Available online at www.elixirpublishers.com (Elixir International Journal)

Electrical Engineering

Elixir Elec. Engg. 82 (2015) 32591-32595

ISSN: 2229-712X

A Comparative Study of Fuzzy Logic Controlled and Traditional Control Techniques based SAF for 400Hz aircraft electric power system

Saifullah Khalid and Neetu Agrawal
Member, IEEE, India.

ARTICLE INFO

Article history:
Received: 12 March 2015;
Received in revised form:
2 May 2015;
Accepted: 15 May 2015;

Keywords
Aircraft electrical system,
Shunt Active filter (SAF),
Fuzzy logic control,
Total harmonic distortion,
Constant instantaneous power control strategy.

ABSTRACT

Constant Instantaneous Power Control technique for extracting reference currents for shunt active power filters has been assessed for 400Hz aircraft electric power system. Thereafter, its performance has been compared when optimized using fuzzy logic control. Critical analysis of Comparisons of the compensation ability of these two techniques based on THD and compensation time will be done and suggestions will be given for the selection of best technique to be used. The simulated results using MATLAB model are presented. That will prove the importance of the proposed control method of aircraft shunt SAF in aviation industry.

Introduction

More advanced aircraft power system [1]-[3] has been need due to increased application of electrical power in place of other alternate power sources. The subsystems like flight control, flight surface actuators, passenger entertainment, etc. are driven using electric power, which consecutively increased the demand for creating aircraft power system more intelligent and advanced. These subsystems has considerable increased electrical loads i.e. power electronic devices, increased consumption of electrical energy, more demand for power, and over to all of that; much more stability and power quality problems.

In distinction to normal supply system source frequency of 50 Hz, aircraft ac power system is using source frequency of 400 Hz [1]-[3]. Aircraft power utility is having source voltage of 115/200V. The loads associated with the aircraft ac system are dissimilar from the normal loads used in 50 Hz supply system [1]. When we consider as the generation portion; aircraft system will remain AC driven from the engine for aircraft primary power. Fuel cell technology can be used to generate a DC output for ground power where its silence process would match up to adequately with the Auxiliary Power Unit (APU). However when considering the distribution of primary power, whether AC or DC; each approach has its merits. In DC distribution, HVDC power distribution systems permit the more resourceful employ of generated power by antithetical loss from skin effect. This allows paralleling and load sharing among the generators. In AC distribution, Switching of AC is very clear-cut even at high levels as it logically has a zero crossing point. Due to its high reliability over HVDC system, wide range of Contactors, Relays can be exploited.

While talking about Aircraft Power Systems we also need to consider increased power electronics application in aircraft which creates harmonics, large neutral currents, waveform distortion of both supply voltage and current, poor power factor and excessive current demand. Besides if a number of non linear loads are impressed upon a supply their effects are additive. Due to these troubles, there may be nuisance tripping of circuit breakers or increased loss and thermal heating effects which may provoke early component failure. This is very large problem to any motor loads on the system. Therefore good power quality of the generation system is of particular attention to the Aircraft manufacturer. We know that aircraft systems work on high frequency so even on the higher frequencies in the range of 360 to 900Hz; these components would still remain very significant.

Today, advance soft computing techniques are used widely in automatic control system or for optimization of the system applied. Some of them are such as fuzzy logic [4]-[8], optimization of active power filter using GA[9]-[12], power loss minimization using particle swarm optimization[13], neural network control [14]-[18] applied in both machinery and filter devices.

In this paper, Fuzzy logic controller has been used to improve the overall performance of active filter for reduction of harmonics and other related problems generated into the aircraft electrical system due to the non linear loads [1]. The simulation results clearly show their effectiveness. The simulation results obtained with novel optimized model will prove its superiority over traditional constant instantaneous power control technique.

The paper has been structured in the following manner. The SAF configuration and the loads under consideration are discussed in Section II. The control algorithm for SAF is discussed in Section III. MATLAB/ Simulink based simulation results are discussed in Section IV and finally Section V concludes the paper.

System Description

The aircraft system is a three-phase power system with source frequency of 400 Hz. As exposed in Figure 1, shunt Active Power filter improves the power quality and compensates the harmonic currents in the system [22],[24]-[25],[27]-[28]. The shunt SAF is comprehended by using one voltage source inverters (VSIs) connected at point of common coupling (PCC) with a common DC link voltage [20]-23].

