International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

High Voltage Gain Switched-Capacitor Based Converter and Multilevel Inverter for Solar Energy Applications

Komagal Raja Priya K[1], Porselvi T[2]

[1]PG Student, Sri Sairam Engineering College, Chennai, India

[2]Associate Professor, Sri Sairam Engineering College, Chennai, India

Abstract: ***This paper proposes switched-capacitor technique based on the active network converter and multilevel inverter for the solar energy applications. In solar energy systems, high voltage gain is required with the low input voltage. This converter proposes without using extremely high duty ratio, high voltage gain is obtained. In addition to that, there is a low voltage stress on the active switches and output diodes. So, low voltage components can be used. Then the three phase cascaded H-bridge multilevel inverter circuit is used in the inverter side. This proposed multilevel inverter circuit uses very less number of switches to produce the three phase multilevel output voltage.***

Keywords: Switched-capacitor, low voltage stress, Multilevel inverter

1. Introduction

Fuels and electricity prices are increasing nowadays due to the limited availability of conventional energy resources. In this modern society, greenhouse gases reduction and energy conservation are one of the important issues. Now environmental protection becomes a major concern. Since the energy sector is the major source for carbon gas emissions via combustion fuels, technologies such as photovoltaics, a very eco-friendly energy can be a substitution for the fossil fuels, should be increasingly used.

While considering solar energy, it is one of the most extensively exploited natural energy. Many countries are infusing substantial manpower in the solar energy based projects. Many research works have been carried out in solar energy based projects to improve the efficiency [1]-[3]. For boosting the low input voltage to relatively high output voltage, high step up DC-DC converters are used. The output voltage of the PV modules, fuel cells, battery sources and super capacitors are relatively very low output voltage. In order to feed that voltage to ac grid or any other applications it should be boosted to high output voltage [4]-[6]. Many research works have been carried out to improve the high step-up voltage gain without using an extremely high duty ratio. The isolated converters can able to boost the voltage by increasing the turn's ratio of the coupled inductor or the high frequency transformer. When leakage inductor is present in the circuit care should be taken that, it will causes voltage spikes across the switches or diodes [7]-[8]. In some of the isolated high step-up converters, the converters are used with dual voltage doubler circuits, converters with voltage multipliers [9], coupled inductors integrated with isolated transformers[10].The non dissipative snubber circuit is used in the flyback converter circuit to reduce the voltage stress across the switch [11].

The non coupled inductor type can also able to achieve the high voltage gain. The voltage conversion ratio of the boost converters are the product of each stage. With the multistage structure, the topology becomes more complex. Even though if the multistage circuit has less complexity, the voltage and current stress across the switch is high [12]. Based on the concept of the switched-capacitor and switched-inductor technique, switched capacitor based active network converter is derived. This converter has high step up conversion ratio without extremely increasing the duty ratio, low voltage stress across the power switches and the diodes [13].

Multilevel inverters find its wide applications in medium and high power industries for producing the staircase output voltage with less amount of distortion. The significance of using the multilevel inverters is to produce improved quality of the output voltage with the reduced ratings of power semiconductor switches [14]. There are three topologies of multilevel inverters: cascaded H-bridge cells [15]-[17], flying capacitors [18], diode clamped [19]. Among them, cascaded H-bridge module needs an independent dc source voltage. In flying capacitor multilevel inverter, there is a necessity of using more capacitors which will make the volume of the system larger. In diode clamped multilevel inverter more number of capacitors and diodes are needed. In addition to that complex PWM controls are used for generating the output level. The basic block diagram of PV system is shown in figure.1. In the PV array, sunlight rays are converted in to dc voltage in less amount depending upon the number of solar cells used in the PV array .Then the dc voltage is fed to the controller unit. Here, the controller unit is Switched-Capacitor based active network Converter

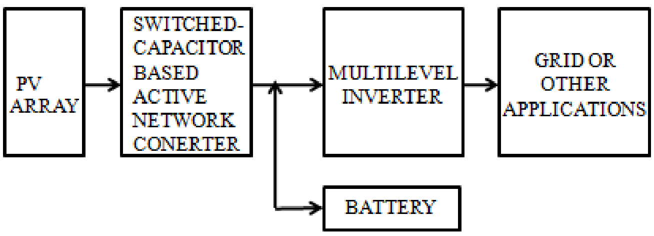

Figure 1: Block diagram of PV system

This converter helps to step up the low dc voltage to high step up dc voltage. Then the dc voltage is either stored in the battery or given to the multilevel inverter. If ac voltage is desired, then the stepped up voltage is given to the multilevel inverter. It helps to produce the staircase three phase multilevel ac output voltage with less number of switching components. Then the three phase multilevel output voltage is given to the grid or any other applications such as new energy vehicles, uninterruptible power supplies and so on.

