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Diode Clamed Mulilevel Matrix Converter for DFIG Based Wind Energy Conversion System

G.PanduRangaReddy[1], M.Venkateshwarlu[2] , Dr.M.Vijaya Kumar[3]

Abstract: *People of the world are in need to find and develop new sources of energy to power their lives.Owing to the increasing demand for electrical energy, world's fossil fuel supply will thus be depleted in a few decades.Hence, alternative or renewable sources of energy have to be developed to meet the future energy requirement.Grid connected wind capacity is undergoing through fastest rate ofgrowth compared to any other form of renewable power generation, achieving global annual growth rates of 20–30 %. The power electronic converters play a major role in wind energy conversion system for controlling and conditioning of output power from wind energy.During last few years matrix converters and multi level converter topologies have generated significant interest.This paper discusses the diode clamped multilevel matrix converter design for double fed induction generator based wind energy conversion system.The MATLAB/SIMULINK software is used for analyzing the converter performance.*

Index Terms*: Double fed induction generator, diode clamped multilevel matrix converters, grid, matrix Converter, space vector pulse width modulation technique, wind turbine.*

I. INTRODUCTION

Energy plays a vital role in our daily activities. As populations grow more rapidly, decreases the fossil fuels then consuming the more natural resources to meet the requirements.Wind energy plays an impartment role among all renewable energy. It is important because it holds immense potential in supplying electricity across the world. Unlike other sources of electricity that require fuel in processing plants, wind energy generates electricity through wind, which is free. Wind is considered a native fuel that does not need to be transported or mined, eliminating two costly expenses from long-term energy expenses.

The benefits of wind energy are numerous. Wind energy is home grown, and local landowners and small businesses can operate single turbines or clusters of turbines. It doesn't emit contaminants into lakes and streams, and it doesn't produce hazardous airborne pollutants.Wind energy doesn't cause acid rain or contribute to global climate change.

Most other sources of power, including natural gas and coal, produce greenhouse gases, whereas wind energy produces none. Wind energy has a minimal impact on crop production and livestock grazing as well, because wind farms cover only small areas of land.

The major components of a typical wind energy conversion system include a wind turbine, generator, interconnection apparatus and control systems.Wind turbines can be classified into the vertical axis type and the horizontal axis type.Modern wind turbines use HAWT with two or three blades and operate either downwind or upwind configuration. This HAWT can be designed for a constant speed application or for the variable speed operation. Among these two types variable speed wind turbine has high efficiency with reduced mechanical stress and less noise. Variable speed turbines produce more power than constant speed type, comparatively, but it needs sophisticated power converters, control equipments to provide fixed frequency and constant power factor [1].

During the last few years, the variable speed wind turbines with Doubly-fed induction generator (DFIG) dominant the wind energy conversion system (WECS). There are several reasons for using variable-speed DFIG based wind turbines; among those are (i) Possibilities to reduce stresses of the mechanical structure, (ii) Acoustic noise reduction and (iii) The possibility to control active and reactive power. In DFIG the power processed by the power converter is only a fraction of the total wind turbine power, and therefore its size, cost and losses are small [2].

When applying power electronic converters to wind turbines, most manufactures have chosen a solution based on the two-level voltage source converter, combined with a doubly fed induction generator. This topology consists of two power converters, connected by an energy storage element. An alternative to the conventional converters is the matrix converter. The matrix converter might become a competitive alternative to the conventional back-to-back voltage source converter [3]. The matrix converter performs a direct AC to AC conversion, by which the large energy storage element of conventional converters is avoided. Due to the lack of energy storing element, it is expected to have a more compact design.

Nevertheless, the application of matrix converters is still limited to low and medium voltage levels.Multilevel converter topologies, on the other hand, are wellknown solutions for medium and high power applications. Among various multilevel topologies, the most important ones are Diode-Clamped Multilevel Converter (DCMC), Flying Capacitors Multilevel converters (FCMC) and Cascaded Multilevel Converters (CMC).Therefore, various combinations of these topologies, known as Multilevel MatrixConverters (MMC) have been developed for high power direct AC to AC power conversion [4].

This paper presents the designing of diode clamped multilevel matrix converter for DFIG based wind energy conversion system.In view of this the paper is organized as follows: Section 2 deals with the dynamic modeling of wind energy conversion system. The matrix converter topologies and designing of diode clamped multi level matrix converter using SVPWM techniques has been explained in section 3 and 4 respectively. The simulation results of diode clamped multilevel matrix converter for DFIG based WECS have been shown in section 5 and the conclusions are presented in section 6.