The set of loads for aircraft system consist of three loads. First load is a three-phase rectifier in parallel with inductive load and an unbalanced load connected in a phase with midpoint (Load 1). Second one is a three-phase rectifier connects a pure

Tele:
E-mail addresses: drskhalid.atc@gmail.com

resistance directly (Load 2). Third one is a three-phase inductive load linked with the ground point (Load 3). A combination of all three loads connected with system together at different time interval has been done. So, that we can study the effectiveness of the control schemes used. That, in turn will verify the functionality of the active filter and its ability to harmonics compensation. For the case, Load 1 is always connected; Load 2 is initially connected and is disconnected after every 2.5 cycles. Load 3 is connected and disconnected after every half cycle. All the simulations have been done for 15 cycles. The values of the circuit parameters are given in Appendix.

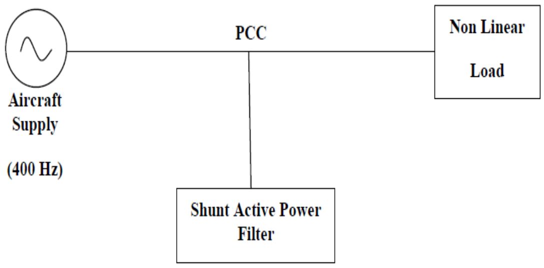

Figure 1. Aircraft system using Shunt Active Power filter

Control Theory

The proposed control of SAF depends on constant instantaneous power control strategy. It has also been optimized with artificial intelligent technique i.e. fuzzy logic control. Constant instantaneous power control strategy has been discussed in brief in this section. The following section also deals with basic application of fuzzy logic in control scheme on constant instantaneous power control strategy [19],[20],[29].

Constant Instantaneous Power Control Strategy (CIPC)

Fig. 2 presents the control diagram of the shunt active filter using constant instantaneous power control strategy. We can observed that four low pass filters have been shown in the control block; in which, three with cut off of 6.4 KHz have been applied to filter the voltages and one for the power p_0. Direct application of the phase voltages cannot be used in the control due to instability problem. There may be resonance between source impedance and the small passive filter. Low pass filters have been applied to the system to attenuate the voltage harmonics at the resonance frequency which are higher than 6.4 KHz. p, q ,p_0 ,v_α and v_β are obtained after the calculation from α-β-0 transformation and sending it to the α-β current reference block, which calculates $i'_{c\alpha}$ and $i'_{c\beta}$ [137]. Finally, α-β-0 inverse transformation block calculates the current references and applied to the PWM current control i.e. hysteresis band controller. Figure 3 presents the Matlab/Simulink model for constant instantaneous power control strategy.

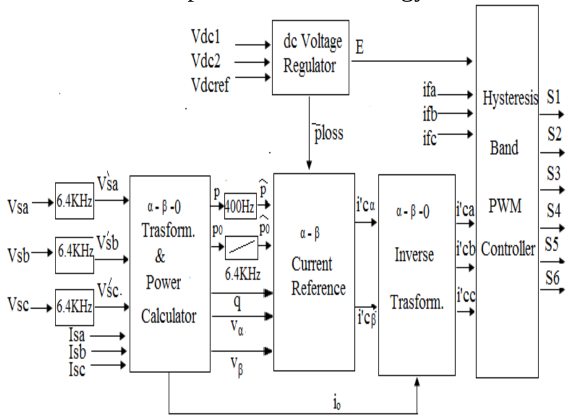

Figure 2. Control block diagram of the shunt active filter using constant instantaneous power control strategy

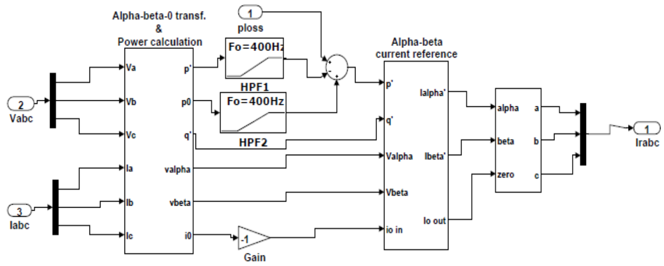

Figure 3. MATLAB/SIMULINK Model of the Shunt Active Filter using Constant Instantaneous Power Control Strategy

Fuzzy logic control application in Constant Instantaneous Power Control Strategy (GA-CIPC)

The fuzzy logic control has been used in the dc voltage control loop of the active power filter. In fuzzy, the design uses centrifugal defuzzification method. The steps involved in the design of a controller using the fuzzy logic require certain set of information. The algorithm is simple once the design problem is identified i.e. number of input and output variables required and the kind of output desired.

