ijiTECH International Journal of Innovative Technologies
WWW.IJITECH.ORG
ISSN 2321-8665
Vol.03,Issue.11,
December-2015,
Pages:2217-2222

Three Phase H6 Transformer less PVA Grid Connected Inverter

SHASHI KUMAR. K[1], S. RAJESH[2], N. NIREEKSHAN[3]
[1]PG Scholar, Dept of EEE(PE), Siddhartha Institute of Engineering and Technology, Hyderabad, TS, India,
E-mail: shashi.psr5@gmail.com.
[2]Associate Professor, Dept of EEE, Siddhartha Institute of Engineering and Technology, Hyderabad, TS, India,
E-mail: rajesh118@gmail.com.
[3]Assistant Professor, Dept of EEE, Siddhartha Institute of Engineering and Technology, Hyderabad, TS, India,
E-mail: nireekshan222@gmail.com.

Abstract: In this paper a new H6 topology is introduced with sinusoidal PWM (Pulse Width Modulation) technique taking a reference of three phase sin waves, each wave with a phase shift of 120 degrees. The input is considered to be PVA with low voltage magnitude, where the H6 converter converts the DC output voltage of the PVA to three phase AC output. During the conversion the output voltage is boosted with a certain gain value increasing the amplitude of the output AC waveform. The PWM output of the converter is fed to LC filter and converted to sinusoidal wave with reducing the THD (Total Harmonic Distortion). The complete analysis is carried out in MATLAB Simulink 2012a software with all graphical representations and reports.

Keywords: THD (Total Harmonic Distortion), PWM (Pulse Width Modulation), PVA.

I. INTRODUCTION

Nowadays, the invention and development of new energy sources are increasing due to the poisonous results caused by oil, gas and nuclear fuels. This has led the renewable energy sources especially the solar PV systems to the prime position in the generation of electricity [4]. Photovoltaic have applications ranging from small power supplies to power grids. Photovoltaic systems connected to the grid have several advantages such as simplicity in installation, high efficiency, reliability and flexibility [5]. With a reduction in system cost PV technology seems to be an efficient means of power generation. A solar grid connected power generating system usually consists of a solar panel in which the solar cells are arranged to track sunlight, an inverter to convert the DC to AC and the grid. This paper evaluates a single phase transformerless inverter topology called H6, which can minimize the dangerous leakage currents between the solar power generation system and the electrical grid. Transformers are employed in the grid tied systems to provide a galvanic isolation between the PV panel and the grid for safety considerations [2].Line frequency transformers were employed in most of the PV grid tied inverters. But in line frequency transformers due to their low frequency, the size, cost, weight etc. will be higher. The next option is the high frequency transformers. The usage of high frequency transformers increases the number of power stages which affects the efficiency in an adverse manner [1]. When these transformers are eliminated there will be a galvanic connection between the solar module and the grid which results in a potential fluctuation between the PV array and the ground.

The potential variation leads to the flow of common mode leakage currents that has to be eliminated which otherwise leads to electromagnetic distortions, interferences, harmonics and other power quality issues. The H6 transformerless inverter topology with unipolar sinusoidal PWM strategy seems to be a better solution to reduce these leakage currents by maintaining the common mode voltage constant. A simple boost converter is employed to boost the voltage available from the PV panel so as to connect to the grid. The block diagram for the system is shown in fig.1.

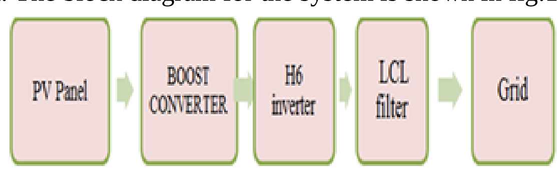

Fig. 1. Operational modules of the inverter.