II. MODELING OF THE WIND ENERGY CONVERSION

2.1 Wind Turbine

The mechanical power, captured by a wind turbine, depends on its power coefficient and wind velocity and can be represented by

$$P_m = \frac{1}{2}\rho C_p(\lambda,\theta)\pi R^2 V_w^3 \quad (1)$$

Where ρ and R correspond to the air density and the radius ofthe turbine propeller, respectively.

The power coefficient CP is defined as the ratio of the mechanical power (Pm) to the wind power (Pw). It is the function of tip speed ratio λ and pitch angle β. Tip speed ratio is the ratio of blade tip speed to wind speed. β is the pitch angle which is the angle between the plane of rotation and the blade cross section chord[5].

$$C_p(\lambda,\beta) = 0.5\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{\frac{-16.5}{\lambda_i}} = \frac{P_m}{P_W} \quad (2)$$

Where λ_i is

$$\lambda_i = \frac{1}{\frac{1}{\lambda + 0.089\beta} - \frac{0.035}{\beta^3 + 1}} \quad (3)$$

According to Betz's Law the theoretical limit for Cp is 0.59, but its practical range of variation is 0.2-0.4. In this paper, the rotor pitch angle is assumed to be fixed.

2.2 Modeling of DFIG

DFIG has two independent active winding sets, and allow the extraction of energy not only from the stator but also from the rotor of the machine enabling the operation at variable speed. Nowadays, this type of DFIG-WECS has a part of wind energy market, which is close to 50%. Major wind turbine producers manufacture wind energy conversion system based on DFIG [6].

For balanced steady state conditions the d and q variables are sinusoidal in allreference frames except the synchronously rotating reference frame wherein they are constants, the d – q components of voltages are described as

$$V_{ds} = R_s i_{ds} + \frac{d\psi_{ds}}{dt} - \omega_s \psi_{qs} \quad (4) \qquad V_{qs} = R_s i_{qs} + \frac{d\psi_{qs}}{dt} + \omega_s \psi_{ds} \quad (5)$$

$$V_{dr} = R_s i_{dr} + \frac{d\psi_{dr}}{dt} - (\omega_s - \omega_r)\psi_{qr} \quad (6) \qquad V_{qr} = R_s i_{qr} + \frac{d\psi_{qr}}{dt} + (\omega_s - \omega_r)\psi_{dr} \quad (7)$$

The ψ stands for flux linkage and is expressed as [8]

$$\psi_{ds} = L_{ss} i_{ds} + L_m i_{dr} \quad (8) \qquad \psi_{qs} = L_{ss} i_{qs} + L_m i_{qr} \quad (9)$$

$$\psi_{dr} = L_{rr} i_{dr} + L_m i_{ds} \quad (10) \qquad \psi_{qr} = L_{rr} i_{qr} + L_m i_{qs} \quad (11)$$

Where

$$L_{ss} = L_s + L_m \quad (12)$$

and

$$L_{rr} = L_r + L_m \quad (13)$$

For a simple mechanical system of moment of inertia J and damping factor F, the rotor swing equation is

$$J \frac{d\omega_{rm}}{dt} + F\omega_{rm} = (T_e - T_m) \quad (14)$$

Where, $T_m$is the mechanical torque
$T_e$represents the electrical torque
ω_{rm} represents the mechanical speed of the rotor

III. BASIC MATRIX CONVERTER TOPOLOGY AND INDIRECT MATRIX CONVERTERS (IMC)

3.1 Basic Matrix Converter

Forced commutated ac-ac converter topologies that can provide simultaneous amplitude and frequency transformation of multi – phase voltage – current systems without intermediate energy storage are referred to as Matrix Converters (MCs). MCs can generate sinusoidal input currents and output voltages with higher electrical output frequencies than the input frequency [7].

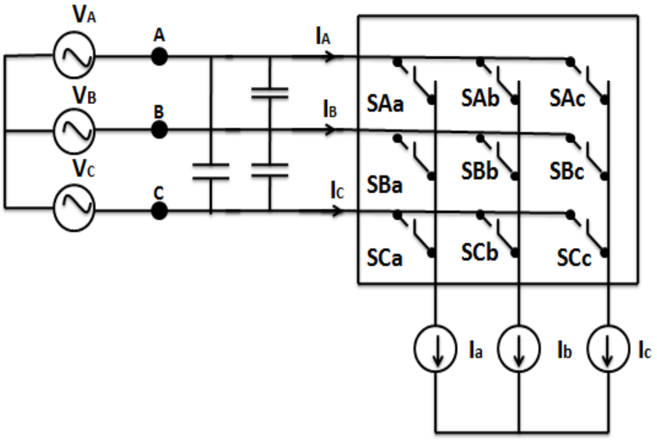

Fig.1. Simplified circuit of a 3×3 matrix converter.