There are two inputs; error and its derivative and one output, which is the command signal. The two inputs uses Gaussian membership functions while the output uses triangle membership function. Table 1 presents the fuzzy control rule. Figure 2 shows the membership functions used.

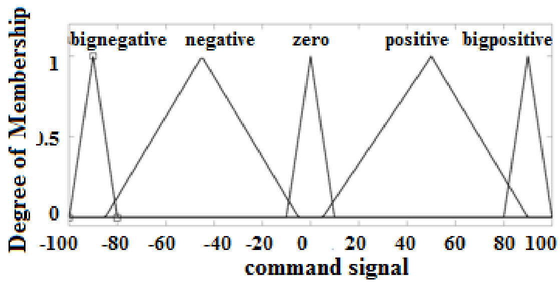

Figure 4. Membership functions

Table 1. Fuzzy Control Rule

Error / de/dt	Negative	Zero	Positive
Negative	Big Negative	Positive	Big Positive
Zero	Big Negative	Zero	Big Positive
Positive	Big Negative	Negative	Big Positive

Simulation Results & Discussions

The proposed scheme of SAF is simulated in MATLAB environment to estimate its performance. The load applied with the aircraft system consists of three-phase rectifier connected a pure resistance directly. To appreciate compensation by SAF, a small inductance is connected at the terminals of the load. The simulation results clearly reveal that the scheme is able to successfully reduce the significant amount of THD in source current and voltage within limits.

Uncompensated system

Figure 5 shows the MATLAB/SIMULINK model for load 1, 2 and 3 connected together in the circuit. From the simulation results shown in fig. 6, it has been observed that that the THD of source current & source voltage was 9.5% and 1.55% respectively, which is obviously not within the limit of the international standard

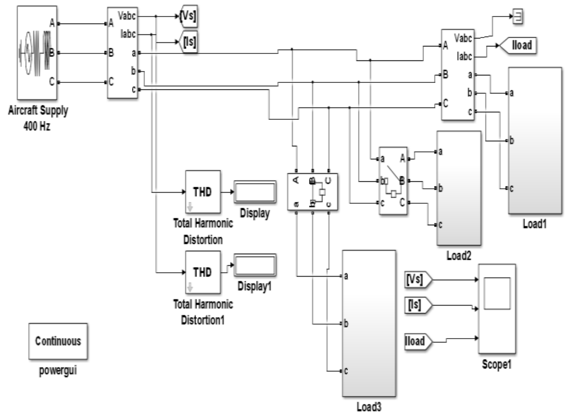

Figure 5. MATLAB/SIMULINK model for load 1, 2 and 3 connected together in the circuit at different time interval

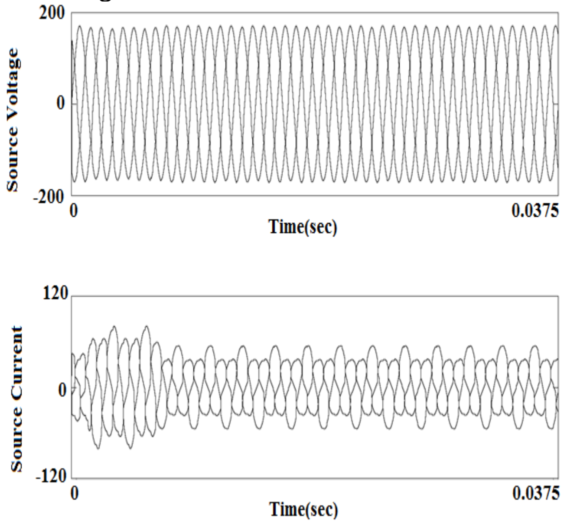

Figure 6. Waveforms of source voltage and source current for load 1, 2 and 3 connected together at different time interval

Performance of SAF

In this section, performance of SAF has been discussed for Constant Instantaneous Power Strategy, and Constant Instantaneous Power Strategy utilizing Fuzzy Logic Control. Simulation results using MATLAB show the affectivity of control techniques.

For Constant Instantaneous Power Control Strategy

The results from simulation are shown in fig. 7. From the results, it is found that the THDs of source current & source voltage were 2.84% and 1.88% respectively. At t=0.0059 sec, we can see that the waveforms for source voltage and source current have become sinusoidal. The observed compensation time was 0.0059 sec.

