

# Zero Current Switched Cyclo-Inverter

Mayank kumar<sup>1</sup>, Nirmal Kumar Kushwaha<sup>2</sup>, Vineeta Agarwal<sup>3</sup>

**Abstract**— This paper proposes a new zero current switched, IGBT based cyclo-Inverter, capable of converting power at the main frequency to a higher frequency. An auxiliary switch along with an inductor is used to commutate the IGBT at zero current in order to decrease total internal losses and total harmonic distortion factor in the converter. The proposed converter is compared with the conventional cyclo-inverter and it has been demonstrated that the losses has been reduced approximately 50% by this new switching technique. A prototype of the converter is developed in the lab for verification of the results.

**Keywords**— Cyclo-Inverter, IGBT, Triggering Pulses, Zero Crossing Detector (ZCD).

## I. Introduction

Cyclo-inverter is ideal for high frequency generation without any intermediate DC link. It finds its application in induction heating, fluorescent lighting, ballast, high frequency power supplies and so many other applications where high frequency reduces the size of equipment. A wide variety of cyclo-converter circuits are possible depending upon the output frequency and voltage [1-4]. Simplest is the single phase centre-tapped transformer configuration cyclo-inverter [5]. The output voltage of a hard switched cyclo-inverter is fairly rich in harmonics [6] and the switching losses are also high which do not only adversely affect the inverter efficiency but the additional heat sinking need increases its size and weight [7]. This can be improved by using resonant cyclo-inverter where the switches can be configured to operate at either zero current or zero voltage points in the waveform, and thus greatly reducing their stress levels [8].

In this paper a zero voltage switched cyclo-inverter has been proposed where zero voltage switching is achieved by addition of a resonant inductor along with an auxiliary power semiconductor switch that decreases total internal losses as well as total harmonic distortion factor in order to increase its efficiency. Trigger requirements are obtained for single-phase centre tapped transformer configuration. Results are presented for R-L load where resonant inductance is used as a part of load.

## II. Proposed ZCS Cyclo-Inverter

Figure 1 shows the detailed circuit of the proposed ZVS cyclo-inverter. It consists of two converters a positive converter PC and a negative converter NC connected in anti parallel. Two types of switches have been used: the Main switches (i.e. T1M, T2M, T3M, and T4M) and Auxiliary (Energy transfer) switches (i.e. T1A, T2A, T3A, and T4A). Main switches take energy from source and supply to the load while Auxiliary switches are used to transfer the potential energy to the load that is stored in the inductor. Output is obtained through proper conduction of IGBTs in the two input cycles. For example, to generate an output frequency double to the input frequency a firing sequence of 14, 23, 14, ..., and so on, is adopted whereas for an output frequency of three time that of input frequency, this firing sequence becomes 141, 323, 141, ..., and so on. Thus, the output of converter will have a frequency,  $f_o = f_i \times N_r$  where  $N_r$  is an integer and  $f_i$  is the source frequency.

When the main switch  $T_{1M}$  turns ON during the period  $T_{ON}$ , current flowing through the source is responsible for charging of inductor. The voltage across the inductor is in the form of magnetic field.

