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Application of PVA in H6 Transformer-less Inverter Topology with less THD

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Abstract —Increase in load demand requirement has to be supplied with various sources integrated to the grid system. All conventional sources produce hazardous gases creating global warming. The replacement to these conventional sources is through renewable sources, which can be solar energy, wind energy or bio chemical sources of generation system. In this paper introduce a new H6 inverter topology converting DC output of the PVA (Photo Voltaic Array) to PWM AC output and reduce the THD of the PWM AC voltage with the help of LCL filter. The complete analysis and outputs are explained with all graphical representations in MATLAB Simulink software.

Keywords- Grid-tied inverter, photovoltaic (PV) generation system, transformer less inverter

I. INTRODUCTION

Utilization of PVA in commercial and domestic applications has been rapidly increased from past few years. The investments on integration of renewable sources into grid have also been taken seriously even though the installation cost is high. Because of these high initial investments, the inverters designs have to be done very carefully with high efficiency outputs utilizing maximum power outputs of the renewable sources. The inverters designed must also produce lesser harmonics when connected to grid, as it may affect the loads connected to the point of common coupling (PCC). Many filters are designed to reduce the harmonics produced by the PWM inverters in which the LCL filter is highly efficient reducing the Thermal Harmonic Distortion output of the inverter. [1-3]

Conventional 1-phase inverters have 4 power electronic switches controlled by SPWM (Sinusoidal Pulse width modulation) with sin wave as reference waveform and triangular waveform as carrier signals. Figure 1 is a simple inverter with four power electronic switches traditionally used in many inverter operations interconnected to grid. [4]

The PWM technique used to generate four pulses to the inverter can be shown in Figure 2. With further modifications the conventional inverter with four switches is developed to H5 (Hybrid five switch) inverter with an extra power electronic switch added at the source side. It employs an extra switch on the dc side of inverter.

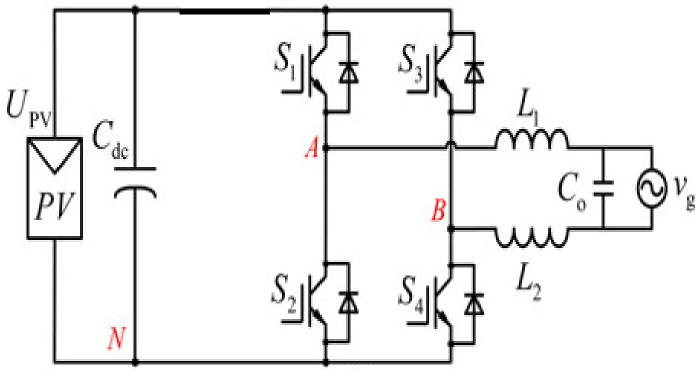

Figure 1. Conventional Four Switch Inverter

The modified H5 topology from conventional four switch topology can be seen in Figure 3 with similar source and IGBT switches connected anti parallel to diodes to avoid circulating currents in the circuit. [5]

The extra switch in H5 topology acts as an isolator which disconnects the PVA from the grid during zero voltage level of the inverter output voltage to avoid leakage currents. The reduction of leakage currents in the circuit reduces the emphasis on the power electronic switches also reduction of voltage stress in the switches.

The H5 topology is further modified to achieve the **H**ighly **E**fficient and **R**eliable **I**nverter **C**oncept (HERIC) topology with removal of the fifth switch and addition of a bidirectional switch at the inverter side before the LCL filter.