From the aforementioned analysis, an extra switch S6 is introduced into the H5 inverter topology between the positive terminal of the PV array and the terminal (B) to form a new current path. As a result, a novel H6 transformerless full-bridge inverter topology is derived, as shown in Fig. 2. Similarly, the extra switch S6 can be introduced into the H5 inverter topology between the positive terminal of the PV array and the terminal (A) to form a new current path as well, as shown in Fig. 2. Therefore, a new circuit structure of novel H6 inverter is presented. As a result, the conduction loss of the proposed H6 topologies is higher than HERIC topology and less than H5 topology.

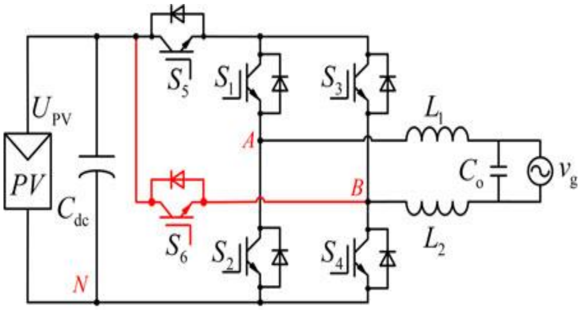

Fig. 2. Proposed H6 topology for one phase.

II. OPERATIONAL MODES

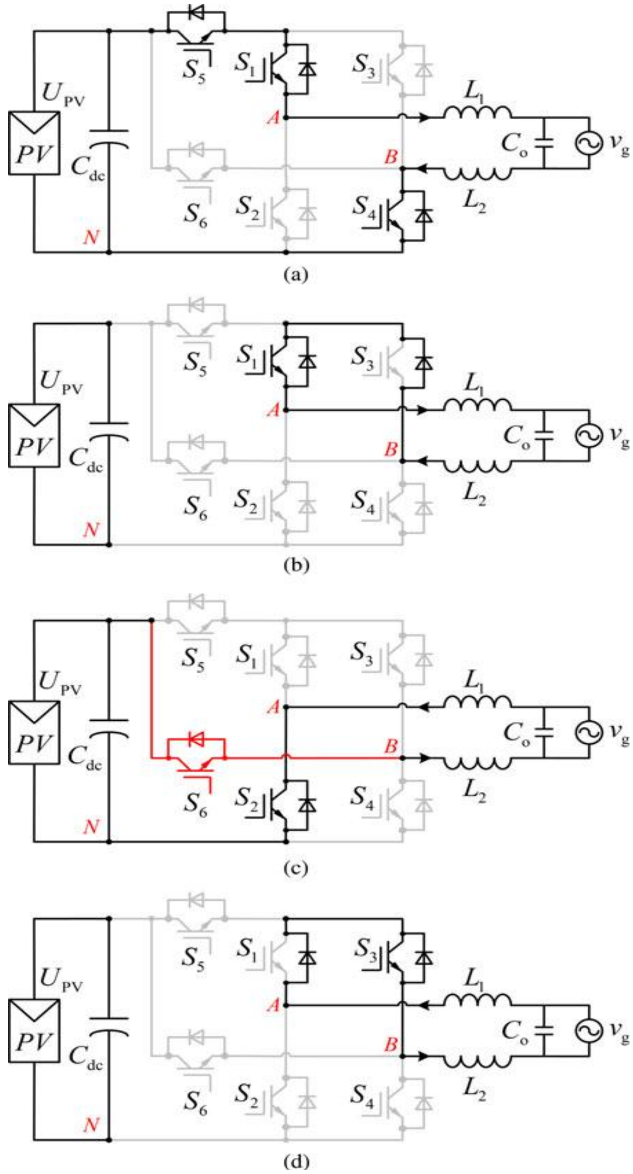

Fig. 3. Equivalent circuits of operation modes. (a) Active mode in the positive half period. (b) Freewheeling mode in the positive half period. (c) Active mode in the negative half period. (d) Freewheeling mode in the negative half period.

