International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 5, No. 1, July 2014, pp. 76~82
ISSN: 2088-8694

Harmonic Analysis of Seven and Nine Level Cascade Multilevel Inverter using Multi-Carrier PWM Technique

Chetanya Gupta*, Devbrat Kuanr*, Abhishek Varshney*, Tahir Khurshaid, Kapil Dev Singh***
* Department of Power Electronics and Drives Engineering, Galgotias University, India
** Department of Power System Engineering, Galgotias University, India

Article Info

Article history:

Received Mar 30, 2014
Revised May 7, 2014
Accepted May 25, 2014

Keyword:

High Power Applications
Multi-Carrier Technique
Multilevel Inverter
Voltage Source Inverter

ABSTRACT

The use of multilevel inverters has become popular in recent years for high-power applications. Multilevel Inverters are power converter systems composed by an array of power semiconductor sources that when properly connected and controlled can generate a multistep voltage waveform with variable and controllable frequency, phase and amplitude. This study deals with the comparison of a 7-level inverter with a 9-level inverter system; the voltage source inverters (VSI) are modelled and simulated using MATLAB Simulink and the results are presented. The test results verify the effectiveness of the proposed strategy in terms of computational efficiency as well as the capability of the inverter to produce very low distorted voltage with low-switching losses. This research aims to extend the knowledge about the performance of different clamped multilevel inverter through harmonic analysis. Simulations results validate up to the mark performance of the mentioned topologies.

Corresponding Author:

Chetanya Gupta
Department of Power Electronics and Drives Engineering
Galgotias University
Plot No.2,Sector-17A,Yamuna ExpressWay,Greater Noida,Uttar Pradesh, India
Email: chetan.frenz@gmail.com

1. INTRODUCTION

Power Electronic Converters, especially DC/AC PWM inverters have been extending their range of use in industry because they provide reduced energy consumption, better system efficiency, improved quality of product, good maintenance, and so on.

For a medium voltage grid, it is troublesome to connect only one power semiconductor switches directly [1]-[3]. As a result, a multilevel power converter structure has been introduced as an alternative in high power and medium voltage situations such as laminators, mills, conveyors, pumps, fans, blowers, compressors, and so on. As a cost effective solution, multilevel converter not only achieves high power ratings, but also enables the use of low power application in renewable energy sources such as photovoltaic, wind, and fuel cells which can be easily interfaced to a multilevel converter system for a high power application.

The most common initial application of multilevel converters has been in traction, both in locomotives and track-side static converters [4]. More recent applications have been for power system converters for VAR compensation and stability enhancement [5], Active Filtering [6], High-Voltage motor drive [3], High-voltage DC transmission [7], and most recently for medium voltage Induction motor variable speed drives [8].

The previous approaches inherited the benefit of well-known circuit structures and control methods. However, the newer semiconductors are more expensive, and by going higher in power, other power-quality requirements have to be fulfilled, introducing the need of power filters. The new approach uses the well-known and cheaper semiconductors, but the more complex circuit structures came along with several challenges for implementation and control. Nevertheless, these challenges turned rapidly into new opportunities, since the more complex circuit structures enabled more control degrees of freedom that could be used to improve power conversion in several aspects, especially in relation to power quality and efficiency.

2. THE MULTILEVEL INVERTER CONCEPT

The concept of multilevel converters has been introduced since 1975 and the cascade multilevel inverter was first proposed [14]. The advantages of cascade multilevel inverters were prominent for motor drives and utility applications. The cascade inverter is also used in regenerative-type motor drive applications. Recently, some new topologies of multilevel inverters have emerged. These multilevel inverters can extend rated inverter voltage and power by increasing the number of voltage levels. They can also increase equivalent switching frequency without the increase of actual switching frequency, thus reducing ripple component of inverter output voltage and electromagnetic interference effect.

A multilevel converter can be implemented in many different ways. The simplest techniques involve the parallel or series connection of conventional converters to form the multilevel waveforms. More complex structures effectively insert converters within converters. The voltage or current rating of the multilevel converter becomes a multiple of the individual switches, and so the power rating of the converter can exceed the limit imposed by the individual switching devices.