The waveforms of compensation current, dc capacitor voltage and load current can be seen from fig 7. There is variation in dc voltage which can be seen clearly in the waveforms. If there is need of increasing the compensation current for fulfilling the demand of load current, it releases the energy and after that it charges and tries to regain its set value.

After close observation, we can find out that the compensation current is completing the demand of load current and after applying the active filter, the source current and voltage is forcefully become sinusoidal. Comparative performance of compensation current, source current and source voltage for various loads used for different control strategies are discussed in further chapters. After comparison with the uncompensated system, it has been observed that the system using active filter has compensated the supply system. The results are within the limit of IEEE 519-1992 standard defined for voltage and current harmonics.

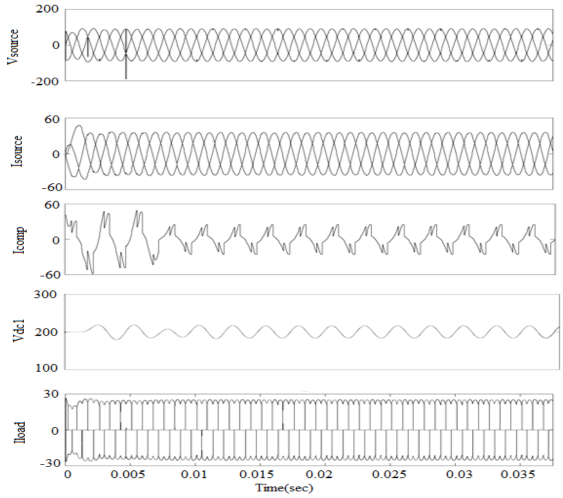

Figure 7. Source Voltage, Source Current, Compensation Current (Phase b), DC Link Voltage and Load Current Waveforms of Active Power Filter Constant Instantaneous Power Control Strategy with All Three Loads Connected for Aircraft System

For Constant Instantaneous Power Control Strategy using Fuzzy Controller (CIPC-Fuzzy)

From Fig. 8 it has been empiric that that the THDs of source current and source voltage were 2.33% and 1.03% respectively. The compensation time was 0.0044 sec. At t=0.0044 sec, it is apparent that the waveforms for source voltage and source current have become sinusoidal. Fig. 8 shows the waveforms of compensation current, dc capacitor voltage and load current. The aberration in dc voltage can be acutely apparent in the waveforms. As per claim for accretion the compensation current for accomplishing the load current demand, it releases the energy and thereafter it accuses and tries to achieve its set value.

If we carefully observe, we can acquisition out that the compensation current is in fact accomplishing the appeal of load current and afterwards the active filtering the source current and voltage is affected to be sinusoidal. When comparing with the uncompensated system, it is empiric that this system with active filter clarify has able-bodied compensated the supply system. This can be calmly empiric that the after-effects are aural the absolute of IEEE 519-1992 standard authentic for voltage and accepted harmonics.

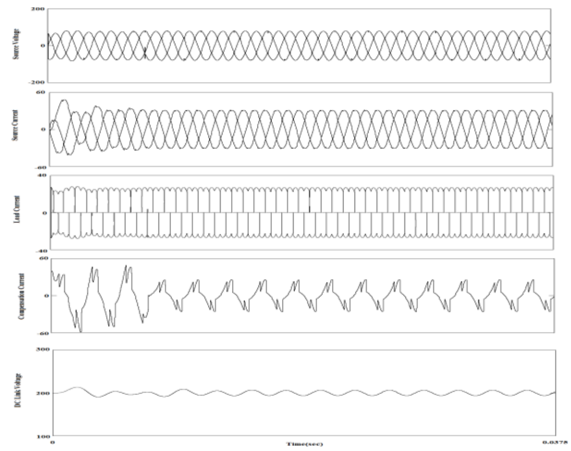

Figure 8. Source Voltage, Source Current, Load Current, Compensation Current (Phase b) and DC Link Voltage Waveforms of Active Power Filter using Constant Instantaneous Power Control Strategy using Fuzzy Logic Control with All Three Loads Connected for Aircraft System

Comparative Analysis of the Simulation Results

Simulation results, shown in figure 7 and figure 8, have been tabulated in Table 2. From the table, we can easily say that CIPC-Fuzzy strategy is better than conventional CIPC strategy.