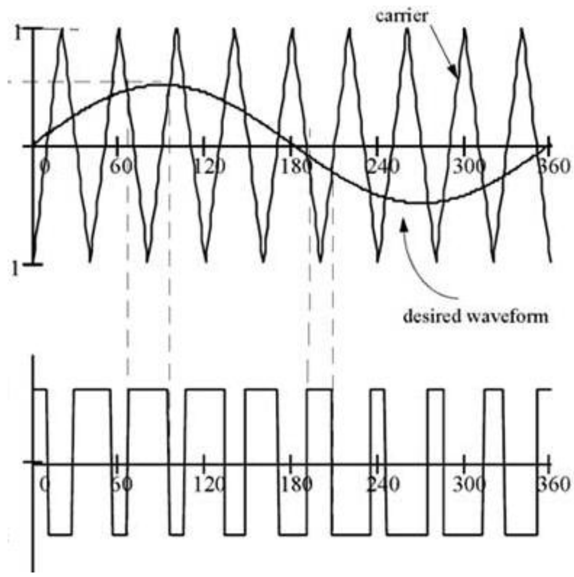

Figure 1. PWM Scheme for Conventional Inverter

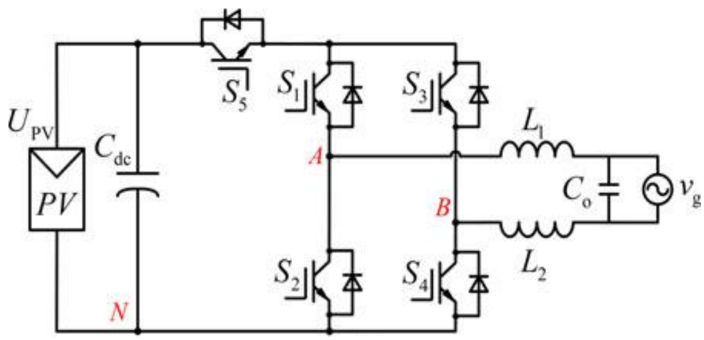

Figure 2. H5 Topology

The HERIC topology shown in Fig. 4 employs 2 extra switches on the AC side of inverter. However, its power device cost is higher than that of the H5 topology. The circuit design can be seen in Figure 4 below. [6]

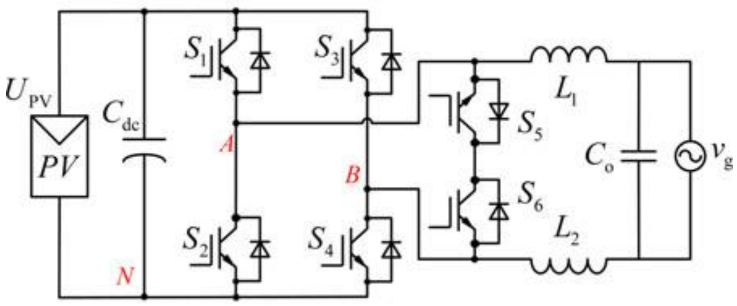

Figure 3. HERIC Topology

The bidirectional switch is a combination of two S5 & S6 IGBTs connected back to back with freewheeling diodes which are also back to back connected to ensure bidirectional operation. Even in HERIC topology the leakage currents are cut off and increase the efficiency of the circuit. [7]

With further modifications six switches are connected in two legs creating a conventional H6 topology [8], which can be seen in Figure. 5 below.

The H6 topology has three switches in each leg controlling the output voltage with PWM technique also reducing the leakage currents further with attachment of two diodes reducing the effect circulating currents in the circuit topology. H6 topology has achieved the minimum conduction loss with low leakage currents.

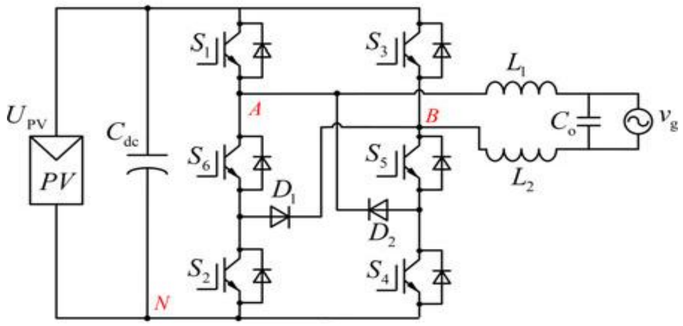

Figure 4. Conventional H6 Topology

II. PWM TECHNIQUE

The PWM technique is generally used for the conversion of DC to AC waveforms. In this paper we discussed a full-bridge inverter with 6- IGBTs can be used to convert DC to 3-phase AC. Each phase angle has to shifted each other by 120^0 and has to be phase shifted in synchronize with the PV grid to which it is being connected. The pulses are to be given to the IGBTs are generated with a fundamental waveform which will compared with a triangular waveform. The fundamental waveform has the frequency of the PV grid and the carrier (triangular) waveform has higher frequency to create a modulation signal. The fundamental and the carrier waveform diagrams are shown below in Fig. 6. 6- pulses are formed by applying NOT gates to the 3 pulses produced by the comparison of the fundamental and carrier waveforms. The generated pulses are fed to the Voltage source Inverter (VSI) with G1,G2,G3,G4,G5 and G6 switches. A simple PWM construction scheme for conventional inverter is shown in Figure 2.

The rating of IGBT is taken as,

Internal resistance R_{ON} = 0.001 Ω, Snubber resistance R_S = 100 kΩ, Snubber capacitance C_S = 1F

Due to the impedance load the load current gets ceased during sudden switch OFF of the IGBT switch and generate high voltage peaks in the output voltage. To avoid this an anti- parallel diode is attached to the switch (IGBT) so that the inductor current from the impedance load can pass through the diode.