2. System Modeling

A. PV Array

The basic building block of the PV array is the solar cell, which is basically the p-n junction. The light energy is converted into electric energy due to photovoltaic effect. Solar cells consist of parasitic series and shunt resistances. The equivalent circuit diagram is shown in the figure.2. The photo current of the cell is represented by I_{PH}. The intrinsic series and shunt resistances are represented by R_s and R_{sh}. Usually the value of resistance R_s is very small and that of R_{sh} is very large, hence it can be neglected to simplify the analysis.

The diode model of the solar cell is shown in the figure.2. PV cells are grouped in larger units called PV modules which are further interconnected in series-parallel configuration to form PV arrays or PV generators.

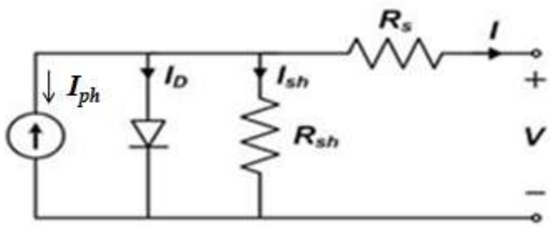

Figure 2: Diode model of the solar cell

$I_{ph}=I+I_D$ (2.1)

$I_D=I_o(e^{(v*q/k*T)}-1)$ (2.2)

Where, I_{ph} is the photon generated current, I is the Load current, I_D is the diode current, I_O is the reverse saturation current of diode, V is the forward voltage in volt, q is the charge in Coulomb, K is the Boltzmann constant and T is the temperature in Kelvin.

B. Switched-Capacitor Based Converter

The switched-capacitor based on active network converter technique [13] is shown in the figure.3.

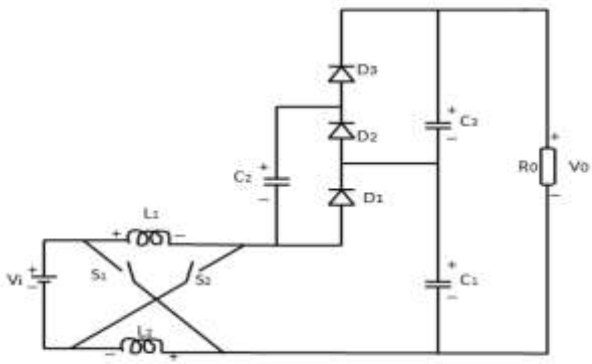

Figure 3: Circuit diagram of the Switched-Capacitor based Converter

This converter is fed from the solar panel with the input voltage of Vi. It consists of series and parallel connection of series and parallel connection of two inductors L_1 and L_2. There are two power MOSFET switches S_1 and S_2. These two switches are sharing the same switching signal. The inductors L_1 and L_2 are parallel connected when the switches S_1 and S_2 are turned ON simultaneously. When the switches S_1 and S_2 are turned OFF, then the inductors L_1 and L_2 are connected in series. The switched capacitor unit is formed by the multiple capacitors and diodes on the output stacking form. High voltage gain is achieved by the series and parallel connection of capacitors. Diodes D_1, D_2, D_3 and capacitors C_1, C_2, C_3 forms the switched capacitor unit.

There are two modes of operation. During mode-I, switch S_1 and S_2 are turned ON and the inductors L_1 and L_2 are charged in parallel through the dc source also the capacitor C_2 gets charged. Then the energy in the capacitor C_1, C_3 gets released into the load. During mode-II, switches S_1 and S_2 are turned OFF. Capacitors C_1 gets charged and the capacitor C_2 is discharged. The high voltage gain is achieved by the Switched-Capacitor based Converter, that ten times of the voltage ratio. Thus, current ripple and current stress of the power components are greatly reduced. During analysis of the proposed converter, the voltage stress across the switch is also less which is beneficial to the cost and efficiency.