Table 2. Summaries of Simulation Results Using SAF

Strategy Used	THD-I (%)	THD-V (%)	Compensation Time(sec)
CIPC	2.84	1.88	0.0147
CIPC-FUZZY	2.33	1.03	0.0044

Figure 9 presents the bar chart for total harmonic distortion calculated for source current and source voltage. We can clearly observe the significant reduction in THD of both source voltage and source current for CIPC-Fuzzy from CIPC strategy. Current THD is reduced from 2.84% to 2.33%. Voltage THD is reduced from 1.88% to 1.03% . The compensation time for CIPC-Fuzzy is less than CIPC strategy, which clearly proves that CIPC-Fuzzy is fast and overall better than traditional CIPC strategy.

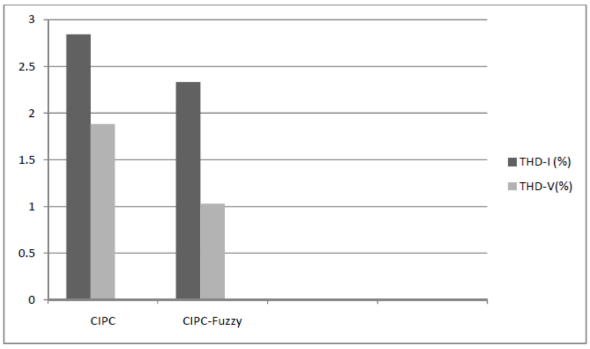

Figure 9. THD of Source Current and Source voltage for CIPC and CIPC-Fuzzy strategy

Conclusion

This paper has done a critical analysis of traditional (CIPC) and soft computing control strategies (CIPC-Fuzzy) for shunt SAFs installed in aircraft power utility of 400 HZ. The ideas have been given for the optimum selection of strategy based on compensation time and THDs of source current and voltage. Constant Instantaneous Power Control Strategy's performance has been improved like anything when modified using Fuzzy Logic control. CIPC-Fuzzy has been observed better as well as fast as compare to CIPC control strategy discussed.

Appendix

The system parameters used are as follows [1]:
Three-phase source voltage: 110V/400 Hz
Filter inductor=0.25m H
Filter capacitor: 5 uF,
Dc voltage reference: 400 V
Dc capacitor: 4700uF

References

[1] Chen Donghua, Tao Guo, Shaojun Xie, Bo Zhou, "Shunt Active Power Filters Applied in the Aircraft Power Utility," 36th Power Electronics Specialists Conference, PESC '05, IEEE, 2005, pp. 59-63.

[2] Zixin Li,Yaohua Li, Ping Wang, Haibin Zhu, Congwei Liu, and Fanqiang Gao, "Single-Loop Digital Control of High-Power 400-Hz Ground Power Unit for Airplanes, IEEE Transactions on Industrial Electronics, Vol. 57, No. 2, pp. 532- 543, February 2010.

[3] Haibing Hu, Yan Xing, "Design Considerations and Fully Digital Implementation of 400-Hz Active Power Filter for Aircraft Applications," IEEE Transactions on Industrial Electronics, Vol. 61, Issue 8, pp. 3823 – 3834, 2014.

[4] Ahmed A. Helal, Nahla E. Zakzouk, and Yasser G. Desouky, "Fuzzy Logic Controlled Shunt Active Power Filter for Three-phase Four-wire Systems with Balanced and Unbalanced Loads", World Academy of Science, Engineering and Technology, Vol. 58, pp. 621-626, 2009.

[5] Bimal K. Bose, "Expert System, Fuzzy Logic, and Neural Network Applications in Power Electronics and Motion Control, Proceedings of the IEEE, Vol. 82, No. 8, 1303-1323. August 1994.

[6] S. Jain, P. Agrawal, and H. Gupta, "Fuzzy logic controlled shunt active power filter for power quality improvement," in IEE Proceedings of the Electric Power Applications, Vol. 149, pp. 317-28. 2002.

[7] B. Mazari and F. Mekri, "Fuzzy Hysteresis Control and Parameter Optimization of a Shunt Active Power Filter", Journal of Information Science and Engineering, Vol. 21, pp. 1139-1156, 2005.

[8] Saifullah Khalid, Bharti Dwivedi, "Power quality improvement of constant frequency aircraft electric power system using Fuzzy Logic, Genetic Algorithm and Neural network control based control scheme," International Electrical Engineering Journal (IEEJ), Vol. 4, No. 3, pp 1098-1104, 2013.

[9] Babak Keshavarz Hedayati, Abdolreza Rahmati, "Genetic Algorithm Application in Controlling Performance and Power Dissipation of Active Power Filters", Canadian Journal on Electrical & Electronics Engineering, Vol. 1, No. 1, pp. 15-19, February 2010.

