P.C Chakravarthy, M.Daivaasirvadam / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 2, Issue 6, November- December 2012, pp.1660-1665

A Hybrid Cascaded Seven-Level Inverter With Novel Pulse Width Modulation Technique For Pv Applications

P.C Chakravarthy, M.Daivaasirvadam
PG student, Power & Industrial Drives, Department of EEE, VIIT, Visakhapatnam,(A.P), India.
Assistant professor, EEE Dept, VIIT, A.P, India.

ABSTRACT

The most popular cascaded H-bridge apart from other multilevel inverters is the capability of utilizing different dc voltages on the individual H-bridge cells which results in splitting the power conversion amongst higher-voltage lower-frequency and lower-voltage higher-frequency inverters. This paper proposes a single-phase seven-level inverter for grid-connected photovoltaic systems, with a novel pulse width-modulated (PWM) control scheme. Three reference signals that are identical to each other with an offset that is equivalent to the amplitude of the triangular carrier signal were used to generate the PWM signals. The inverter is capable of producing seven levels of output-voltage levels (*V*dc, 2*V*dc/3, *V*dc/3, 0, −*V*dc,−2*V*dc/3,−*V*dc/3) from the dc supply voltage. In this paper a new nine level multilevel inverter with reduced number of switches is proposed and MATLAB/Simulink results are presented.

Keywords —Grid connected, modulation index, multilevel inverter, photovoltaic (PV) system, pulse width-modulated (PWM), total harmonic distortion (THD).

I. INTRODUCTION

Nowadays, the non conventional energy sources are used compared with conventional energy source because day by day the conventional energy sources are reduces. The main energy supplier of the worldwide economy is fossil fuel. This however has led to many problems such as global warming and air pollution. Therefore, with regard to the worldwide trend of green energy, solar power technology has become one of the most promising energy resources. The number of PV installations has had an exponential growth mainly due to the governments and utility companies who support the idea of the green energy. One of the most important types of PV installation is the grid connected inverter configurations. The PV cells are producing the dc sources. But all electrical equipments are operated ac supply. So I want the ac supply by using inverters photovoltaic cells are most popularly used. So the photo voltaic cells are producing the dc source. These dc sources give to inverter. The inverter converts dc to ac power. But the inverter produces square wave ac. The square wave contains infinite number of harmonics are presented. The multilevel inverter means the level refers to the various voltage values in a cycle. The multilevel inverter output levels increase near to the sine wave shape formed. Then the number of harmonic content reduced in the output of the multilevel inverter output.

II. PHOTO VOLTAIC SYSTEMS

A Photovoltaic (PV) system directly converts sunlight into electricity. The basic device of a PV system is the PV cell. Cells may be grouped to form panels or arrays. The voltage and current available at the terminals of a PV device may directly feed small loads such as lighting systems and DC motors. A Photo voltaic cell is basically a semiconductor diode whose p–n junction is exposed to light. Photovoltaic cells are made of several types of semiconductors using different manufacturing processes. The incidence of light on the cell generates charge carriers that originate an electric current if the cell is short circuited.

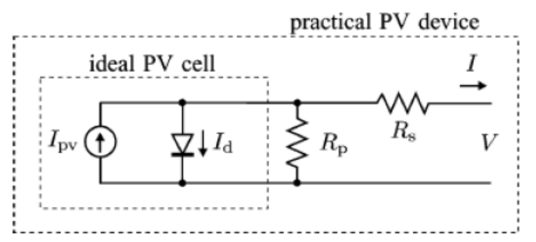

Fig.1 Equivalent cirucuit of a PV device including the Series and Parallel Resistances. The equivalent circuit of PV cell is shown in Figure 1. In the above diagram the PV cell is represented by a current source in parallel with diode. Rs and Rp represent series and parallel resistance respectively. The output current and voltage from PV cell are represented by I and V.