$$V_L = V_{ac}(1 - e^{-Rt/L}) \quad (1)$$

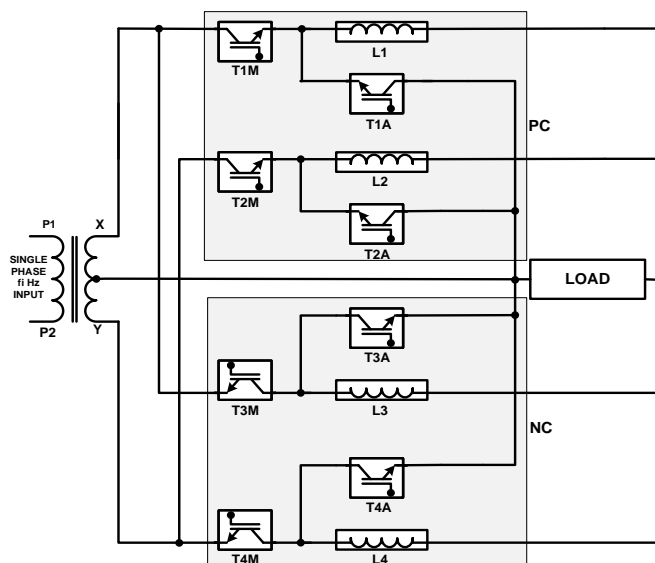


Fig. 1. IGBT Based ZCS Cyclo-inverter

<sup>1,2,3</sup> Department of Electrical Engineering  
Motilal Nehru National Institute of Technology, Allahabad  
India  
dedicatetmayank@gmail.com  
neer.el30@gmail.com  
vineeta@mnnit.ac.in

Figure 2 shows the idealized waveform with a firing sequence of 1, 4, 3, 2, 1, 4, 3, 2, ..., for an output frequency double to the input frequency for a purely resistive load.

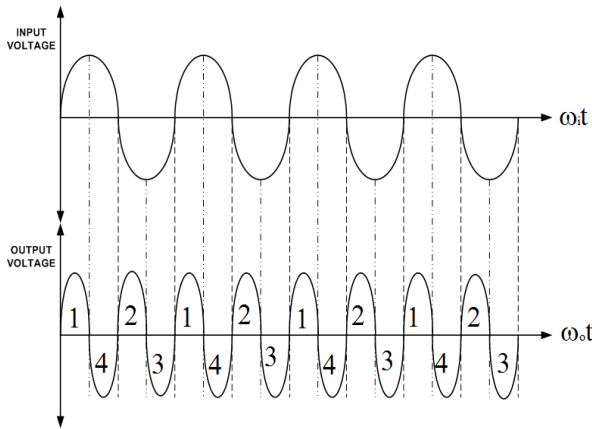


Fig. 2. Idealized Waveform of Frequency Multiplier for  $f_{or} = f_i \times 2$

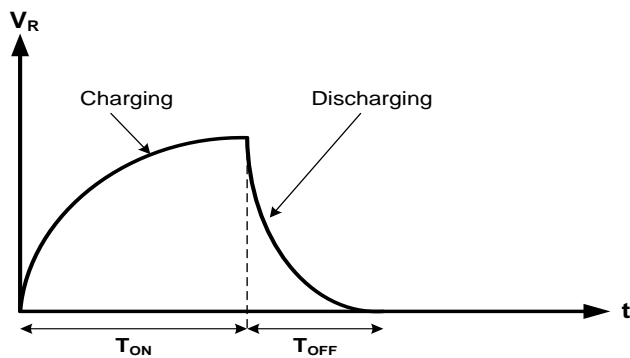


Fig. 3. Idealized Waveform for Charging and Discharging of inductor

At  $t = T_o/4$ , when main switch turns OFF, the auxiliary switch is turned ON, and stored energy in the inductor is dissipated across the load according to the equation given by (2).

$$V_R = i \times R \times e^{-Rt/L} \quad (2)$$

When all the stored energy is dissipated, the next main switch T2M is turned on at zero current. In this way each time the inductor connected in series with the switch will store the energy and then dissipate it to the load through corresponding auxiliary switch and thus attain zero current switching.

### III. Principle Of Triggering Pulse Generation

Figure 4 shows the schematic details of the trigger scheme to generate the required high frequency output with zero current switching.. The input signal having frequency  $f_i$ , which has to be converted into high frequency signal, is stepped down from a step down transformer and converted into a square signal using Zero Crossing Detector (ZCD) in an input interfacing circuit. Two reference signals, having frequency  $f_o$  and  $2f_o$  are derived directly from square wave generators. These three signals are synchronized in a synchronization circuit. The output of synchronizing circuit is fed to a pulse generator block which generates the required pulse for IGBT. The signal with frequency  $2f_o$  with 70% duty ratio is used to transfer the energy from the inductor to the load when main switch is turned OFF. The output of pulse-wave generator is fed to the driver circuit which isolates and boosts the level of pulses. The isolated pulses thus obtained, drives the gate of individual IGBTs.