When higher voltage conversion is required then more capacitors and diodes can be added in the output stack. The multiple stage structure will also follow the same operating principle of the proposed converter. The voltage gain for the multiple capacitors and diodes is given as,

$$G = \frac{Vo}{Vi} = \frac{n+D}{1-D} \qquad (3.1)$$

Where D represents the duty ratio and n must be an odd number.

The proposed converter will show some start-up problem due to large inrush current. In order to limit the inrush current, a small inductor is added in the circuit.

C. Multilevel Inverter

A three phase multilevel inverter is used to synthesize AC voltage from several levels of DC voltage. The DC levels are considered to be the output of solar cells, batteries, capacitors. Numerous topologies have been proposed for multilevel inverters. The popular being the diode clamped, flying capacitor and the cascaded bridge structures. Besides these basic topologies, other topologies have also been proposed and most of these are hybrid circuits, combination of two or more of the basic topologies. The main disadvantages regarding these multilevel topologies are they need a large number of auxiliary dc levels, provided either by independent supplies and circuit complexity requiring high number of power switches.

This paper proposes the new converter topology. This topology used in the power stage offers improvement in terms of reduced number of switches and reduced layout complexity. In this topology no separate dc supply is required for each stage. The schematic diagram of the multilevel inverter is shown in the figure.4.

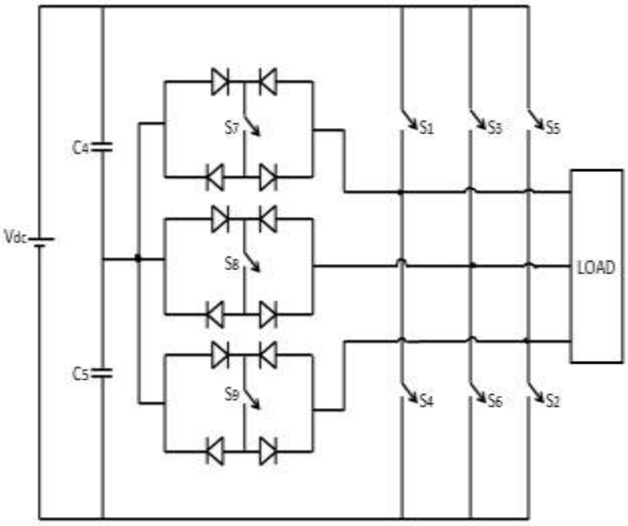

Figure 4: Schematic circuit of Multilevel Inverter Circuit Topology

The input dc supply given to the multilevel inverter topology is V_{dc}, which is the output dc voltage of the converter. Six main switches namely S_1, S_2, S_3, S_4, S_5, S_6 are used and three bidirectional switches such as S_7, S_8, $S_9$are also used. These nine switches are used to produce the three phase multilevel output voltage. Each main switch will conducts for a period of 150^0.And then each auxillary switch will conducts once in that 150^0.

3. Simulation Results

The output voltage of the Solar panel is designed as 30V. This output dc voltage of the solar panel is given as the input to the Switched-Capacitor based Converter. The duty cycle of the switches in the converter is designed as 0.64 [13]. The input voltage given to the converter is stepped up to higher output voltage. Then the stepped up dc voltage is given as the input to the Multilevel inverter circuit and staircase output voltage is obtained. . The design specifications for the converter and multilevel inverter are given below in Table1 and Table 2.

Table 1: Design Specifications of the Converter

Quantity	Nominal Value
Input Voltage	30V
Switching Frequency	50KHZ
Output Voltage	200V

Table 2: Design Parameters of the Converter and Multilevel Inverter

Components	Values
Output Capacitors C_1,C_2,C_3	470µf, 1µF
Inductors L_1,L_2	500µH
Input Capacitors of Multilevel Inverter C_4,C_5	8000µF

The three phase multilevel output voltage is then fed to grid or any other applications. The results are shown in the figures below. Fig. 5 shows the input voltage and output voltage of the proposed converter.