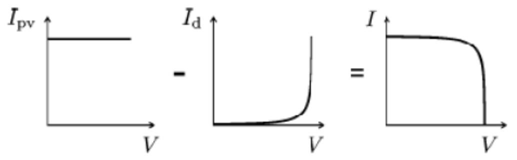

Fig.2 Characteristic I-V curve of the PV cell

The I-V characteristics of PV cell are shown in Figure 2. The net cell current I is composed of the light-generated current IPV and diode current Id.

$$I= IPV - Id \quad (1)$$

Where

Id =$I0$ exp (qV/akT)

$I0$ = leakage current of the diode

q=electron charge

k=Bolzmann constant

T=temperature of pn junction

a=diode ideality constant

The basic equation (1) of PV cell does not represent the *I-V* characteristic of a practical PV array. Practical array are composed of several connected PV cells and the observation of the characteristics at the terminals of the PV array requires the inclusion of additional parameters to the basic equation.

$$I=IPV - exp\ V+RsIVta -1 -V+RsIRp \quad (2)$$

Where

$Vt= NskT/q$s is the thermal voltage of the array with Ns cells connected in series. Cells connected in parallel increase the current and cells connected in series provide greater output voltages. The I-V characteristics of a practical PV cell with maximum power point (MPP), short circuit current (Isc) and open circuit voltage (Voc) is shown in Figure 3. The MPP represents the point at which maximum power is obtained.

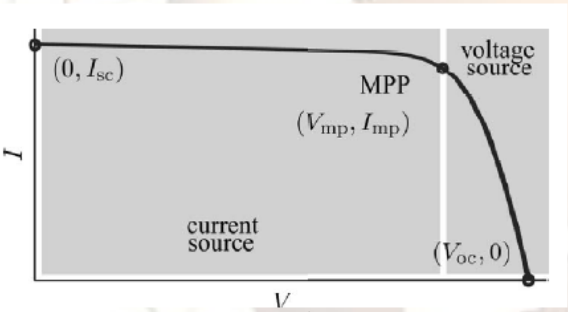

Fig.3 I-V Characteristic of the practical PV cell Vmp and Imp are voltage and current at MPP respectively. The output from PV cell is not the same throughout the day; it varies with varying temperature and insolation (amount of radiation). Hence with varying teperature and insulation maximum power should be tracked so as to achieve the efficient operation of PV system.

III.MULTILEVEL INVERTERS

The multilevel inverter are three types. They are 1.Diode clamped multilevel inverter 2.Flying capacitor multilevel inverter 3.Cascaded H-bridge multilevel inverter.The multilevel inverters are used for high power rating compared to the inverters. A multilevel inverter not only achieves high power ratings, but also improves the performance of the whole system in terms of harmonics, dv/dt stresses, and stresses in the bearings of a motor. The concept of multilevel inverters performing power conversion in multiple voltage steps to obtain improved power quality, lower switching losses, better electromagnetic compatibility, and higher voltage capability. One of the significant advantages of multilevel configuration is the harmonic reduction in the output waveform without increasing switching frequency or decreasing the inverter power output. The output voltage waveform of a multilevel inverter is composed of the number of levels of voltages, typically obtained from capacitor voltage sources. The so-called multilevel starts from three levels. As the number of levels reach infinity, the output THD approaches zero. The number of the achievable voltage levels, however, is limited by voltage unbalance problems voltage clamping requirement, circuit layout, and packaging constraints. A single-phase grid-connected inverter is usually used for residential or low-power applications of power ranges that are less than 10 kW.

As the number of level increases, the THD content approaches to small value as expect. Thus it eliminates the need for filter. Though, THD decreases with increase in number of levels, some lower or higher harmonic contents remain dominant in each level. These will be more dangerous in induction drives.

A novel PWM modulation technique is used to generate switching signals for the switches and to generate seven output-voltage levels: 0, +Vdc/3, +2Vdc/3, +Vdc, Vdc/3, -2Vdc/3,-Vdc. Simulation results are presented to validate the proposed inverter configuration.