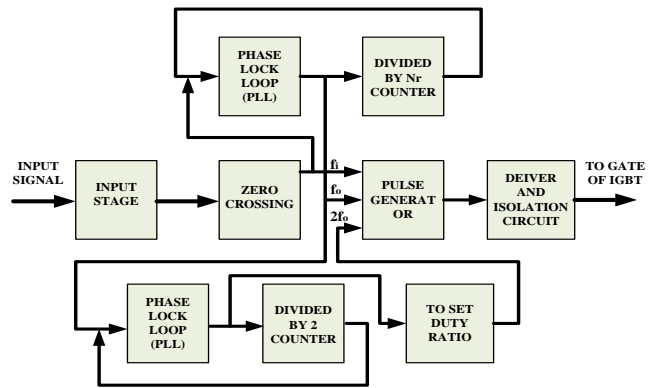


Fig. 4. Block Diagram for trigger pulse generation

The triggering pulses are different for the same IGBT for different values of  $N_r$ . For example for  $N_r = 3$ , the gating pulses are generated using three set of pulses having frequencies 50 Hz (input supply frequency), 150 Hz ( $N_r$  times the input supply frequency that is desired output frequency) and 300 Hz ( $2 \times N_r$  times the input supply frequency that is desired output frequency) as shown in Figure 5.

Let  $X_1$  represents the pulses at a frequency of 50 Hz,  $X_2$  of 150 Hz and  $X_3$  of 300 Hz. Then ANDing of  $X_1$ ,  $X_2$  and  $X_3$  will result the pulses required by the IGBT T1. Further if this  $X_2$  is inverted by a NOT gate, then the ANDing of  $X_1$ ,  $\overline{X_2}$  and  $X_3$  will result the pulses required by the IGBT T4. Similarly, the pulses for other IGBTs are obtained as illustrated in Figure 6. The next section illustrates the MATLAB simulation of this technique.