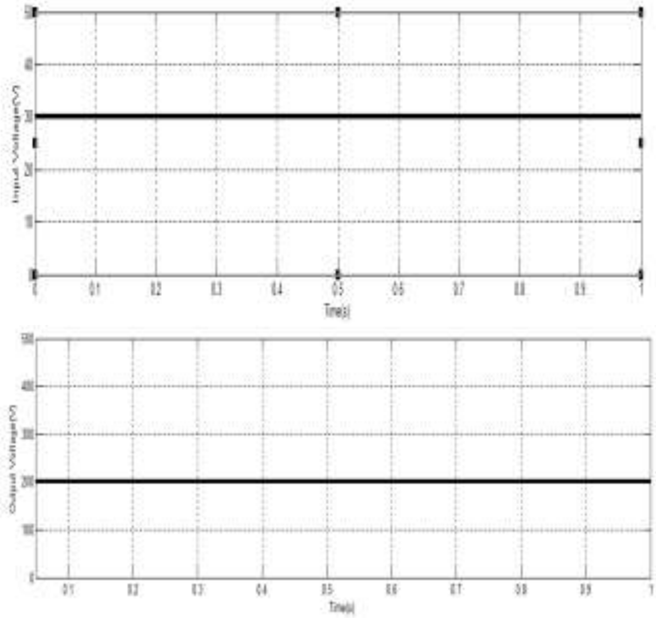

Figure 5: Input and Output Voltage of the Converter

The triggering pulses for the switches in the multilevel inverter topology is shown in the figure.6.

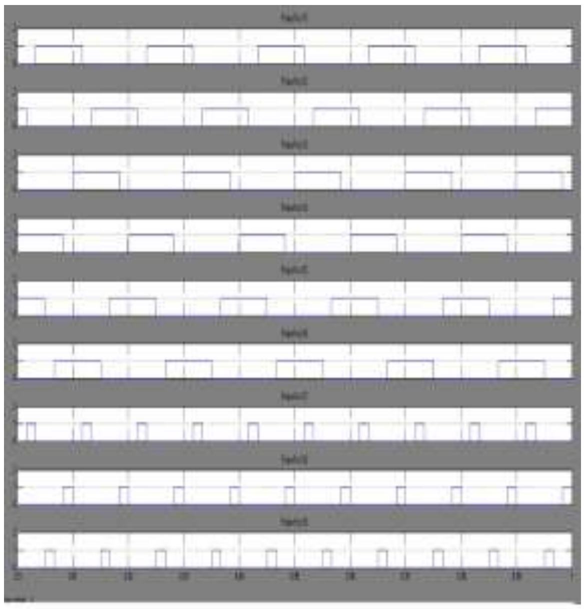

Figure 6: Triggering Pulses for the switches in the Multilevel Inverter

Then the phase output voltage and the line output voltages of the multilevel inverter are shown in figure.7 and 8.