This paper recounts the development of a novel modified H-bridge single-phase multilevel inverter that has two diode embedded bidirectional switches and a novel pulse width modulated (PWM) technique.

IV. HYBRID SEVEN LEVEL INVERTER

A Full H-Bridge:

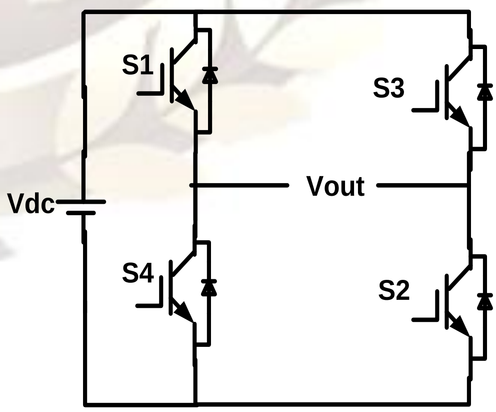

Figure. 4 Full H-Bridge

Fig.4 shows the Full H-Bridge Configuration. By using single H-Bridge we can get 3 voltage levels. The number output voltage levels of cascaded Full H-Bridge are given by 2n+1 and voltage step of each level is given by Vdc/n. Where n is number of H-bridges connected in cascaded. The switching table is given in Table 1.

Table 1. Switching table for Full H-Bridge

Switches Turn ON	Voltage Level
S1,S2	Vdc
S3,S4	-Vdc
S4,D2	0

B Hybrid H-Bridge

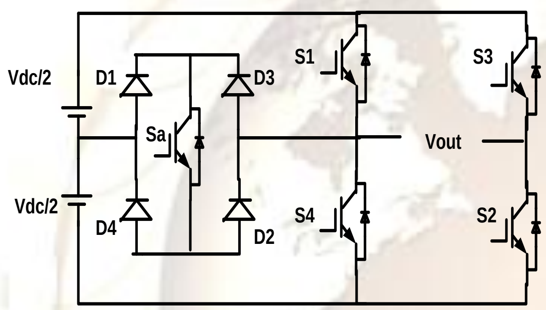

Figure. 5 Hybrid H-Bridges

Fig. 5 shows the Hybrid H-Bridge configuration. By using single Hybrid H-Bridge we can get 5 voltage levels. The number output voltage levels of cascaded Hybrid H-Bridge are given by 4n+1 and voltage step of each level is given by Vdc/2n. Where n is number of H-bridges connected in cascaded. The switching table of Hybrid H-Bridge is given in Table 2.

Table 2. Switching table for Hybrid H-Bridge

Switches Turn On	**Voltage Level**
Sa, S1	Vdc/2
S1,S2	Vdc
S4,D2	0
Sa,S3	-Vdc/2
S3,S4	-Vdc

V HYBRID CASCADED MULTILEVEL INVERTER

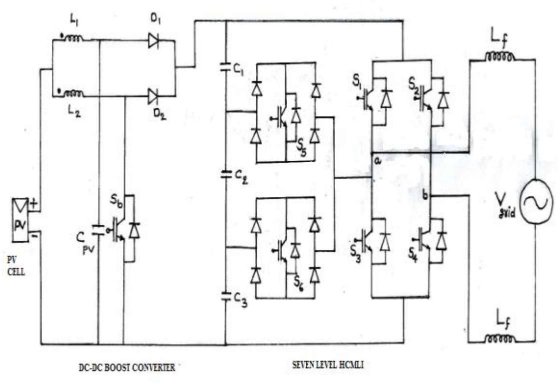

Fig 6: Hybrid cascaded multilevel inverter for photovoltaic system

Fig.6. A single phase hybrid cascaded seven-level grid-
connected inverter for photovoltaic systems.