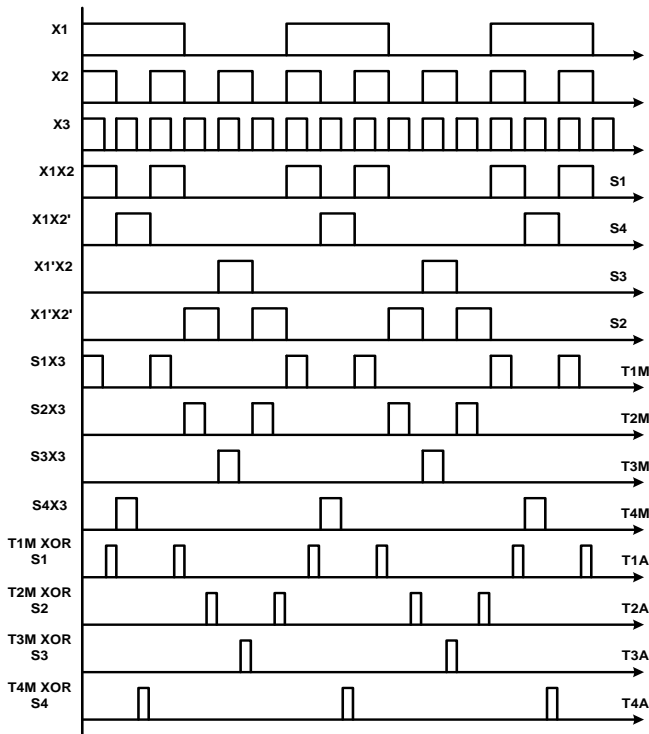


Fig. 5. Gate pulses for Different IGBTs

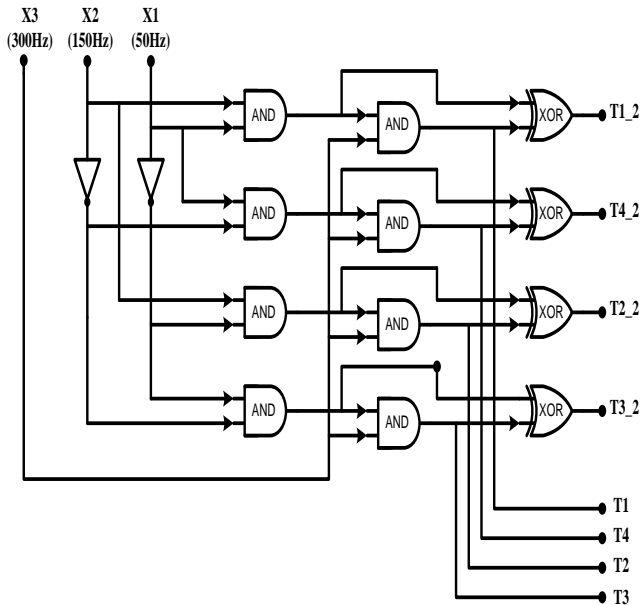
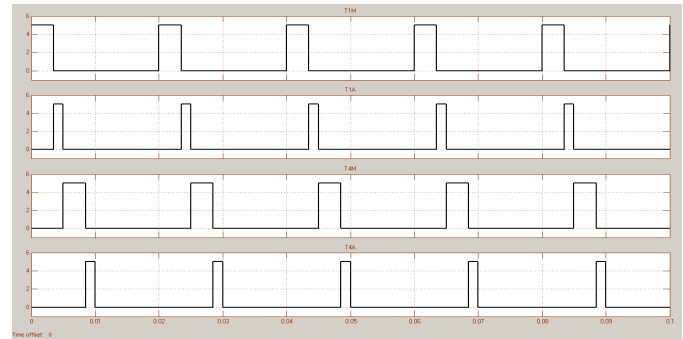


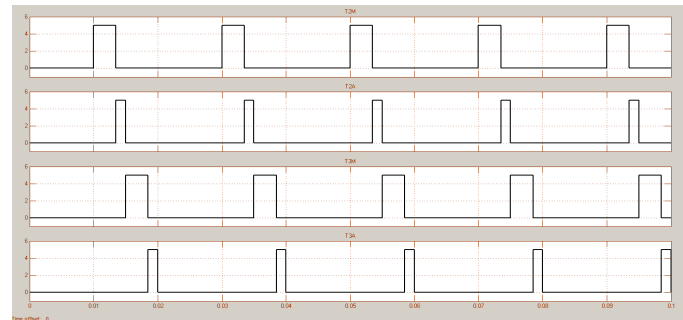
Fig. 6. The Circuit Diagram Generating the Gate pulses

### iv. Simulation Results

MATLAB/Simulink has been used to design and test the circuit. Figure 7, shows the gate pulses generated to trigger the main IGBTs & auxiliary IGBTs. T1M to T4M are the trigger pulses for Main IGBTs while T1A to T4A are used to trigger Auxiliary IGBTs. Figure 7, shows the pulses for positive converter (PC) and negative converter (NC) respectively.