The elementary concept of a multilevel converter to achieve higher power is to use a series of power semiconductor switches with several lower voltage dc sources to perform the power conversion by synthesizing a staircase voltage waveform. Capacitors, batteries, and renewable energy voltage sources can be used as the multiple dc voltage sources. The commutation of the power switches aggregate these multiple dc sources in order to achieve high voltage at the output; however, the rated voltage of the power semiconductor switches depends only upon the rating of the dc voltage sources to which they are connected.

3. MULTILEVEL CONVERTER CLASSIFICATION

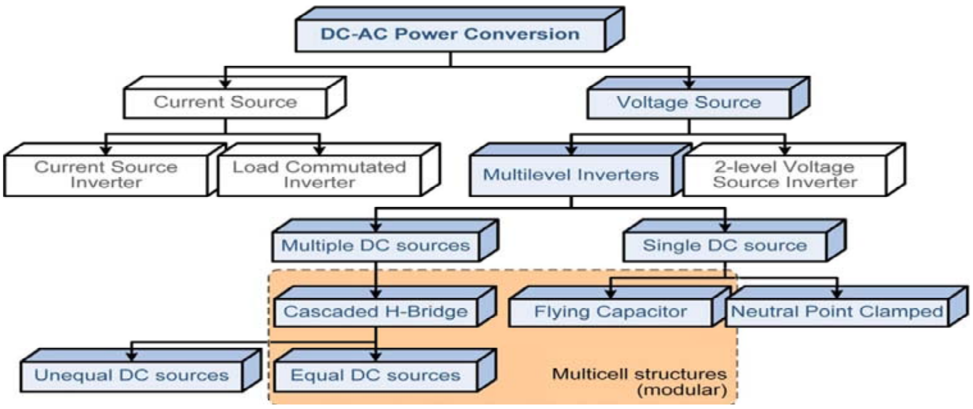

Figure 1. Classification of Multilevel converter

4. FEATURES OF MULTILEVEL INVERTER

A multilevel converter has several advantages over a conventional two-level converter that uses high switching frequency pulse width modulation (PWM).

a) Staircase wave form quality: Multilevel converters not only can generate the output voltages with very low distortion, but also can reduce the dv/dt stresses; therefore electromagnetic compatibility (EMC) problems can be reduced.
b) Common-mode (CM) voltage: Multilevel converters produce smaller CM voltage; therefore, the stress in the bearings of a motor connected to a multilevel motor drive can be reduced. Input current: Multilevel converters can draw input current with low distortion.
c) Switching frequency: Multilevel converters can operate at both fundamental switching frequency and high switching frequency PWM. It should be noted that lower switching frequency usually means lower switching loss and higher efficiency.

5. CASCADE MULTILEVEL INVERTER

Cascade H Bridge are multilevel converters formed by the series connection of two or more single-phase H-bridge inverters, hence the name. Each H-bridge corresponds to two voltage source phase legs, where the line–line voltage is the converter output. Therefore, a single H-bridge converter is able to generate three different voltage levels. Each leg has only two possible switching states, to avoid dc-link capacitor short-circuit. Since there are two legs, four different switching states are possible, although two of them have redundant output voltage. The zero level can be generated connecting the phase outputs to the positive or the negative bars of the inverter. When two or more H-bridges are connected in series, their output voltages can be combined to form different output levels, increasing the total inverter output voltage and also its rated power.

6. MULTI CARRIER PWM TECHNIQUE

The most common and popular technique ofdigital pure-sine wave generation is pulse width modulation. The PWM technique involves generation of a digital waveform, for which the dutycycle is modulated such that the average voltage of the waveform corresponds to a pure sine wave. The simplest way of producing the PWM signal is through comparison of a low-power reference sine wave with a triangle wave. Multicarrier PWM methods uses high switching frequency carrier waves in comparison to the reference waves to generate a sinusoidal output wave. The Figure 2 shows multicarrier PWM waveform for cascaded multilevel inverter.