The proposed single-phase seven-level inverter was developed from the five-level inverter in. It comprises a single-phase conventional H-bridge inverter, two bidirectional switches, and a capacitor voltage divider formed by $C1$, $C2$, and $C3$, as shown in Fig. 1. The modified H-bridge topology is significantly advantageous over other topologies, i.e., less power switch, power diodes, and less capacitor for inverters of the same number of levels. Photo voltaic (PV) arrays were connected to the inverter via a dc–dc boost converter. The power generated by the inverter is to be delivered to the power network, so the utility grid, rather than a load, was used. The dc–dc boost converter was required because the PV arrays had a voltage that was lower than the grid voltage. High dc bus voltages are necessary to ensure that power flows from the PV arrays to the grid. A filtering inductance Lf was used to filter the current injected into the grid. Proper switching of the inverter can produce seven output-voltage levels (Vdc, $2Vdc/3$, $Vdc/3$, $0, -Vdc, -2Vdc/3, -Vdc/3$) from the dc supply voltage. The proposed inverter operation can be divided into seven switching states, as shown in the table-3.

a.To obtain + Vdc: S1 is ON and S4 is ON. All other controlled switches are OFF, the voltage applied to the load terminals is + Vdc.

b. **To obtain + 2Vdc/3:** The bidirectional switch S5 is ON
and S4 is ON. All other controlled switches are OFF, the voltage applied to the load terminals is + 2Vdc /3.

c. **To obtain + Vdc /3:** The bidirectional switch S6 is ON
and S4 is ON. All other controlled switches are OFF,
the voltage applied to the load terminals is + Vdc /3.

d) **To obtain Zero output:** This level can be produced
by two switching combinations; switches S3 and S4 are
ON, or S1and S2 are ON, and all other controlled switches are OFF, the voltage applied to the load terminals are zero.
e) **To obtain - Vdc /3:** The bidirectional switch S5 is ON
and S2 is ON. All other controlled switches are OFF,
the voltage applied to the load terminals is - Vdc /3.
f) **To obtain -2Vdc/3:** The bidirectional switch S6 is ON
and S2 is ON. All other controlled switches are OFF,
the voltage applied to the load terminals is - 2Vdc /3.
g) **To obtain - Vdc:** S2 is ON and S3 is ON. All other
controlled switches are OFF, the voltage applied to the load terminals is - Vdc.

TABLE 3
OUTPUT VOLTAGE ACCORDING TO THE SWITCHES' ON–OFF CONDITION

v_0	S_1	S_2	S_3	S_4	S_5	S_6
V_{dc}	on	off	off	on	off	off
$2V_{dc}/3$	off	off	off	on	on	off
$V_{dc}/3$	off	off	off	on	off	on
0	off	off	on	on	off	off
0*	on	on	off	off	off	off
$-V_{dc}/3$	off	on	off	off	on	off
$-2V_{dc}/3$	off	on	off	off	off	on
$-V_{dc}$	off	on	on	off	off	off

Table 3 shows the switching combinations that generated the seven output-voltage levels (0,−*V*dc,−2*V*dc⁄3,−*V*dc⁄3, *V*dc, 2*V*dc⁄3, *V*dc⁄3).

V PWM MODULATION

A novel PWM modulation technique was introduced to generate the PWM switching signals. Three reference signals (*V*ref1, *V*ref2, and *V*ref3) were compared with a carrier signal (*Vcarrier*). The reference signals had the same frequency and amplitude and were in phase with an offset value that was equivalent to the amplitude of the carrier signal. The reference signals were each compared with the carrier signal. If *V*ref1 had exceeded the peak amplitude of *V*carrier, *V*ref2 was compared with *V*carrier until it had exceeded the peak amplitude of *V*carrier. Then, onward, *V*ref3 would take charge and would be compared with *V*carrier until it reached zero. Once *V*ref3 had reached zero, *V*ref2 would be compared until it reached zero. Then, onward, *V*ref1 would be compared with *V*carrier.