[10] Parmod Kumar, and Alka Mahajan, "Soft Computing Techniques for the Control of an Active Power Filter", IEEE Transactions on Power Delivery, Vol. 24, No. 1, pp. 452-461,January 2009.

[11] Marco Liserre, Antonio Dell Aquila, and Frede Blaabjerg, "Genetic Algorithm-Based Design of the Active Damping for an LCL-Filter Three-Phase Active Rectifier", IEEE Transactions on Power Electronics, Vol. 19, No. 1, pp.76-86, January 2004.

[12] Taha, M.H., "Single Phase Series Active Filter load Compensation for Aircraft Applications," 16th International Power Electronics and Motion Control Conference and Exposition (PEMC), pp. 449 – 454, 2014.

[13] Radha Thangaraj, Thanga Raj Chelliah, Millie Pant, Ajit Abraham and Crina Grosan, "Optimal gain tuning of PI speed controller in induction motor drives using particle swarm optimization," Logic Journal of IGPL Advance Access, pp.1-14, July 2010.

[14] Whei-Min Lin, Chih-Ming Hong, "A New Elman Neural Network-Based Control Algorithm for Adjustable-Pitch Variable-Speed Wind-Energy Conversion Systems," IEEE Transactions on Power Electronics, Vol. 26, No. 2, pp. 473-481, February 2011.

[15] Jiang You-Hua, Chen Yong-Wei, "Neural Network Control Techniques of Hybrid Active Power Filter," Proceedings of International Conference on Artificial Intelligence and Computational Intelligence, 2009, pp. 26-30.

[16] Saifullah Khalid, Bharti Dwivedi, Bhim Singh, " New Optimum Three-Phase Shunt Active Power Filter based on Adaptive Tabu Search and Genetic Algorithm using ANN control in unbalanced and distorted supply conditions," Elektrika : Journal of Electrical Engineering, Vol. 14, Issue 2, pp. 09-14, 2012,.

[17] Saifullah Khalid, Bharti Dwivedi, "Power quality improvement of constant frequency aircraft electric power system using Fuzzy Logic, Genetic Algorithm and Neural network control based control scheme," International Electrical Engineering Journal (IEEJ), Vol. 4, No. 3, pp 1098-1104, 2013.

[18] R. Dehini, A. Bassou, B. Ferdi, “Artificial Neural Networks Application to Improve Shunt Active Power Filter,” International Journal of Computer and Information Engineering, Vol. 3, No. 4, pp. 247-254, 2009.
[19] Kanjiya, P. ,Khadkikar, V. , Zeineldin, H.H.., “Optimal Control of Shunt Active Power Filter to Meet IEEE Std. 519 Current Harmonic Constraints Under Non-ideal Supply Condition,” IEEE Transactions on Industrial Electronics, Volume: 62 , Issue: 2 , pp. 724-734, 2015.
[20] Mauricio Aredes, Jurgen Hafner, Klemens Heumann, “Three-Phase Four-Wire Shunt Active Filter Control Strategies,” IEEE Transactions on Power Electronics, Vol. 12, No. 2, pp. 311-318, March 1997.
[21] S.Khalid, Bharti Dwivedi, “Power Quality Issues, Problems, Standards & Their Effects in Industry with Corrective Means”, International Journal of Advances in Engineering & Technology, Vol. 1, Issue 2, pp.1-11, May 2011.
[22] S.Khalid, B.Dwivedi, “Power Quality: An Important Aspect,” International Journal of Engineering, Science and Technology, Vol. 2, Issue 11, pp. 6485-6490, Nov 2010.
[23] B.K.Bose, “Recent Advances in Power Electronics,” IEEE Trans. on Power Electronics, Vol. 7, No.1, pp. 2-15, Jan.1992.
[24] R. C. Dugan, M. F. McGranaghan, and H. W. Beaty, Electrical Power Systems Quality. New York: McGraw-Hill, 1996.
[25] S.Khalid, B.Dwivedi, “Power Quality: An Important Aspect,” International Journal of Engineering, Science and Technology, Vol. 2, Issue 11, pp. 6485-6490, Nov 2010.
[26] IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems, IEEE Standard 519-1992, 1992.
[27] A. Ghosh and G. Ledwich, Power Quality Enhancement Using Custom Power Devices. Boston, MA: Kluwer, 2002.
[28] N.Mohan, T. Undeland, and Robbins, “W. Power Electronics – Converters, Applications, and Design,” 2nd. ed. Canada: John Wiley & Sons, 1995.