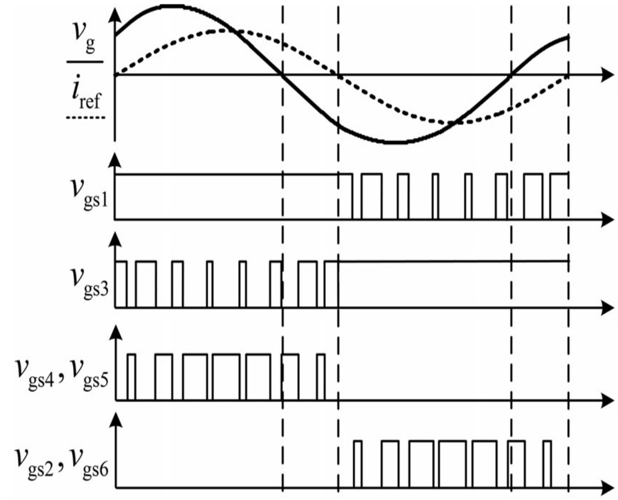

Fig. 4. Pulse generation for switches S1-S6.

The circuit structure of proposed novel H6 inverter topologies shown in Fig. 3(a) is taken as an example to analysis. PV grid-tied systems usually operate with unity power factor. The waveforms of the gate drive signals for the proposed novel H6 topology are shown in Fig. 3, where vg is the voltage of utility grid. iref is the inductor current reference. vgs1 to vgs6 represent the gate drive signals of switches S_1 to S_6, respectively.

- Mode I is the active mode in the positive half period of the utility grid voltage, as shown in Fig. 3(a). S1,S4, and S5 are turned ON, and the other switches are turnedOFF. The inductor current is flowing through S1,S4, and S5. vAN = UPV,vBN = 0; thus, vAB = UPV, and the CM voltage vCM =(vAN + vBN)/2 = 0.5UPV.
- Mode II is the freewheeling mode in the positive half period of the utility grid voltage, as shown in Fig. 3(b). S1 is turned ON; the other switches are turned OFF. The inductor current is flowing through S1 and the antiparalleled diode of S3. vAN = vBN ≈ 0.5UPV; thus, vAB = 0, and the CM voltage vCM =(vAN + vBN)/2 ≈ 0.5UPV.
- Mode III is the active mode in the negative half period of the utility grid voltage, as shown in Fig. 3(c). S2,S3, andS6 are turned ON; the other switches are turned OFF. The inductor current is flowing through S2 and S6. Although S3 is turned ON, there is no current flowing through it, and the switch S3 has no conduction loss in this mode. Nevertheless, in the H5 topology, the inductor current flows through S2,S3, and S5. Therefore, the conduction loss of proposed topology is less than that of H5 topology. In this mode, vAN = 0, vBN = UPV; thus, vAB = −UPV, and theCM voltage vCM=(vAN + vBN)/2 = 0.5UPV.
- Mode IV is the freewheeling mode in the negative half period of the utility grid voltage, as shown in Fig. 3(d). S3 is turned ON, and the other switches are turned OFF. The inductor current is flowing through S3 and the antiparalleled diode of S1. vAN = vBN ≈ 0.5UPV; thus,

vAB = 0, and the CM voltage vCM =(vAN + vBN)/2 ≈ 0.5UPV.Based on the aforementioned analysis, the PV array can be disconnected from the utility grid when the output voltage of the proposed H6 inverter is at zero voltage level and the leakage current path is cut off.

The CM voltage of the proposed topology in each operation mode is equals to 0.5UPV, and it results in low leakage current characteristic of the proposed H6 topologies. The proposed H6 topology with unipolar SPWM method not only can achieve unity power factor, but also has the ability to control the phase shifts between voltage and current waveforms. The modulation strategy is shown in Fig. 4. The drive signal is in phase with the grid-tied current. Therefore, it has the capability of injecting or absorbing reactive power, which meets the demand for VDE-4105 standard.