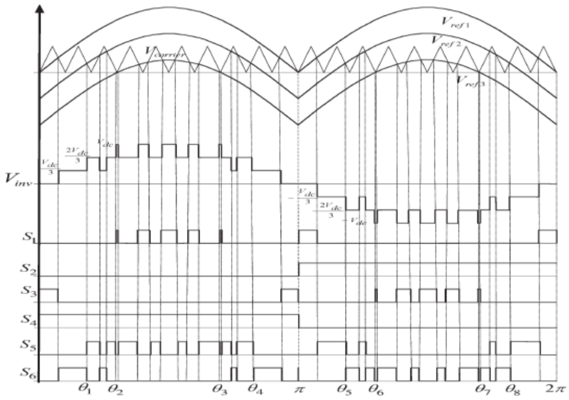

Fig. 7. Switching pattern for the single-phase seven-level inverter.

Fig.7 shows the resulting switching pattern. Switches *S*1, *S*3, *S*5, and *S*6 would be switching at the rate of the carrier signal frequency, whereas *S*2 and *S*4 would operate at a frequency that was equivalent to the fundamental frequency.
For one cycle of the fundamental frequency, the proposed inverter operated through six modes.
Fig. 8shows the per unit output-voltage signal for one cycle. The six modes are described as follows:
Mode 1 : $0 < \omega t < \theta 1$ and $\theta 4 < \omega t < \pi$
Mode 2 : $\theta 1 < \omega t < \theta 2$ and $\theta 3 < \omega t < \theta 4$
Mode 3 : $\theta 2 < \omega t < \theta 3$
Mode 4 : $\pi < \omega t < \theta 5$ and $\theta 8 < \omega t < 2\pi$
Mode 5 : $\theta 5 < \omega t < \theta 6$ and $\theta 7 < \omega t < \theta 8$
Mode 6 : $\theta 6 < \omega t < \theta 7$.

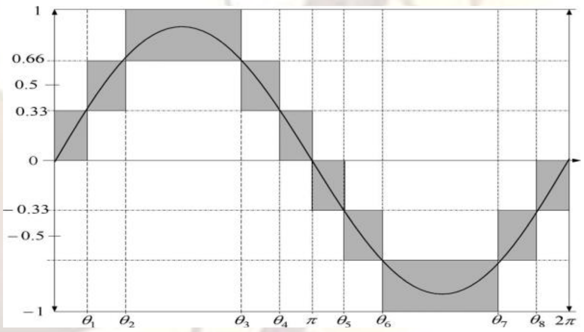

Fig. 8. Seven-level output voltage (*V*ab) and switching angles.

VI MATLAB/SIMULINK MODEL and SIMULATION RESULTS

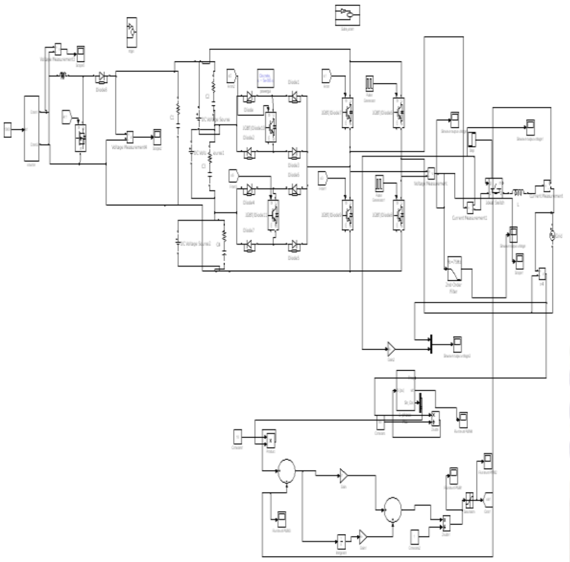

Fig. 9 Matlab/Simulink model of Grid connected PV system

Fig. 9 shows the Matlab/ Simulink model of grid connected photovoltaic system. It consist of a DC to DC conversion stage and Dc to AC multilevel inversion stage.