To eliminate the minimum harmonics, we have to use LC filter to filtering the higher order harmonics from the 3-phase AC voltage waveforms. The three sinusoidal fundamental waveforms are generated as,
$V_a = V_m \text{Sin}(wt)$, $V_b = V_m \text{Sin}(wt+2\pi/3)$, $V_c = V_m \text{Sin}(wt-2\pi/3)$
Where, V_m = maximum voltage i.e., amplitude of sinusoidal waveform which is '1'.

The modulation index in PWM waveform is controlled by controlling the amplitude of the fundamental waveform. By reducing amplitude of the sinusoidal wave, the space between the pulse is increased & reducing the amplitude of the PWM waveform. The phase of the reference wave considered decides the phase of the PWM waveform.

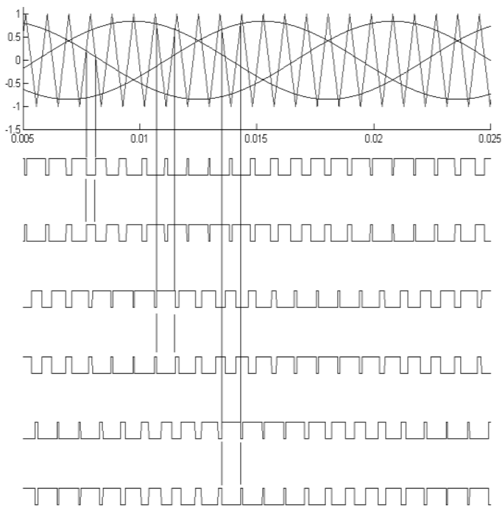

Figure 5. Generation of Pulses with respect to Reference Fundamental Waveforms

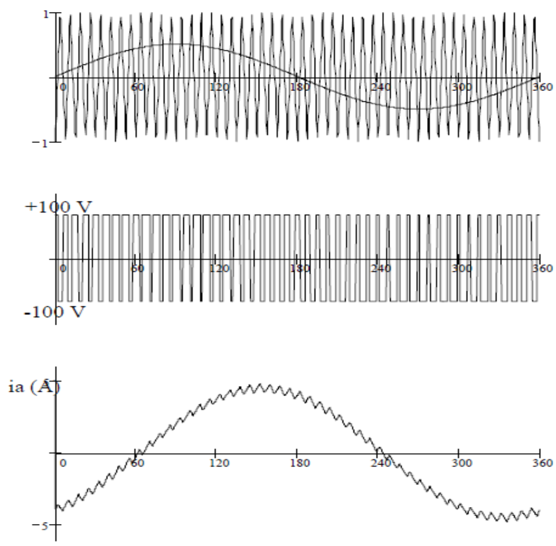

Figure 6. Effect of Change in Amplitude of Sinusoidal Waveform

III. MODELING OF PHOTO VOLTAIC ARRAY (PVA)

For getting efficient renewable power generation, it is used to generate power from solar irradiation. As day by day the load demand is increasing the power generation also has to be increased. Because of this the efficiency of the PVA has to be increased by adding some silicon surface on the PV panel. And also employ Maximum Power Point Tracking (MPPT) techniques to tracking out maximum power at during any irradiation and atmospheric conditions. The design of PV Array is done in MATLAB Simulation with Simulink block with the help of mathematical representation.

Voltage of PV array completely depends on solar irradiation (S_x) and ambient temperature (T_x). PVA is a combination of parallel and series solar cells arranged in an array to generated the required voltage and current. Every series combination of cells can be considered as photo voltaic module. Increase parallel cells will be increases the current capacity and increase series cells will be increases the voltage and increase. Formulation for voltage of each cell is given below [15],

$$Vc = \frac{AkTc}{e}\ln\left(\frac{Iph + I0 - Ic}{I0}\right) - RsIc \qquad \text{--- (1)}$$

Where, e = Electron Charge (1.6 × 10ˉ19 C)
Vc = Cell voltage, V
k = Boltzmann constant (1.38×10^{-23} J/°K).
T_c = Reference cell operating temperature (20°C)
I_{ph} = Photocurrent (5A)
I_0 = Reverse saturation current of diode (0.0002A)
I_c = Cell output current, A
R_s = Series resistance of cell

The Boltzmann constant and the ref. temperature have to be in same units i.e., either ^{0}C or ^{0}K. The mathematical modeling of the equation we discussed above can be constructed using Simulink blocks is as below.