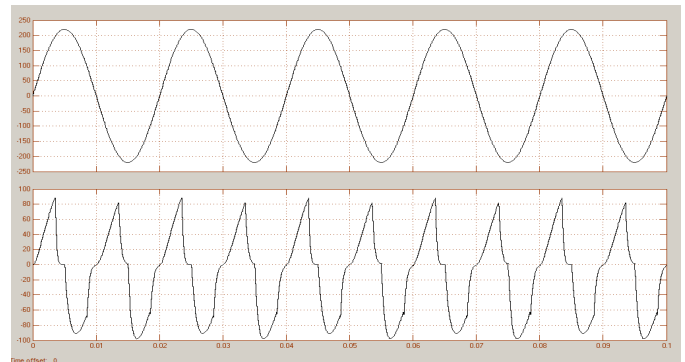
(a) Positive Converter (PC) pulses



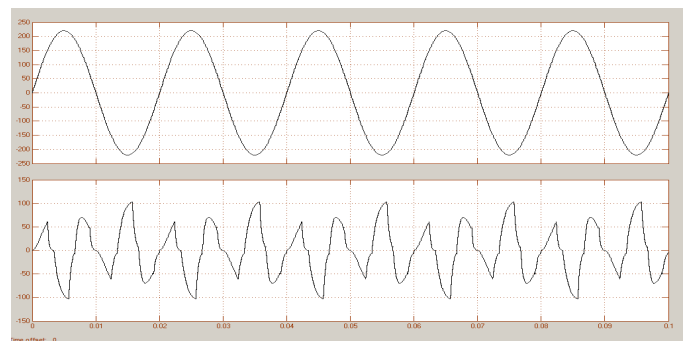
(b) Negative Converter (NC) pulses

Fig. 7. Gate pulses for IGBTs

Figure 8, illustrates the output of Cyclo-inverter for frequency  $f_o = 100$  Hz, and  $f_o = 150$  Hz. A comparative analysis with a Conventional Cyclo-inverter and Proposed Cyclo-inverter is given in Figure 9.