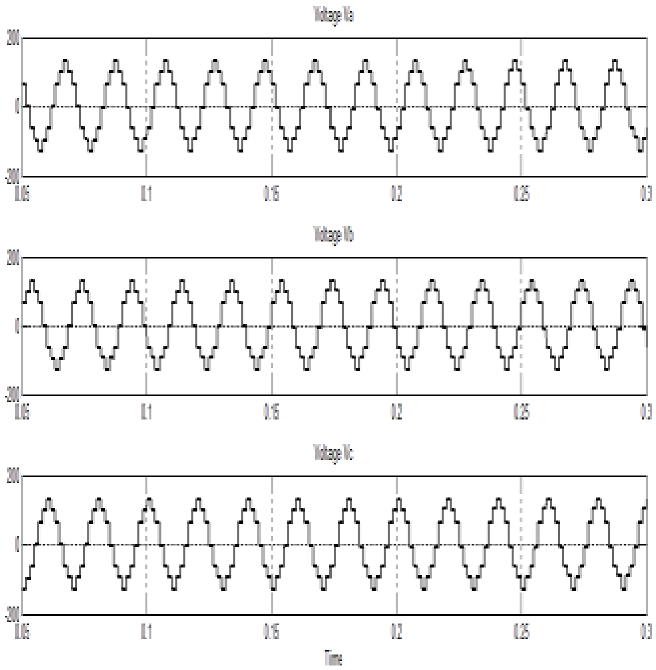

Figure 7: Output Phase Voltage of the Multilevel Inverter

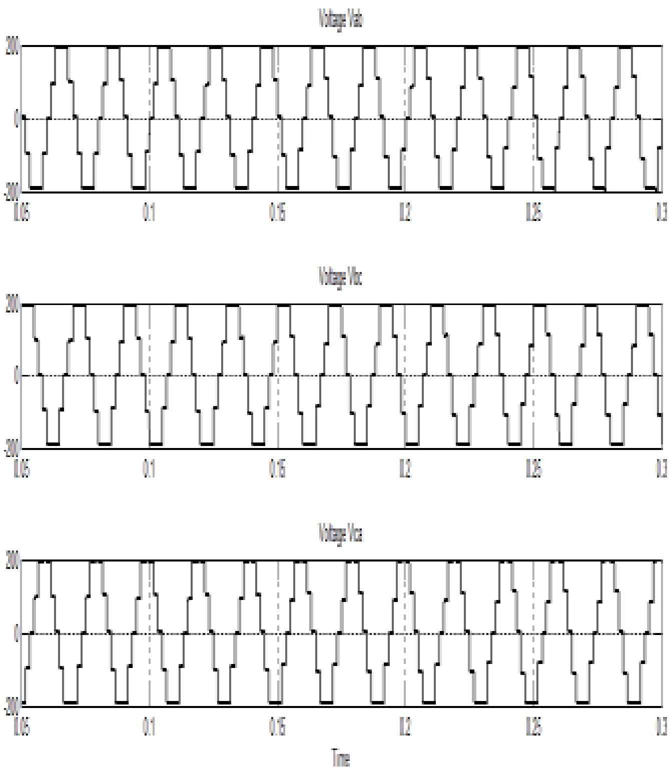

Figure 8: Output Line Voltage of the Multilevel Inverter

4. Conclusion

This paper has presented the Switched-Capacitor based active network converter technique and Multilevel Inverter for solar energy applications. The Converter is used to achieve the high step-up voltage gain. Then the multilevel inverter presented in this paper uses less number of switches than basic multilevel inverter topology. The simulation result shows the high step up voltage gain and multilevel output voltage of multilevel inverter.

References

[1] J. M. Shen, H. L. Jou, and J. C. Wu, "Novel transformer less grid connected power converter with negative grounding for photovoltaic generation system," *IEEE Trans. Power Electron.*, vol. 27, no. 4, pp. 1818–1829, Apr. 2012.

[2] L. Zhang, K. Sun, L. Feng, and H. Ge, "A modular grid-connected photovoltaic generation system based on DC bus," *IEEE Trans. Power Electron.*, vol. 26, no. 2, pp. 523–531, Feb. 2011.

[3] T. Suntio, J. Leppaaho, and J. Huusari, "Issues on solar-generator interfacing with voltage-fed converter," in *Proc. IEEE IECON*, 2009,pp. 595–600.

[4] X.Wu, J. Zhang, X.Ye, and Z. Qian, "Analysis and derivations for a family ZVS converter based on a new active clamp ZVS cell," *IEEE Trans. Ind. Electron.*, vol. 55, no. 2, pp. 773–781, Feb. 2008.

[5] W. Li, L. Fan, Y. Zhao, X. He, D. Xu, and B.Wu, "High-step-up and high efficiency fuel-cell power-generation system with active-clamp flyback– forward converter," *IEEE Trans. Ind. Electron.*, vol. 59, no. 1, pp. 599–610, Jan. 2012.

[6] L.-Sheng Yang and T.-J. Liang, "Analysis and implementation of a novel bidirectional DC–DC converter," *IEEE Trans. Ind. Electron.*, vol. 59, no. 1, pp. 422–434, Jan. 2012.

[7] F. Forest, A. Thierry Meynard, E. Laboure, B. Gelis, J.-J. Huselstein, and J. C. Brandelero, "An isolated multicell intercell transformer converter for applications with a high step-up ratio," *IEEE Trans. Power Electron.*, vol. 28, no. 3, pp. 1107–1119, Mar. 2013.

[8] C. M. Wang, "A novel ZCS-PWM flyback converter with a simple ZCS PWM commutation cell," *IEEE Trans. Ind. Electron.*, vol. 55, no. 2, pp. 749–757, Feb. 2008.

[9] G. Spiazzi, P. Mattavelli, and A. Costabeber, "High step-up ratio flyback converter with active clamp and voltage multiplier," *IEEE Trans. Power Electron.*, vol. 26, no. 11, pp. 3205–3214, Nov. 2011.

