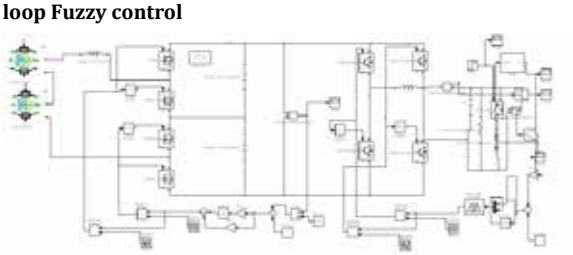


Fig.15. Implementation of the proposed system in MATLAB/SIMULINK

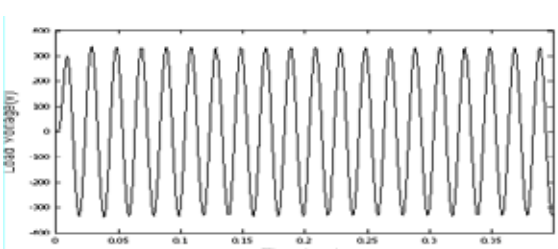


Fig.16. The Load voltage waveform during load variations using Fuzzy controller

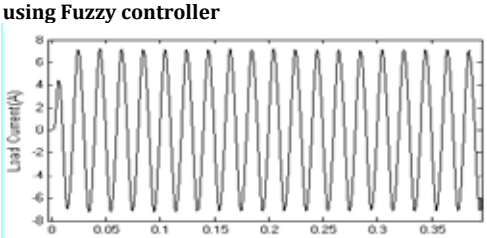


Fig.17.Load current waveform during load variations

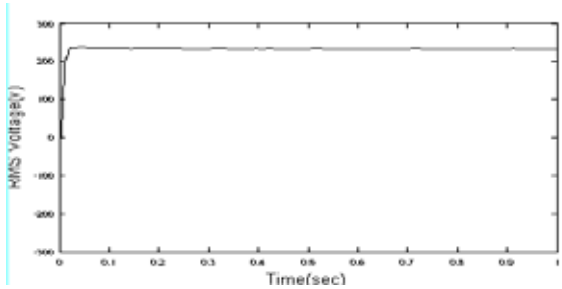


Fig.18. Inverter output voltage waveform during load variations using Fuzzy control

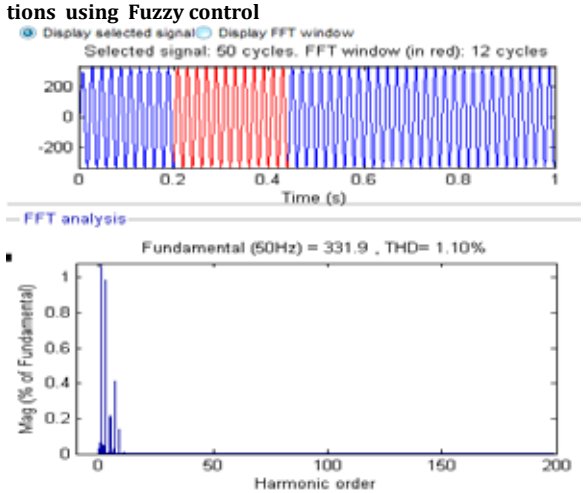


Fig.19.THD waveform of output voltage waveform during load variations using Fuzzy control

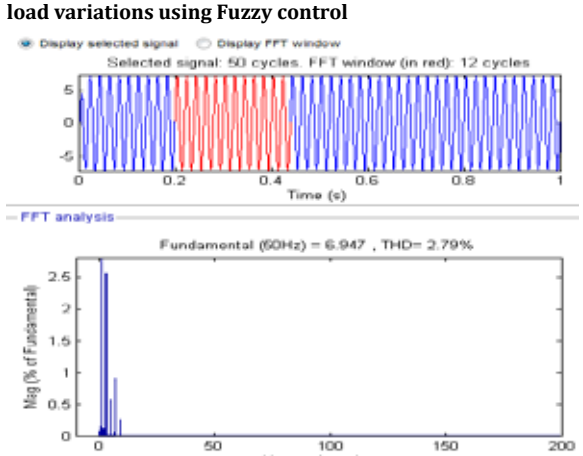


Fig.20. THD waveform of output current waveform during load variation using Fuzzy control