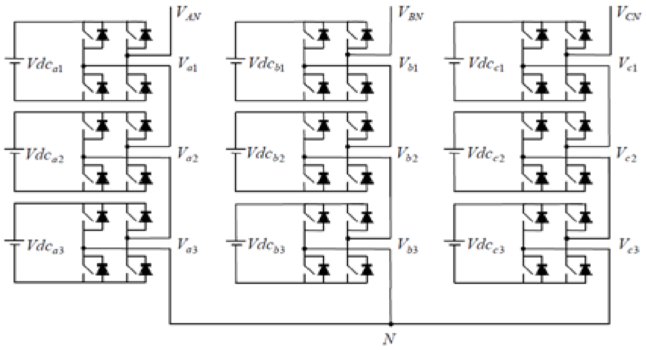

Figure 2. Cascade Multilevel converter

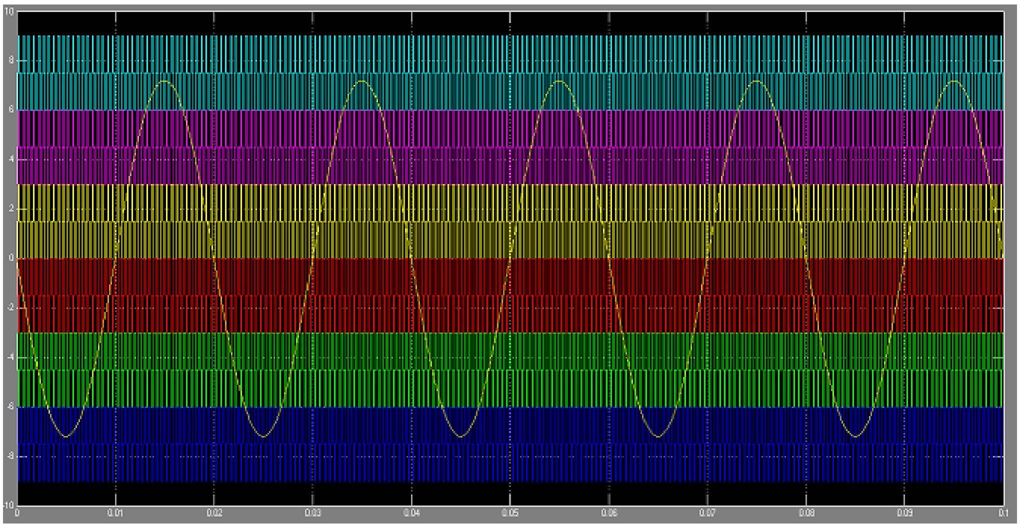

Figure 3. MATLAB Simulated Reference and Carrier waves

7. MATLAB SIMULINK BASED CASCADE MULTILEVEL INVERTER

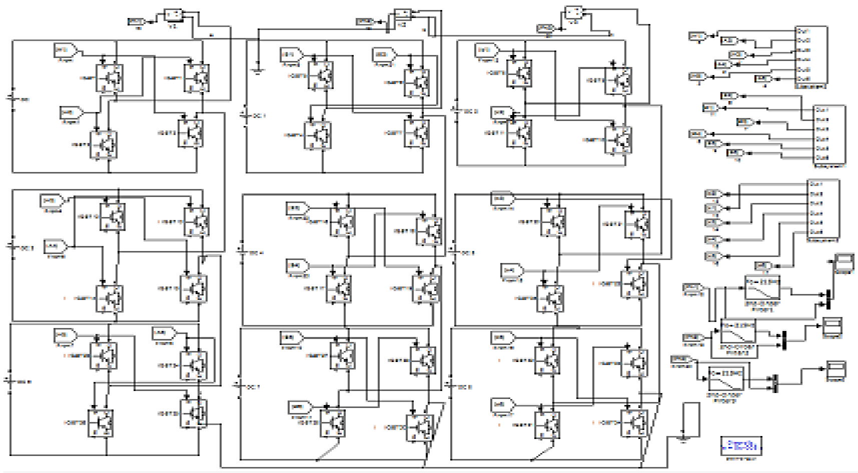

Figure 4. Simulink based seven level model

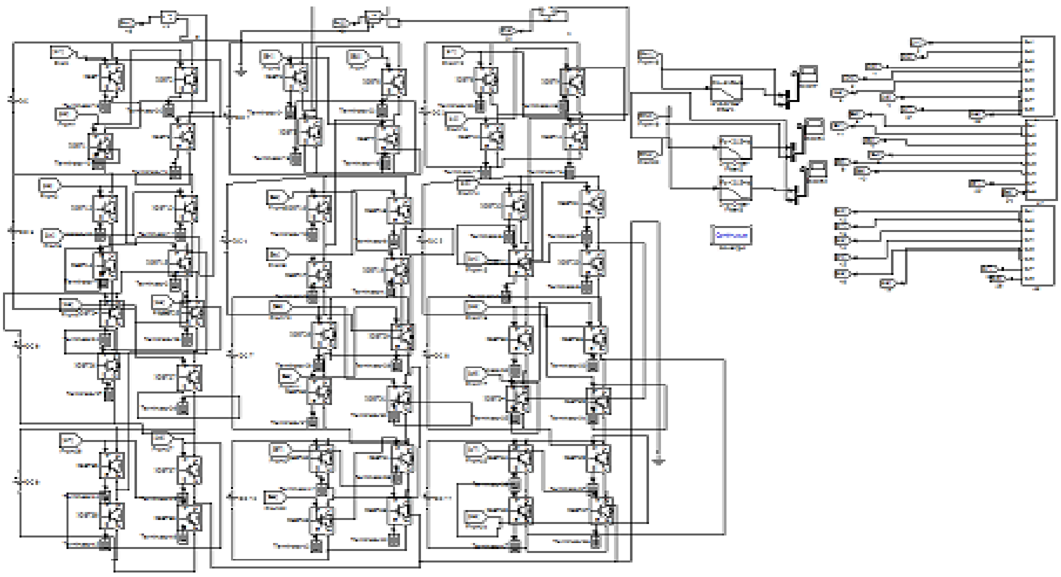

Figure 5. Simulink based nine level model

8. RESULTS AND ANALYSIS

The circuit is simulated in matlab and harmonics are obtained using FFT analysis. The output voltages waveforms are shown.

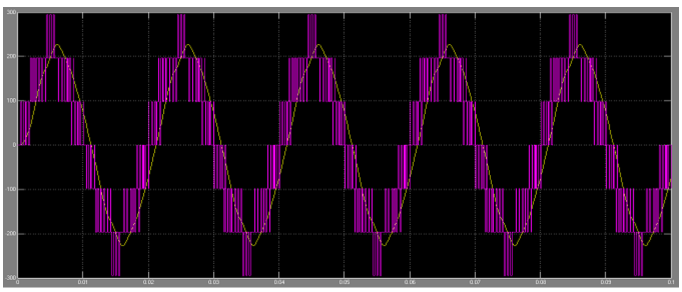