3.2 Indirect Matrix Converter

The Indirect Matrix Converter as shown in Fig. 2.It consist of a two-stage (indirect) power conversion with a bidirectional, unipolar current source input stage with six bidirectional switches and a two-level voltage source converter output stage.

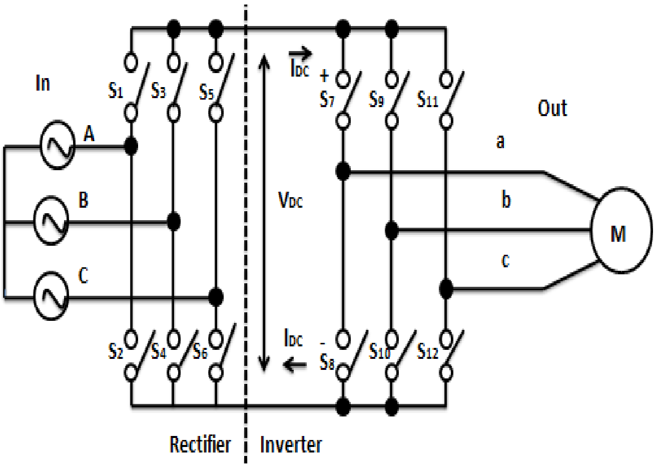

Fig.2. Indirect Matrix Converter

IV. DIODE CLAMPED MULTILEVEL MATRIX CONVERTER

To increase the power level, achieve higher efficiency, and provide better output voltage quality, the multilevel concept has been adapted to develop multilevel matrix converter topologies. The indirect matrix converter (IMC) topologies as shown in fig (2).By considering this, other implementations of multilevel matrix converters are possible. For this purpose, the inverter and the rectifier stages can be replaced with the multilevel converter circuit as shownin Fig.3. The neutral point of the two converters are connected together and instead of two buses three current passes exist between rectifier and inverter stages.[8]

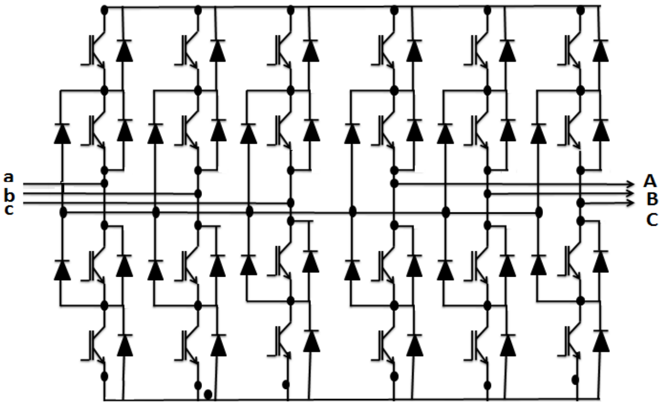

Fig. 3. One possible multilevel matrix converter topology

On the other hand, to avoid spikes and high current surges, the input voltage sources should not be short circuited and the output current should always find a path to flow. But satisfying these rules for the three buses makes the modulation very complicated and it can be shown that under some circumstances for higher number of levels it is not possible to comply with the rules.