III. MODELING OF PVA

For efficient renewable power generation PVA is used to generate power from solar irradiation. As the load demand is increasing day by day the power generation also has to be increased, but due to the traditional way of power generation is causing global warming. Due to this the efficiency of the PVA has to be increased by adding silicon surface on the panel. And also employ MPPT techniques to track maximum power during any irradiation and atmospheric conditions. The design of PVA is done in MATLAB with Simulink block, with mathematical representation. Voltage of PVA completely depends on solar irradiation (Sx) and ambient temperature (Tx). PVA (Photo voltaic array) is a combination of series and parallel solar cells arranged in an array to generated the required voltage and current. Each series combination of cells can be considered as photo voltaic module. Increase in series cells increases the voltage and increase in parallel cells increases the current capacity. Formulation for voltage of each cell is given below

$$V_C = \frac{AkT_C}{e}\ln\left(\frac{I_{ph}+I_0-I_C}{I_0}\right)-R_S I_C \quad (1)$$

Where, k = Boltzmann constant (1.38 × 10-23 J/oK).
I_c = cell output current, Amp.
I_{ph} = photocurrent
I_0= reverse saturation current of diode
R_s= series resistance of cell
T_c= reference cell operating temperature
V_c= cell voltage, V.

The Boltzmann constant and the reference temperature have to be in same units ie., either ^{0}C or ^{0}K. The mathematical modeling of the above equation can be constructed using simulink blocks is as below Fig.5. The above design is for a single cell voltage, in order to increase the voltage of the PVA the cell voltage has to be multiplied to a desired values considering each cell voltage as 0.4V. So, the number of series connected cells (Ns) can be calculated as

$$N_s = V_o/0.4 \quad (2)$$

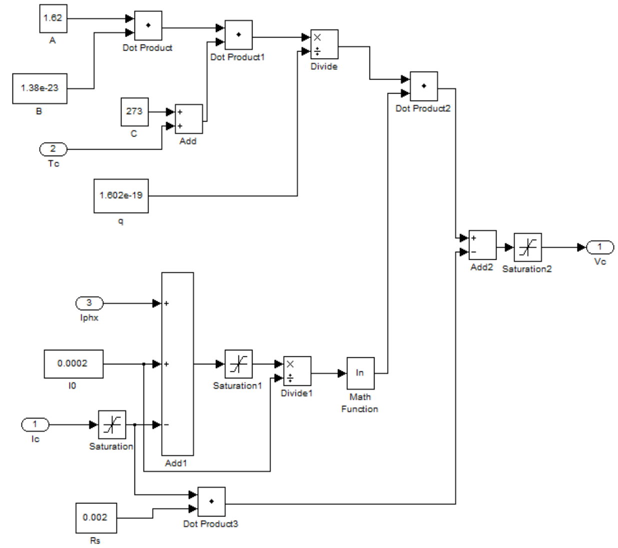

Fig. 5. Simulink model of Vc.

To get each cell current, the total current output from the dependable source has to be divided by number of parallel connected cells (N_p). Therefore, parallel connected cells are considered as

$$N_p = Io/I_{cell} \quad (3)$$

The representation in simulink is taken as shown in Fig.6.

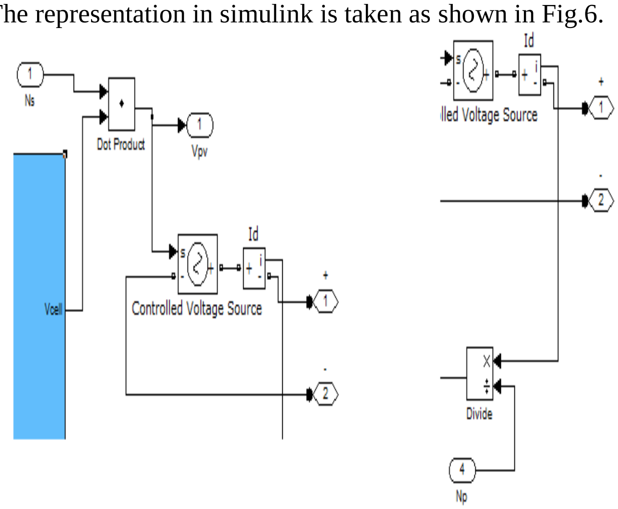

Fig. 6. Simulink modeling of Ns &Np.