Figure 6. Output voltage waveform of seven level MLI

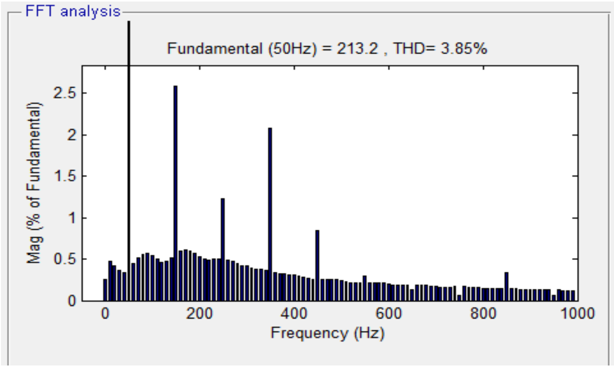

Figure 7. Seven level MLI FFT analysis

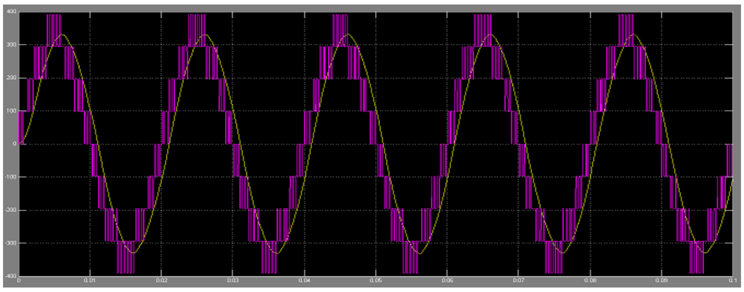

Figure 8. Output voltage waveform of nine level MLI

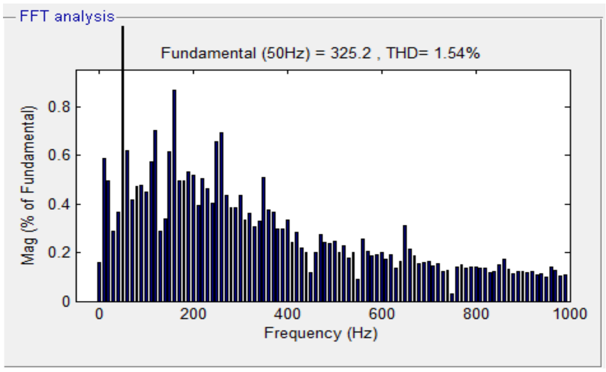

Figure 9. Nine level MLI FFT analysis

The simulation results for seven-level and nine level cascaded inverters and their harmonic analysis are also discussed. The THD of cascaded multi-level inverters have been calculated. The THD of seven and nine level MLI are 3.85% and 1.54% respectively.