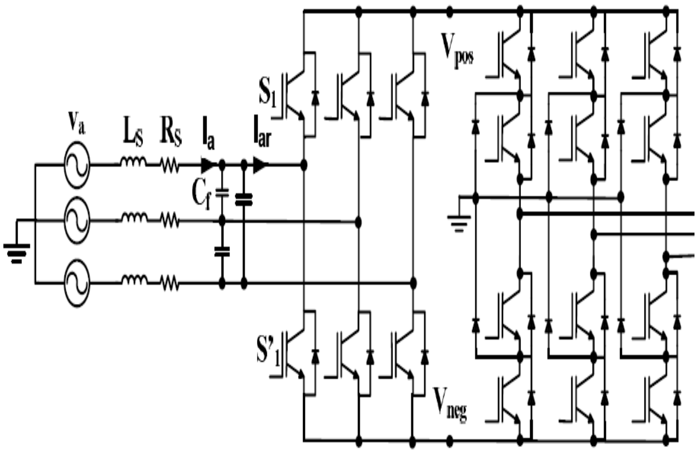

Fig 4. Diode clamped multilevel matrix converter

However, another configuration is possible which does not have the aforementioned problems. If the input current rectifier stage remains as a two level converter, the result would be a simpler topology as shown in Fig.4. In the above fig the rectifier stage is switched at the line frequency, and becauselow frequency, high power and high voltage switches areavailable in the market with reasonable prices, there is noneed to substitute this stage with multilevel converter. It isworth mentioning that the neutral point of the multilevel stageis connected to ground to keep it at zero voltage and thetwo positive and negative buses are supplied by the two levelrectifier stage. In this the rectifier stage is synchronized with the source voltage. Therefore, the fundamental harmonics of the input currents are in phase with the corresponding source voltages. Utilizing basic SVM techniques for multiplexed inverters, the output stage can be controlled to generate controllable AC voltage waveforms with a desired frequency.

To prevent a short circuit at the input stage and an open circuit at the output stage, certain precautions must be taken. To avoid an open circuit, the rectifier stage is switched at the zero vector period of the multilevel inverter stage. The short circuit problem occurs if more than two switches among upper or lower switches are turned on. However, this is prevented by using the simple switching pattern illustrated in Fig. 5, because as soon as an upper switch is turned off, another upper switch will be turned on.

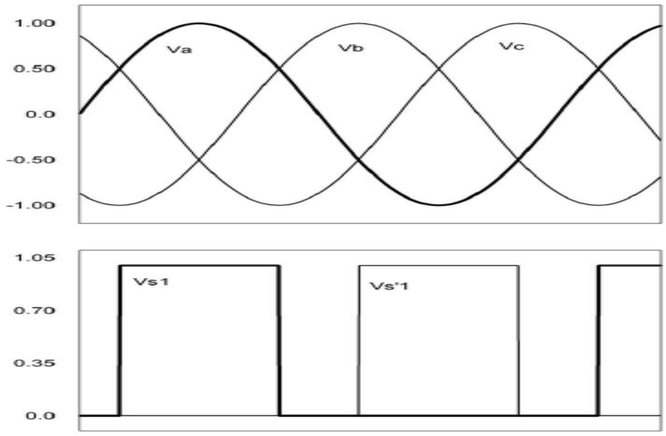

Fig.5.The rectifier bridge switching actions of the proposed MMC shown in Fig. 4

4.1 Space Vector Pulse Width Modulation Technique

Space vector pulse width modulation is applied to output voltageand input current control. This method is an advantage because of increasedflexibility in the choice of switching vector for both input current and outputvoltage control. It can yield useful advantage under unbalanced conditions.For a sufficientlysmall time interval, the reference voltage vector can be approximated by a setof stationary vectors generated by a matrix converter.

If this time interval is the sample time for converter control, then atthe next sampling instant when the reference voltage vector rotates to a newangular position, it may correspond to a new set of stationary voltage vectors. Carrying this process onwards by sampling the entirewaveform of the desired voltage vector being synthesized in sequence, theaverage output voltage would closely emulate the reference voltage.Meanwhile, the selected stationary vectors can also give the desirable phaseshift between input voltage and current [9]. The space vector diagram with sectors as shown in Fig.6.

The dwelling time can be evaluated using the equations

$$T_1 = \frac{\sqrt{3}T_S\left|\bar{V}_{ref}\right|}{V_{dc}}\left[\sin\left\{\frac{\pi}{3}-\alpha+\frac{(s-1)\pi}{3}\right\}\right] \qquad (15)$$

$$T_2 = \frac{\sqrt{3}T_S\left|\bar{V}_{ref}\right|}{V_{dc}}\left[\sin\left\{\alpha-\frac{(s-1)\pi}{3}\right\}\right] \qquad (16)$$