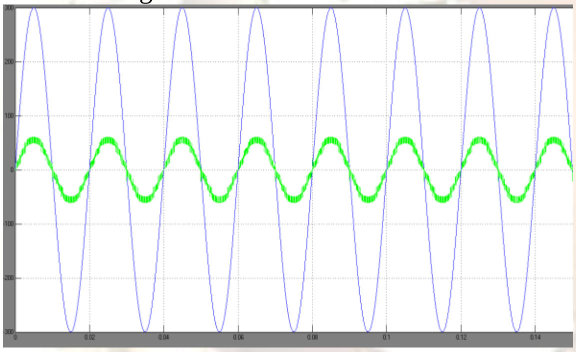

Fig.10. Grid Voltage and Grid Current

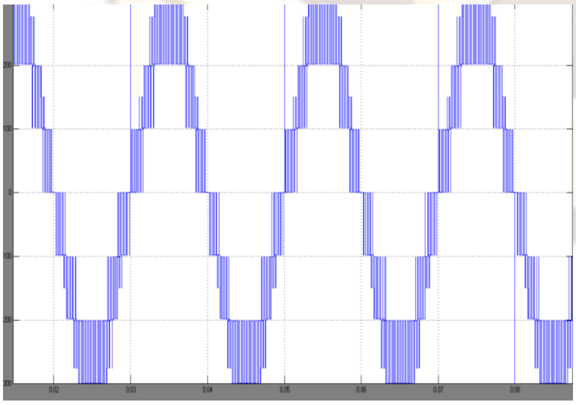

Fig. 11. Seven Level Voltage output

Fig. 11 shows the seven level PWM output. Fig. 10 shows the grid voltage and grid current. From the figure it is clear that grid voltage and current are in pahse.

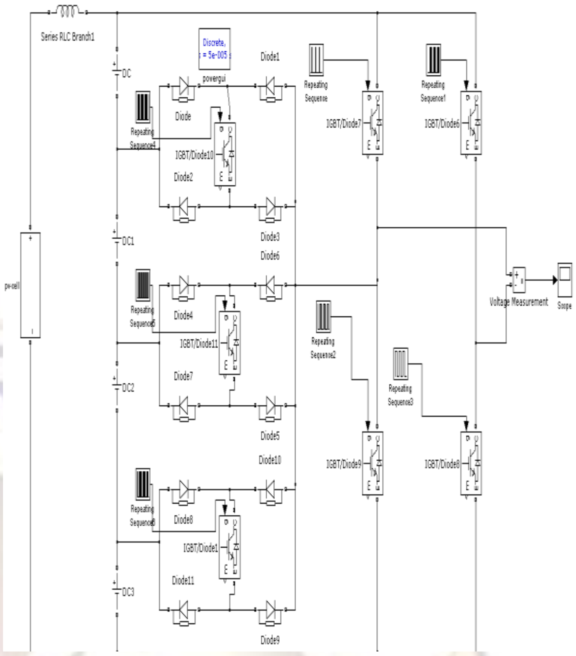

Fig.12 Matlab/SImulink modle of proposed Nine level Inverter

Fig. 12 shows the Matlab/Simulink model of proposed nine level Hybrid H-Bridge inverter.

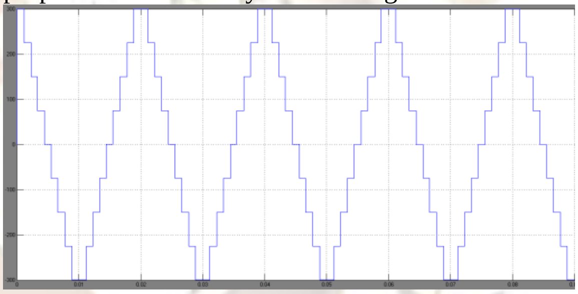

Fig.13 Nine level output of proposed converter

Fig. 13 shows the output of proposed nine level inverter. In proposed converter for nine level seven switches are required. In order to produce the same levels cascaded H-Bridge requires sixteen switches.