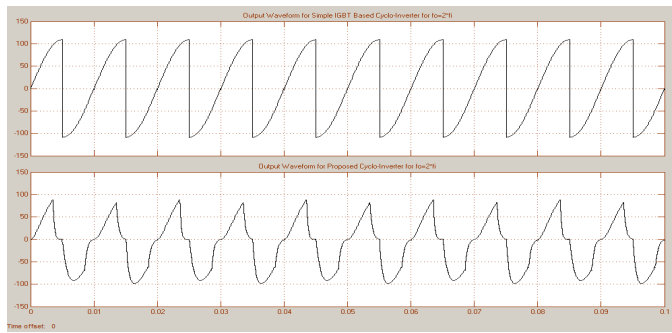


(a)  $f_o = 100$ Hz

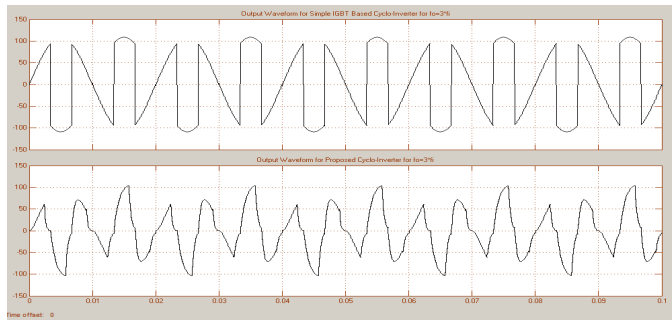


(c)  $f_o = 150$  Hz

Fig. 8. Input - Output waveform

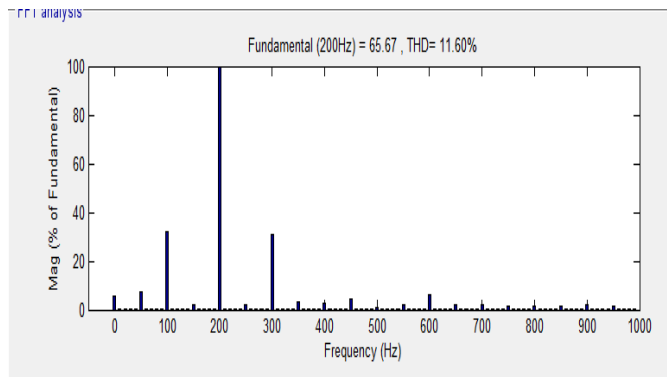


(a)  $f_o = 100$  Hz

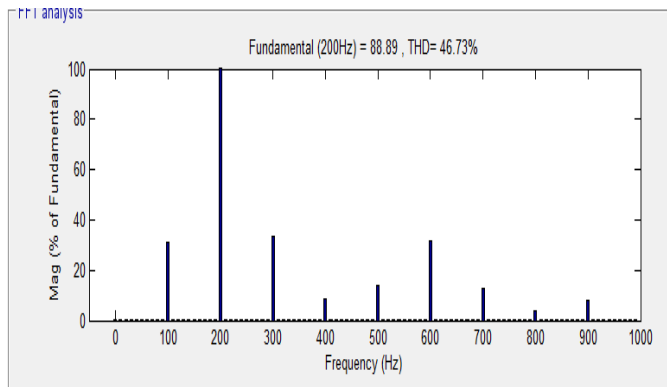


(b)  $f_o = 150$  Hz

Fig. 9. Comparative Performance of Output Waveform



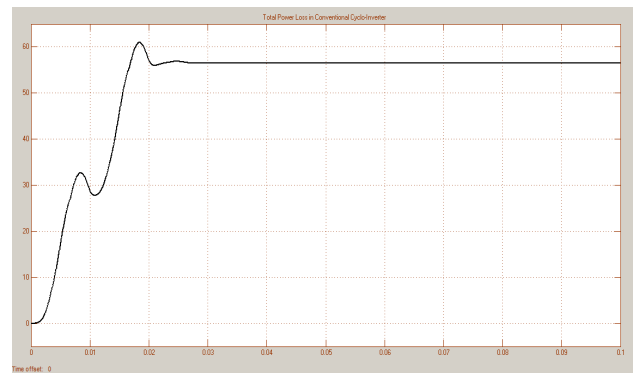
(a)



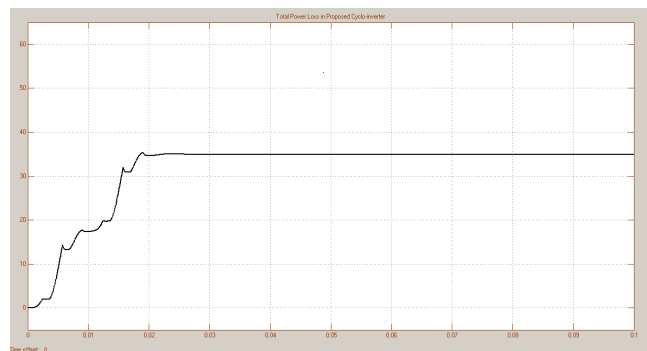
(b)

Fig. 10. Total Harmonic Distortion in (a) Proposed Cyclo-inverter (b) Conventional Cyclo-Inverter

Total Harmonic Distortion of proposed cyclo-inverter and conventional Cyclo-Inverter is illustrated in Figure 10. It can be observed from this figure that, though the side band harmonics are somewhat increased in the proposed converter but at the same time the third harmonic in the proposed converter has been reduced considerably as compared to conventional cyclo-inverter. Figure 11 depicts the total loss in the cyclo-inverter. It has been observed that the total loss calculated in the proposed cyclo-inverter has been reduced to half as compared to that of conventional cyclo-inverter. This increases the efficiency of cyclo-inverter. The converter is tested from 100 Hz to 10 KHz and the performance of cyclo-inverter has been found to be improved in each case.



(a)



(b)

Fig.11. Total Power Loss at  $f_o=3*f_i$  for (a) Conventional Cyclo-Inverter (b) Proposed Cyclo-inverter

## v. Conclusion

A new zero voltage switched cyclo-inverter has been proposed which generates an output frequency that is high to the input frequency. A methodology is obtained for generating trigger signal such that each IGBT is turned OFF at zero voltage. This reduces the total power losses in the circuit and total Harmonic distortion also been reduced. The operation of proposed system has been found satisfactory.