$$T_0 = T_S - (T_1 + T_2)\,(17)$$

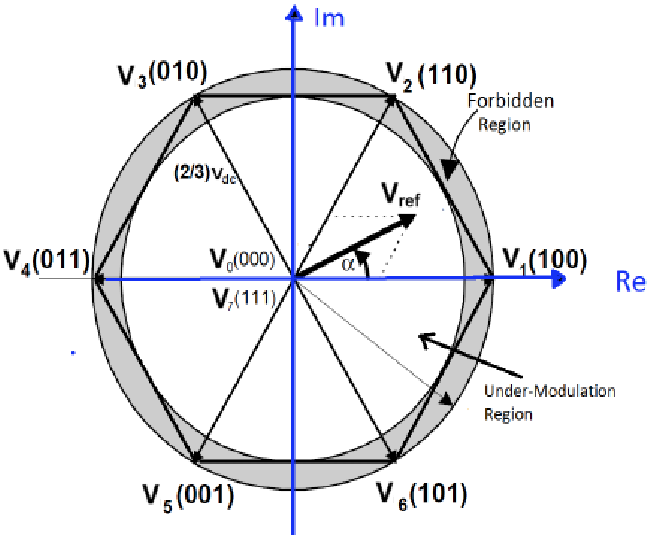

Fig.6. Space Vector Diagram with Sectors

V. SIMULATION RESULTS AND DISCUSSION

The MATLAB/SIMULINK software is used for design and analyzing the diode clamped multilevel matrix converter (MMC) for DFIG based wind energy conversion system. In this the SVPWM technique is used for controlling the converter switches.In this paper up to t = 0.2 the WECSdoes not connected to the grid. After t = 0.2 the WECS employing DFIG with diode clamped MMCis connected to the grid.

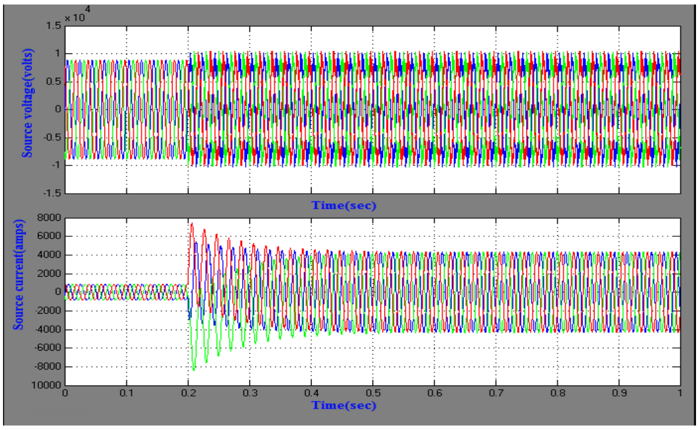

Fig.7. Source voltage & Source current of DFIG based WECS employing Diode clamped MMC

The simulation result of Fig.7 shows the source voltage and current of the DFIG systememploying Diode clamped MMC. These voltages and currents are uncontrolled.

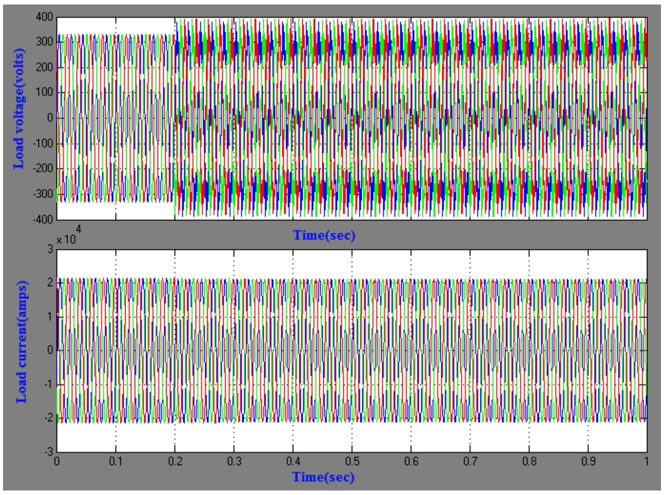

Fig.8. Load voltage & Load current of DFIG based WECS employing Diode clamped MMC

The simulation result of Fig.8 shows the load voltage and current of the DFIG systememploying Diode clamped MMC. These voltages and currents are controlled and meet the grid voltage and grid currents from t= 0.2 sec.