[10] B. R. Lin, J. Y. Dong, and J. J. Chen, "Analysis and implementation of a ZVS/ZCS DC–DC switching converter with voltage step-up," *IEEE Trans. Ind. Electron.*, vol. 58, no. 7, pp. 2962–2971, Jul. 2011.

[11] W. Li, L. Fan, Y. Zhao, X. He, and B. Wu, "High-step-up and high-efficiency fuel-cell power-generation system with active-clamp flyback–forward converter," *IEEE Trans. Ind. Electron.*, vol. 59, no. 1, pp. 599–610, Jan. 2012.

[12] B. Yuan, X. Yang, X. Zeng, J. Duan, J. Zhai, and D. Li, "Analysis and design of a high step-up current-fed multi resonant DC–DC converter with low circulating energy and zero-current switching for all active switches," *IEEE Trans. Ind. Electron.*, vol. 59, no. 2, pp. 964–978,Feb. 2012.

[13] H. L. Do, "Improved ZVS DC–DC converter with a high voltage gain and a ripple-free input current," *IEEE*

Trans. Circuits Syst. I, Reg. Papers, vol. 59, no. 4, pp. 846–853, Apr. 2012.
[14] T. Ninomiya, T. Tanaka, and K. Harada,"Analysis and optimization of a nondissipative LC turn-off snubber," *IEEE Trans. Power Electron.*, vol. 3, no. 2, pp. 147–156, Apr. 1998.
[15] Jian-hsieng lee, Tsorng-Juu Liang," Isolated coupled inductor integrated dc-dc converter for solar energy applications", *IEEE Transactions on Industrial Electronics*, vol.61, no.7, July 2014.
[16] S.Lai and F.Z.Peng," Multilevel converters –A breed of power converters," *IEEE Trans.Ind.Appl*.,vol.32,no.3,pp.509-517,May/June.1996.
[17] A. Chen and X. He, "Research on hybrid-clamped multilevel-inverter topologies," *IEEE Trans. Ind. Electron.*, vol. 53, no. 6, pp. 1898–1907, Dec. 2006.
[18] D. Krug, S. Bernet, S. S. Fazel, K. Jalili, and M. Malinowski, "Comparison of 2.3-kV medium-voltage multilevel converters for industrial medium-voltage drives," *IEEE Trans. Ind. Electron.*, vol. 54, no. 6, pp. 2979–2992, Dec. 2007.
[19] P. Lezana, C. A. Silva, J. Rodrguez, and M. A. Prez, "Zero-steady state-error input-current controller for regenerative multilevel converters based on single-phase cells," *IEEE Trans. Ind. Electron.*, vol. 54, no. 2, pp. 733–740, Apr. 2007.
[20] C. Rech and J. R. Pinheiro, "Hybrid multilevel converters: Unified analysis and design considerations," *IEEE Trans. Ind. Electron.*, vol. 54, no. 2, pp. 1092–1104, Apr. 2007
[21] Y. Cheng, C. Qian, M. L. Crow, S. Pekarek, and S. Atcitty, "A comparison of diode-clamped and cascaded multilevel converters for a STATCOM with energy storage," *IEEE Trans. Ind. Electron.*, vol. 53, no. 5, pp. 1512–1521, Oct. 2006.

Author Profile

K. Komagal Raja Priya received the B.E degree in Electronics and Communication Engineering from the Einstein College of Engineering, Tirunelveli in 2011 and she is currently pursuing the M.E degree in Power Electronics and Drives from the Sri SaiRam Engineering College, Chennai. Her research interests include Power Electronics, Digital Electronics, Renewable Energy Systems and Communication Engineering.

T. Porselvi received Bachelor's degree in Dr. MGR Engineering College in 1998.She received M.E degree in Power Electronics and Drives from Anna University, Chennai in 2005.She is currently doing the PhD, degree in Power Electronics for Renewable Energy Systems from Anna University. From1998 to 2000, she was a lecturer with the Thangavelu Engineering College, Chennai. Since 2000, she is working with the Department of Electrical Engineering, Sri SaiRam Engineering College, Chennai. She is currently an Associate Professor in Sri SaiRam Engineering College, Chennai. Her research interests includes Power Electronics for Renewable Energy, Drives, Control Systems, Machines.