The design is for a single cell voltage, in order to increase the voltage of the PV Array the cell voltage has to be multiplied to a desired values considering each cell voltage. So, the number of series connected cells can be calculated as, $N_s = V_o/0.4$

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

$N_p = I_o/I_{cell}$

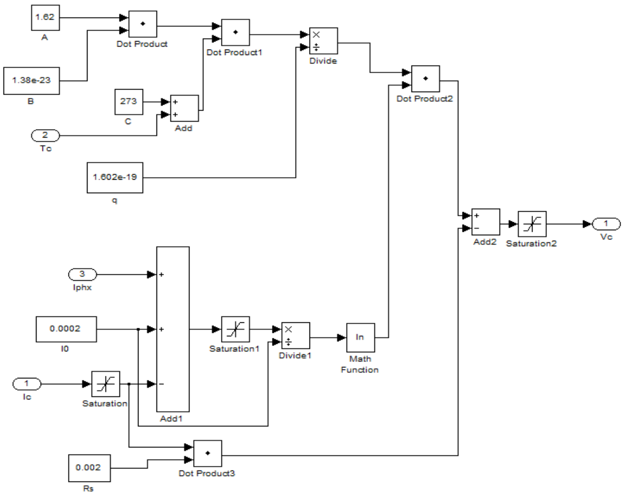

Figure 7. Simulink model of V_c

The Simulink is taken as,

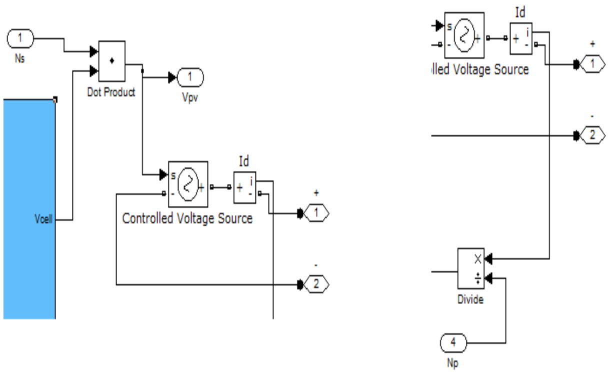

Figure 8. Simulink Modeling of N_S & N_p

For the calculation of cell voltage (V_{CX}) and I_{phx} (Photocurrent), temperature coefficient for cell output voltage (C_{TV} C_{TI}), correction factor for change in cell output voltage (C_{SV} C_{SI}). The formulation is given as [9],
$V_{CX} = C_{TV}\, C_{SV}\, V_C$, $I_{phx} = C_{TI}\, C_{SI}\, I_{ph}$

The correction factors are given as, β
$C_{TV} = 1+\beta_T (T_a - T_x)$, $C_{TI} = 1+\gamma_T/S_c (T_x - T_a)$
$C_{SV} = 1+\beta_T\, \alpha_s (S_x - S_c)$, $C_{SI} = 1+1/S_c (S_x - S_c)$
Where, $\beta_T = 0.004$ and $\gamma_T = 0.06$ for the cell used
T_a = ambient temperature 20°C during cell testing
S_c = reference solar irradiation
S_x = ambient solar irradiation

The values of T_x and S_x changes depending on the Sun rays which change continuously. The effect of change in solar irradiation varies the cell photo-current and also the cell voltage. Now, 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 calculation of the correction factors in Mat-lab Simulink is given below,

Depending on the solar irradiation and temperature the values are calculated which is fed to V_c block to get the cell voltage value as shown below,