## References

- [1] Ambrozic, V.; Bertoluzzo, M.; Buja, G.S.; Menis, R., "An assessment of the inverter switching characteristics in DTC induction motor drives", , IEEE Transactions on Power Electronics, Volume 20, Issue 2, Mar 2005 Page(s):457 – 465
- [2] Nakamori, A.; Eguchi, N.; Nakanishi, Y., "High speed large capacity inverter for power system apparatus", Decision and Control, 1996, Proceedings of the 35th IEEE, Volume 4, 11-13 Dec. 1996 Page(s):4472 - 4473 vol.4.
- [3] Wei Dong; Jae-Young Choi; Yong Li; Huijie Yu; Lai, J.; Boroyevich, D.; Lee, F.C., "Efficiency considerations of load side soft-switching inverters for electric vehicle applications", Applied Power Electronics Conference and Exposition, 2000. APEC 2000. Fifteenth Annual IEEE, Volume 2, 6-10 Feb. 2000 Page(s):1049 - 1055 vol.2.
- [4] Van der Merwe, G.J.; van der Merwe, L., "Inverters-dynamic load responses as a result of the impressed inverter output waveform", IEEE International Symposium on Industrial Electronics, 1998. Proceedings. ISIE '98, Volume 1, 7-10 July 1998 Page(s):45 - 50 vol.1
- [5] Vineeta Agarwal, Peeyush Agarwal, "IGBT Based Cyclo-Inverter" Asian Power Electronics Journal, Vol. 2, No. 1, Apr 2008.
- [6] Po-Tai Cheng; Bhattacharya, S.; Divan, D.M., "Control of square-wave inverters in high-power hybrid active filter systems" Industry Applications, IEEE Transactions on Volume 34, Issue 3, May-June 1998 Page(s):458 – 472.
- [7] Du Yonggui; Xie Keming, "The SPWM inversion mode of suppressing harmonic waves based on genetic algorithm", Electrical Machines and Systems, 2001. ICEMS 2001. Proceedings of the Fifth International Conference, Volume 2, 18-20 Aug. 2001 Page(s):1304 - 1307 vol.2.
- [8] Vineeta Agarwal & Sachin Nema, "Resonant AC to AC Converter" Proceedings of IEEE International Symposium on Industrial Electronics, ISIE 2005, 20-23 June, 2005, Dubrovnik, CROATIA.



**Vineeta Agrawal** (SM'09) received the M.S. degree from Allahabad University, Allahabad, India, in 1984, and the Ph.D. degree in power electronics from Motilal Nehru Regional Engineering College, Allahabad, India.

She joined the Electrical Engineering Department, Motilal Nehru Regional Engineering College, Allahabad, India, as a Lecturer in 1982. She is currently is a Professor with the Department of Electrical Engineering, Motilal Nehru National Institute of Technology, Allahabad. She has taught numerous courses in electrical engineering and electronics. Her research interests are in singlephase to three-phase conversion and ac drives. She has authored and coauthored a number of publications in journals and conferences in her field. She has attended and presented papers at both national and international conferences.

## Biographies



**Mayank Kumar** was born in Varanasi, India on Feb 05, 1986. He graduated from the Uttar Pradesh Technical University, Lucknow, India with B.Tech Hons. degree in Electronics & Communication Engineering in 2010. He is currently pursuing his M.Tech in Power Electronics and ASIC Design at MNNIT Allahabad.



**Nirmal Kumar Kushwaha** was born in Allaahabad, India on April 21, 1988. He graduated from the Uttar Pradesh Technical University, Lucknow, India with B.Tech degree in Electronics Engg in 2010. He is currently pursuing M.Tech in Power Electronics & ASIC Design at MNNIT, Allahabad.