VI.CONCLUSION

A Fuel cell based multilevel DC-DC boost converter system using PI controller and Fuzzy logic controller are implemented in MATLAB environment. A constant high DC link bus voltage is obtained and converted into standard 230V RMS voltage for fuel cell based residential applications. The settling time is less i.e.0.02 sec in Fuzzy control compared to PI control it is 0.2 sec. The %THD of output voltage for PI control is 7.28% and by using Fuzzy logic is 1.10%. Similarly the %THD of current measurement in PI control is 10.88% and by using Fuzzy is 2.79%. The two feedbacks for PI controller and Fuzzy controller are designed to make the system perform well for both steady state and transient conditions. Hence the %THD present at the inverter is also within the limits of 5% in case of Fuzzy control compared to PI control. Therefore, the proposed multilevel

boost DC-DC converter are more suitable for renewable generation systems with improved efficiency and reduction in cost.

REFERENCE

[1] A. Kirubakaran, Shailendra Jain, R.K. Nema," A review on fuel cell technologies and power electronic interface," Renewable and Sustainable Energy Reviews, vol.13, pp. 2430–2440, 2009. | [2] Fan Zhang, Peng, F.Z, and Zhaoming Qian, "Study of the multilevelconverters in DC-DC applications," IEEE 35th Annual Power Electronics Specialists Conf., Vol. 2, pp. 1702 -1704, 2004. | [3] Jih-Sheng Lai and Fang Zheng Peng, "Multilevel converters-a new breed of power converters," IEEE Trans. on Ind. App., Vol. 32, No. | 3, pp. 509 – 517, May-June 1996. | [4] P. Thounthong, S. Sikkabut, P. Sethakul, and B. Davat, "Model Based-Control of Three-Level Boost Converter for Fuel Cell Applications," 10th Int.Conf.on Env. and Elec. Engg., pp. 1-4, 2011. | [5] Julio C. Rosas-Caro, Juan M. Ramírez, Pedro Martín García-Vite,"A Novel DC-DC Multilevel Boost Converter" IEEE Trans. onPow. Electron. pp. 2146-2155, 2008. | [6] P. Thounthong, B. Davat, S. Rael, and P. Sethakul, "Fuel cell high power applications," IEEE Ind. Electron. Mag., vol. 3, no. 1, pp. 32–46, March 2009. | [7] P. J. Grbović, P. Delarue, P. LeMoigne, and P.Bartholomeus, "A | Bidirectional three-level DC–DC converter for the ultracapacitor | applications," IEEE Trans. Ind. Electron., vol. 57, no. 10, pp. 3415– | 3430, Oct. 2010 | [8] Larminie, James & Dicks, Andrew (2003). Fuel Cell Systems Explained. Second edition. Wiley. Chapter 10. | [9] Carlson, Ola, Associate professor, Electric Power division, Chalmers University of Technology. | Discussions (November, 2007) | B.Shanthi Haveela has received her B.Tech in EEE at Vignan's Lara Institute of Technology and Science,Vadlamudi in the year 2011.At present she is pursuing her M.Tech (PEED) at Gudlavalleru Engineering College. Her area of interest is Power Electronics. | | D.Koteswara Raju has received his B.Tech degree (EEE) from DVR&DRHS,MIC College of Technology,Kanchikacherla in the year 2006.M.Tech degree from RVR&JC College of Engineering,Guntur with the specialization in the Power System Engineering in the year 2009.At present he is working as Asst.prof in the EEE Dept in Gudlavalleru Engineering College,Gudlavalleru.His areas of interest is Power System Operation & Control. | Dr.P.Sangameswara Raju has received Ph.D from Sri Venkateswara University, Tirupati. At present he is working as professor and HOD of EEE Department, SVU College of Engineering, Tirupati. His area of interest is Power System Operation & Control.