9. CONCLUSION

Multilevel converters have matured from being an emerging technology to a well-established and attractive solution for medium-voltage high-power applications. The above mentioned topology and modulation method have found industrial application. Initially, the higher power rates together with the improved power quality have been the major market drive and trigger for research and development of multilevel converters. However, the continuous development of technology and the evolution of industrial applications will open new challenges and opportunities that could motivate further improvements to multilevel converter technology. Multilevel converters can achieve an effective increase in overall switch frequency through the cancellation of the lowest order switching frequency terms.

ACKNOWLEDGEMENTS

Sincere gratitude is hereby extended to those who never ceased in helping until this paper is structured. The authors will be highly obliged the unwavering moral, emotional and financial support of our family members and friends.

Above all, utmost appreciation to the Almighty God for the divine intervention in this academic endeavor.

REFERENCES

[1] JS Lai, FZ Peng. Multilevel converters – A new breed of power converters. *IEEE Trans. Ind. Applicat.*, 1996; 32: 1098–1107.
[2] J Rodriguez, JS Lai, FZ Peng. Multilevel inverters: a survey of topologies, controls, and applications. *IEEE Trans. Ind. Electron.*, 2002; 49: 724-738.
[3] LM Tolbert, FZ Peng, TG Habetler. Multilevel converters for large electric drives. *IEEE Trans. Ind. Applicat.*, 1999; 35: 36-44.
[4] H Stemmler. Power electronics in electric traction applications. *IEEE conference of Industrial Electronics, Control and Instrumentation, IECON'93*. 1993; 2: 707-713.
[5] H Fujita, S Tominaga, H Akagi. Analysis and design of an advanced static VAR compensator using quad-series voltage-source inverters. *IEEE Industry Apps Meeting*. 1995; 3: 2565–2572.
[6] Y Yoshioka, S Konishi, N Eguchi, M Yamamoto, K Endo, K Maruyama, K Hino. *Self-commutated static flicker compensator for arc furnaces*. IEEE Applied Power Electronics Conference. 1996; 2: 891–897.
[7] L Gyugyi. Power electronics in electric utilities: static var compensators. Proc. IEEE. 1987; 76: 3.
[8] Peter W Hammond. A new approach to enhance power quality for medium voltage AC drives. *IEEE Trans. Industry Applications*. 1997; 33(1): 202–208.
[9] MF Escalante, JC Vannier, A Arzande. Flying Capacitor Multilevel Inverters and DTC Motor Drive Applications. *IEEE Transactions on Industry Electronics*. 2002; 49(4): 809-815.
[10] LM Tolbert, FZ Peng. Multilevel Converters as a Utility Interface for Renewable Energy Systems. *IEEE Power Engineering Society Summer Meeting*. 2000: 1271-1274.
[11] LM Tolbert, FZ Peng, TG Habetler. A Multilevel Converter-Based Universal Power Conditioner. *IEEE Transactions on Industry Applications*. 2000; 36(2): 596-603.
[12] LM Tolbert, FZ Peng, TG Habetler. Multilevel Inverters for Electric Vehicle Applications. *IEEE Workshop on Power Electronics in Transportation*. Dearborn, Michigan. 1998; 1424-1431.
[13] In Dong Kim, Eui-Cheol Nho, Heung-Geun Kim, Jong Sun Ko. A Generalized Undeland Snubber for Flying Capacitor Multilevel Inverter and Converter. *IEEE transactions on industrial electronics*. 2004; 51(6).
[14] RH Baker, LH Bannister. Electric Power Converter. *U.S. Patent* 3 867 643. 1975.
[15] A Nabae, I Takahashi, H Akagi. A New Neutral-point Clamped PWM inverter. *IEEE Trans. Ind. Applicat.*, 1981; IA-17: 518-523.
[16] Neelashetty Kashappa, K Ramesh Reddy. Comparison of 3-Level and 9-Level Inverter-Fed Induction Motor Drives. *Research Journal of Applied Sciences, Engineering and Technology*. 2011; 3(2): 123-131. ISSN: 2040-7467.
[17] NS Choi, JG Cho, GH Cho. *A general circuit topology of multilevel inverter*. Proc. IEEE PESC'91. 1991: 96–103.
[18] TA Meynard, H Foch. *Multilevel conversion: High voltage choppers and voltage source inverters*. Proc. IEEE PESC'92. 1992: 397–403.
[19] FZ Peng, JS Lai, J Mckeever, J Van Coevering. *A multilevel voltage-source inverter with separate DC source for static var generation. Conf. Rec. IEEE-IAS Annu. Meeting*. 1995: 2541–2548.
[20] WA Hill, CD Harbourt. *Performance of medium voltage multi-level inverters*. Conf. Rec. IEEE-IAS Annu. Meeting. 1999: 1186-92.
[21] MF Aiello, PW Hammond, M Rastogi. Modular multi-level adjustable supply with series connected active inputs. *U.S. Patent* 6 236 580. 2001.
[22] FZ Peng. A generalized multilevel inverter topology with self-voltage balancing. *IEEE Trans. Ind. Applicat.*, 2001; 37: 611-618.