For the calculation of Vcx (cell voltage) and I_{phx} (Photocurrent) we need correction factors C_{TV} C_{TI} C_{SV} C_{SI}. The formulation is given as

$$V_{CX} = C_{TV}C_{SV}V_C \quad (4)$$

$$I_{phx} = C_{TI}C_{SI}I_{ph} \quad (5)$$

The correction factors are given as

$$C_{TV} = 1+\beta_T(T_a - T_x) \quad (5)$$

$$C_{TI} = 1+\frac{\gamma_T}{S_C}(T_x - T_a) \quad (6)$$

$$C_{SV} = 1+\beta_T\alpha_S(S_x - S_C) \quad (7)$$

$$C_{SI} = 1 + \frac{1}{S_C}(S_x - S_C) \tag{8}$$

Where, $\beta_T = 0.004$ and $\gamma_T = 0.06$
T_a = reference temperature
T_x = ambient temperature
S_c = reference solar irradiation
S_x = ambient solar irradiation

The values of T_x and S_x changes depending upon the Sun rays which change continuously and unpredictably. The effect of change in solar irradiation varies the cell photocurrent and also the cell voltage (V_c). Let us consider the initial solar irradiation is I_{sx1}& the increase of the irradiation is I_{sx2} which in turn increases the temperature from T_{x1} to T_{x2}, photocurrent from I_{phx1} to I_{phx2}. The mathematical modeling of the correction factors in simulink is given below Fig.7.

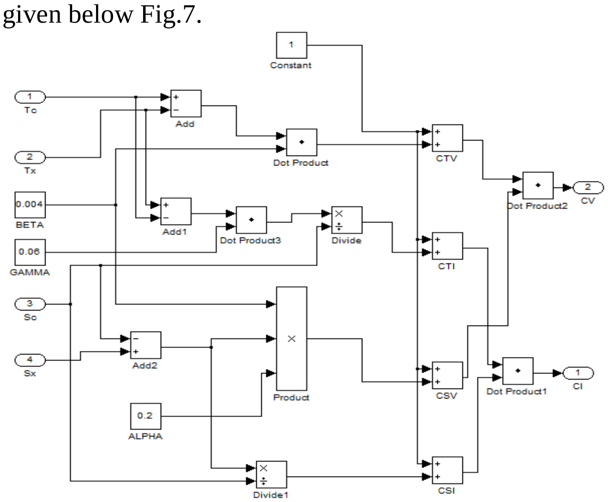

Fig. 7. CI & CV modeling.

Depending upon the solar irradiation and temperature the values of CV & CI are calculated which is fed to V_c block to get the cell voltage value as shown below Fig.8.

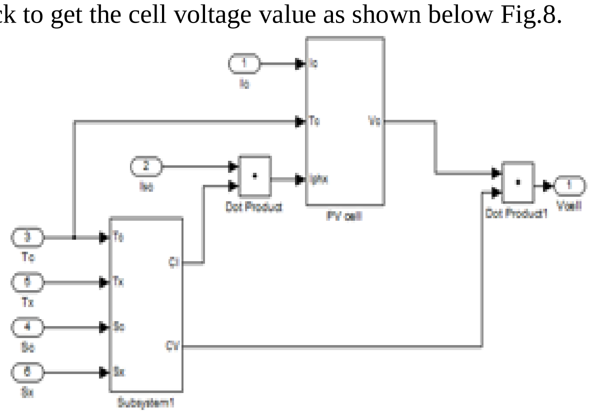

Fig. 8. Combined diagram of CV CI &Vc mathematical models.