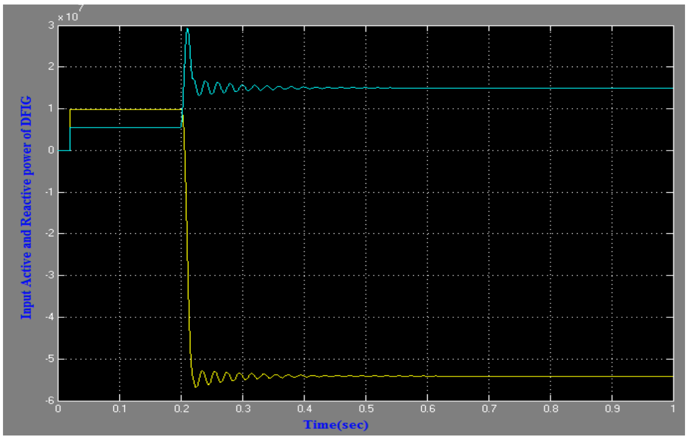

Fig.9. Input Active & Reactive power of DFIG based WECS employing Diode clamped MMC

The simulation result of Fig.9 shows the input active and reactive power of the DFIG systememploying Diode clamped MMC.

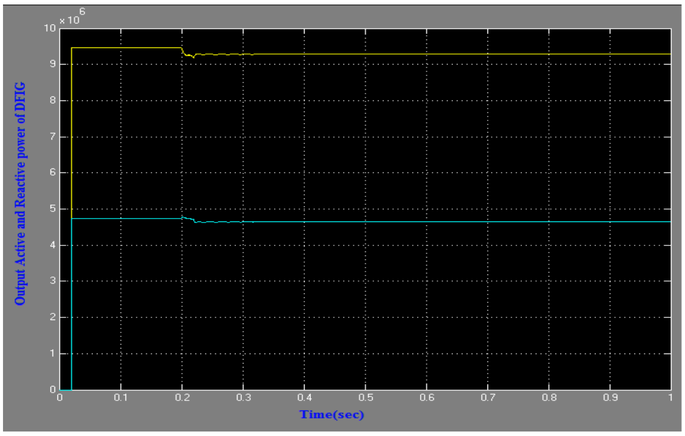

Fig.10. Output Active & Reactive power of DFIG based WECS employing Diode clamped MMC

The simulation result of Fig.10 shows the output active and reactive power of the DFIG system employing Diode clamped MMC.

VI. CONCLUSION

This paper presents a designing of new AC/AC power converter thatis suitable for high power applications and applied to DFIG based wind energy conversion system. The proposed multilevelmatrix converter topology is based on diode clampedmultilevel converter at the output stage and input rectifierusing unidirectional switches. Therefore, compared to otherexisting MMCs, it utilizes the least number of switches andminimizes switching losses. Because of the multilevel outputwaveforms, the output power quality is significantly improved.This topology does not require bulky DC-link capacitors,heavy input inductors or highly controlled flying capacitorsand only uses small input filter capacitors.

The SVPWM control strategy has been employed for controlling the switching sequence of power electronic devices in the power converters.In this SVPWM theory ideal switches have been used for analyzing the diode clamped multilevel matrix converter. From simulation results the output active and reactive powers of DFIG based WECS improved compare to input active and reactive powers.

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G.Pandu Ranga Reddy graduated in Electrical & Electronics Engineering from JNTUH. He received M.Tech in control systems from JNTUA. He is presently a research scholar in J.N.T.U.A; Anantapur, Andhra Pradesh, India. His areas of interests are Wind energy conversion systems, matrix converters and control systems.

M.Venkateswarlu was born in 1979. He received his Graduate in Electrical & Electronics Engineering from G.Pulla reddy Engineering College in the year 2003. He received his M.Tech in power & industrial drives from J.N.T.U.A, Anantapur, in the year 2011.Presently he is working as a Sr.Assistant Professor in Dept. of EEE at G.Pullaiah college of Engg&Tech, Kurnool. He has 9 years of teaching experience. His area of interest is power electronics, converters, and hvdc transmission.

Prof. M. Vijaya Kumar graduated from S.V. University, Tirupathi, A.P, India in 1988. He obtained M.Tech degree from Regional Engineering College, Warangal, India in 1990. He received Doctoral degree from Jawaharlal Nehru Technological University, Hyderabad, India in 2000.Currently he is working as Professor in Electrical and ElectronicsEngineering Department, JNTU College of Engineering, Anantapur, A.P, India. He is a member of Board of studies of few Universities in A.P., India. He has published over 87 research papers in national and inter-national conferences and journals. Four Ph.D.s were awarded under his guidance. He received two research awards from the Institution of Engineers (India). He served as Director, AICTE, New Delhi for a short period. He also served as Founder Registrar of JNT University, Anantapur during 2008 – 2010. His areas of interests include Electrical Machines, Electrical Drives, Microprocessors and Instrumentation.