BIOGRAPHYIES OF AUTHORS

Devbrat Kuanr has received his B.Tech degree in Electrical Engineering from Himachal Pradesh University, Shimla, and Himachal Pradesh, India in 2011. He is currently pursuing his M.Tech degree in Power Electronics and Drives from Galgotias University, Greater Noida, and Uttar Pradesh, India. He is currently working on his thesis project entitled "Power Factor Correction using. Parallel Boost converter His area of interest in research includes Power Electronics, Electrical Drives, Electrical Vehicles, Power Control, Artificial Intelligence and Distributed Generation. He has published a research paper as a co-author entitled "Soft Switched Boost DC-DC Converter systems for Electric Vehicles using an Auxiliary Resonant Circuit".

Abhishek Varshney has received his B.Tech degree in Electronics and Instrumentation Engineering from Gautam Buddha Technical University, Lucknow, and Uttar Pradesh, India in 2011. He is currently pursuing his M.Tech degree in Power Electronics and Drives from Galgotias University, Greater Noida, and Uttar Pradesh, India. He is currently working on his thesis entitled “Development of Improved performance Switched mode DC-DC Converters for Low Power Applications”. His area of interest in research includes Power Electronics, Electrical Drives, Electrical Vehicles, Renewable Energy Systems, Artificial Intelligence, Instrumentation and Control. He has published a research paper as main author entitled “Soft Switched Boost DC-DC Converter systems for Electric Vehicles using an Auxiliary Resonant Circuit”. He was a member of ISTE during 2008-2011

Chetanya Gupta has received his B.Tech degree in Electrical Engineering from BMIT, Jaipur, India in 2012. He is currently pursuing his M.Tech degree in Power Electronics and Drives from Galgotias University, Greater Noida, and Uttar Pradesh, India. He is currently working on his thesis project based on Multilevel Inverters. His area of interest in research includes Power Electronics, Electrical machines, Renewable energy system, Control System and Distributed Generation.

Tahir Khurshaid Lone has received his B.Tech degree in Electrical Engineering from Jammu University, J&K, and India in 2011. He is currently pursuing his M.Tech degree in Power System Engineering from Galgotias University, Greater Noida, and Uttar Pradesh, India. He is currently working on his thesis project based on Deregulated Power System. His area of interest in research includes Power System Analysis, Power Electronics, Distributed Generation, Power System Operation and Control and Power System Reliability.

Kapil Dev Singh has received his B.Tech degree in Instrumentation and Control from Bundelkhand University, Jhansi, and Uttar Pradesh, India in 2011. He is currently pursuing his M.Tech degree in Power Electronics and Drives from Galgotias University, Greater Noida, and Uttar Pradesh, India. He is currently working on his thesis project based on Modelling and Control of Grid Integrated Hybrid Power System. His area of interest in research includes Power Electronics, Electrical Drives, Renewable Energy Systems, Automation Applications, Instrumentation and Control. He has published a research paper as main author entitled “Monitoring of Medical Ventilators using SCADA”.