The total system diagram of the PVA with all the mathematical formulation are put into a subsystem to make it clear and understandable. The output of the Vc multiplied with the Ns constant block defining the total voltage of the combined cells of the PVA is fed to the voltage controlled voltage source block so as to generate the required voltage. A diode is connected in series at the positive terminal of the PVA to avoid reverse currents passing into the PVA. To reduce the ripples a capacitor can be added later after the diode in parallel as the capacitor doesn't allow sudden change of voltages dV/dt. The complete PVA module with internal block construction is shown in the fig.9 below.

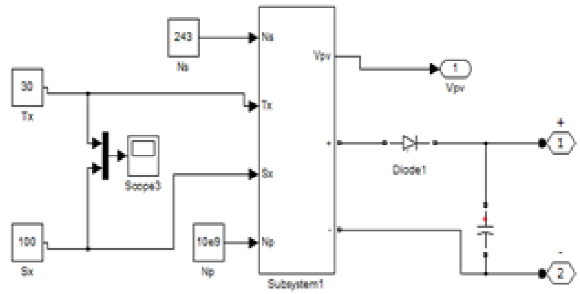

Fig. 9. Complete diagram of PVA.

IV. SIMULINK MODEL AND RESULTS

Simulation results of this paper is as shown in bellow Figs.10 to 13.

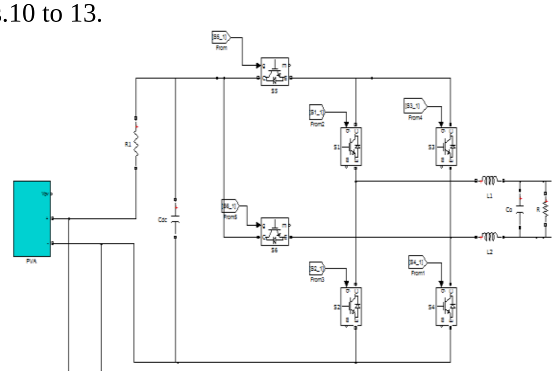

Fig. 10. H6 Simulink model.

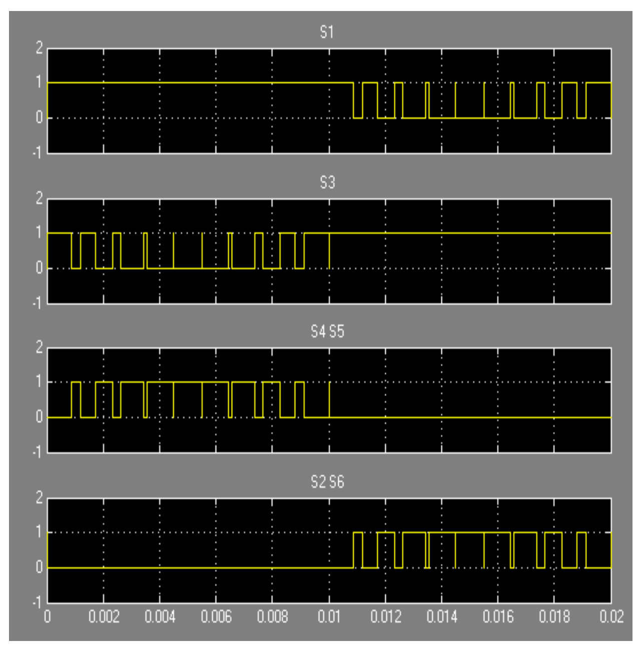

Fig. 11. Pulse waveforms of S1-S6 switches.

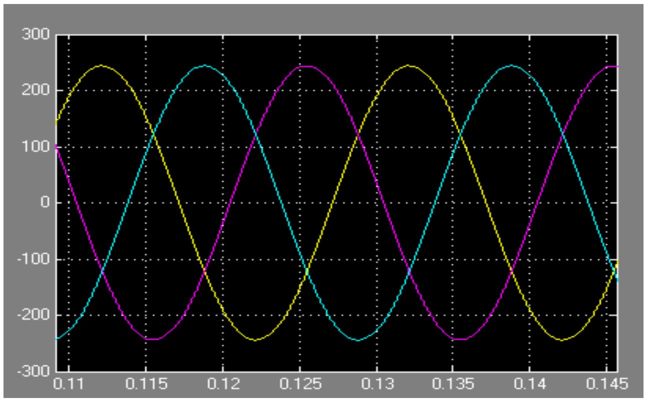

Fig. 12. Three phase output voltages of the three H6 topologies.