VII CONCLUSION

Multilevel hybrid cascaded inverter for seven level has been simulated using MATLAB/Simulink.
Multilevel inverters offer improved output waveforms and lower THD. This paper has presented a novel PWM switching scheme for the proposed multilevel inverter. It utilizes three reference signals and a triangular carrier signal to generate PWM switching signals. The behavior of the proposed multilevel inverter was analyzed in detail. Finally a nine level hybrid H-bridge inverter is proposed and simulation results are presented.

VI. REFERENCES

[1] M. Calais and V. G. Agelidis, "Multilevel converters for single-phase grid connected photovoltaic systems—An overview," in *Proc. IEEE Int. Symp. Ind. Electron.*, 1998, vol. 1, pp. 224–229.
[2] S. B. Kjaer, J. K. Pedersen, and F. Blaabjerg, "A review of single-phase grid connected inverters for photovoltaic modules," *IEEE Trans. Ind. Appl.*, vol. 41, no. 5, pp. 1292–1306, Sep./Oct. 2005.
[3] P. K. Hinga, T. Ohnishi, and T. Suzuki, "A new PWM inverter for photovoltaic power generation system," in *Conf. Rec. IEEE Power Electron. Spec. Conf.*, 1994, pp. 391–395.
[4] 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.
[5] M. Saeedifard, R. Iravani, and J. Pou, "A space vector modulation strategy for a back-to-back five-level HVDC converter system," *IEEE Trans. Ind. Electron.*, vol. 56, no. 2, pp. 452–466, Feb. 2009.
[6] S. Alepuz, S. Busquets-Monge, J. Bordonau, J. A. M. Velasco, C. A. Silva, J. Pontt, and J. Rodríguez, "Control strategies based on symmetrical components for grid-connected converters under voltage dips," *IEEE Trans. Ind. Electron.*, vol. 56, no. 6, pp. 2162–2173, Jun. 2009.
[7] J. Rodríguez, J. S. Lai, and F. Z. Peng, "Multilevel inverters: A surveyof topologies, controls, and applications," *IEEE Trans. Ind. Electron.*,vol. 49, no. 4, pp. 724–738, Aug. 2002.
[8] J. Rodriguez, S. Bernet, B. Wu, J. O. Pontt, and S. Kouro, "Multilevel voltage-source-converter topologies for industrial medium-voltage drives," *IEEE Trans. Ind. Electron.*, vol. 54, no. 6, pp. 2930–2945, Dec. 2007.
[9] M. M. Renge and H. M. Suryawanshi, "Five-level diode clamped inverter to eliminate common mode voltage and reduce dv/dt in medium voltage rating induction motor drives," *IEEE Trans. Power Electron.*, vol. 23, no. 4, pp. 1598–1160, Jul. 2008.
[10] E. Ozdemir, S. Ozdemir, and L. M. Tolbert, "Fundamental-frequencymodulated six-level diode-clamped multilevel inverter for three-phase stand-alone photovoltaic system," *IEEE Trans. Ind. Electron.*, vol. 56, no. 11, pp. 4407–4415, Nov. 2009.

Authors:

M. Daivaasirvadam was born in Andhra Pradesh, India, Received the B.Tech Electrical and Electronics Engineering from Godavari Institute of Information Technology, affiliated to JNT University Hyderabad, and M-Tech Computer controlled industrial power from National Institute of Technology (NIT), Calicut, India. He is currently as a lecturer of Electrical and Electronics Department at Vignan's Institute Of Information Technology, Visakapatnam Affiliated to JNT University , Kakinada, Andhra Pradesh , India.

P. C Chakravarthy was born in Andhra pradesh, India, Received the B.E Electrical and Electronics Engineering from Sir C R Reddy College of engineering, affiliated to Andhra University Visakhapatnam, India. He is currently as a PG Student of Electrical and Electronics Department at Vignan's Institute Of Information Technology, Visakapatnam Affiliated to JNT University , Kakinada, Andhra Pradesh , India.

.