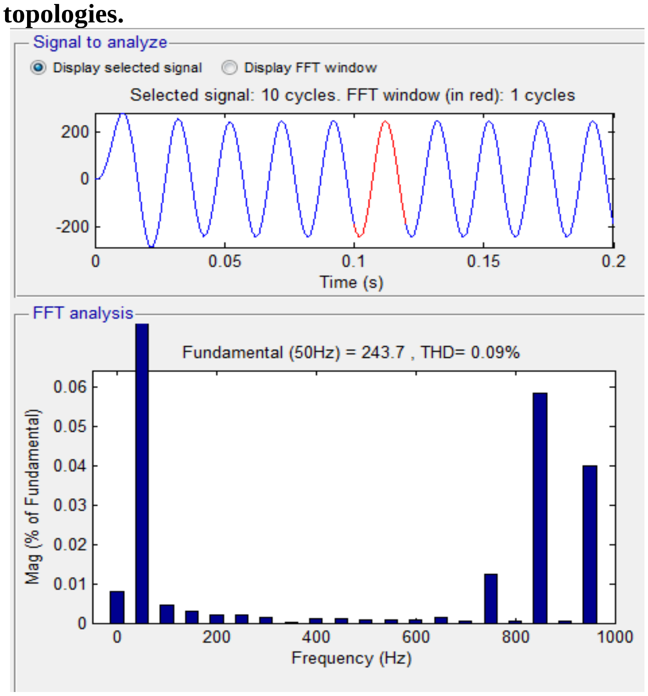

Fig. 13. FFT analysis of phase A voltage (Va).

V. CONCLUSION

With the above results and discussion it can be observed that the output voltages of the three H6 topologies are sinusoidal waveforms with 120 degrees phase shift with a low THD of 0.09%. The LC filter at the output side of the converter minimizes the THD of the H6 topology. As a result the output voltage is boosted to amplitude of 243V from a low voltage of 100V.

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Author's Profile:

K. Shashi Kumar, B.Tech in Electrical and Electronics Engineering in CVR College of Engineering, Hyderabad from JNTUH. Now pursuing M.Tech specialization in power electronics in Siddhartha institute of engineering and Technology. His area of interest is Power electronic and drives systems.

N. Nireekshandone the btech in electrical and electronics in Arjun College of Technology and Science from JNTUH in 2006 and M.Tech specialization in power electronics in lords institute of engineering and technology from JNTUH in 2013 respectively. He done the M.Tech project

unidirectional torque production by using seven level multi level inverter in RV TOPOLOGY technique. He currently serving as Assistant Professor in siddhartha institute of engineering and Technoloy Hyderabad, Telangana, India.He has 3 years teaching experience .

S.Rajesh received the B.Tech degree in Electrical & Electronics Engineering from Jawaharlal Nehru Technological University Hyderabad ,Telangana ,India in 2006 and M.Tech degree in Power Electronics from Jawaharlal Nehru Technological University Hyderabad ,Telangana ,India in 2010 respectively. He has presented nearly 5 papers in National level conferences. His research interests are power electronics applications in distributed power generation and analysis of power converters, control and estimation in induction motor drive and wind turbine driven induction generator. Currently he working on stability studies of Double Fed Induction Generator in Wind power Generation. He is a Student member of IEEE and life Member of ISTE (India). He currently serving as Associate Professor & Head of the Department of Electrical and Electronics engineering in siddhartha institute of engineering and Technology Hyderabad, Telangana, India. He has 8 years experience in teaching.