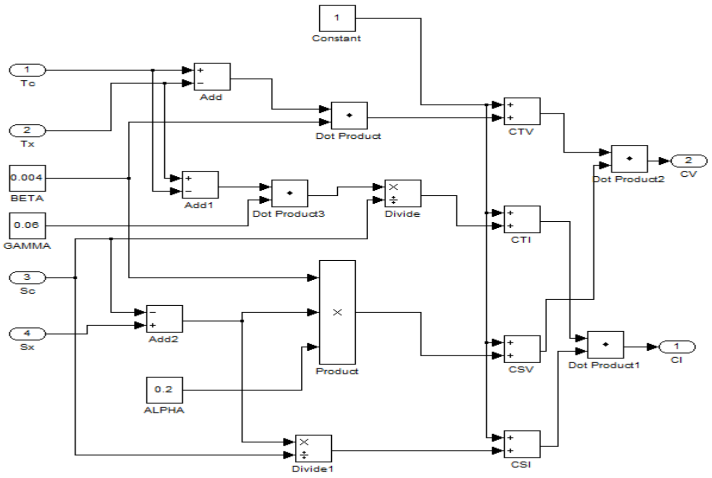

Figure 9. C_I & C_V Modelling

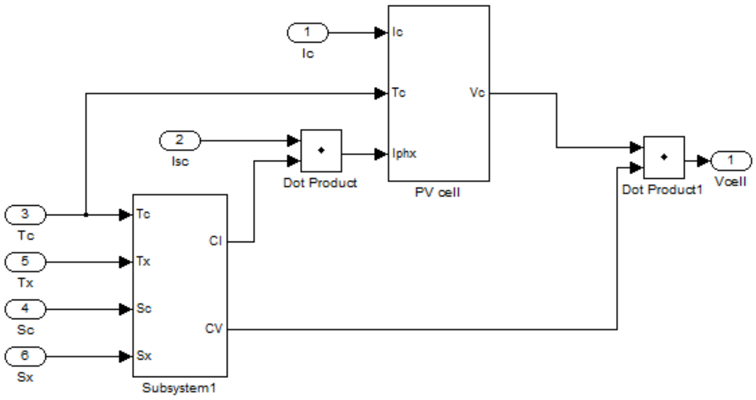

Figure 10. Combined Diagram of C_V, C_I &V_c mathematical models

The total system diagram of the PVA with all the formulation are put into a sub-system to make it clear and understandable. The output of V_c block multiplied to the N_s constant block defining the total voltage value of the combined cells of the PVA is fed to the voltage controlled voltage source block. A diode is connected in series at the positive terminal of the Photovoltaic panel to avoid reverse currents passing into it.

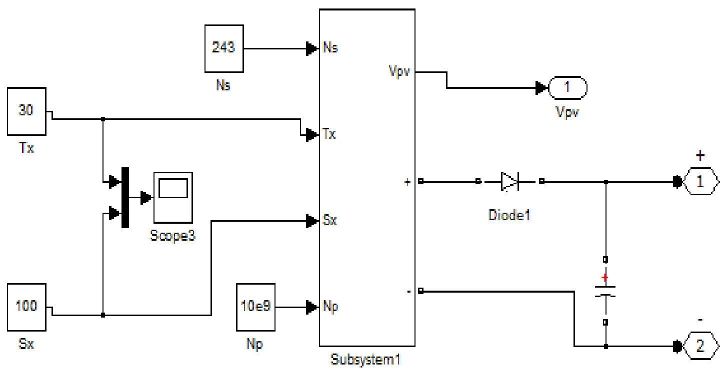

Figure 12. Complete Diagram of PVA

IV. PROPOSED H6 TOPOLOGY

To reduce the harmonic distortion created by the PWM technique in the conventional inverter as mentioned in section I, a novel H6 topology is addressed to reduce these effects of leakage currents and circulating currents. The below Figure 13 is the circuit topology of the proposed H6 inverter with six switch operation [10].

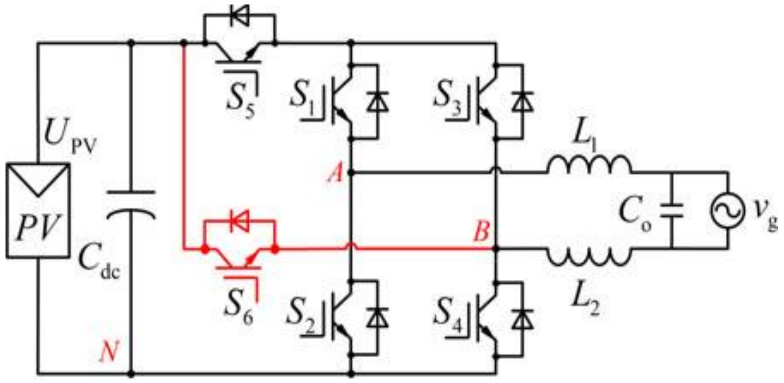

Figure 13. Proposed H6 Topology

A controllable switch, capacitor divider is added to form a bidirectional clamping branch which guarantees that the freewheeling diode path is clamped to half input voltage period and the output current flows through only 3 switches in the power process period, so that the conduction losses can be decreased.

The blocking voltage of added switches is only half of the input voltage, which is beneficial to further improve the efficiency. This topology is suitable for high-power transformer-less grid-connected inverters, particularly in thin-film solar cell applications [11-13].

The proposed H6 topology can be operated in two modes, a) Unity power factor mode b) Other than unity power factor mode. The gate signals for the power electronic switches are generated with sin PWM technique comparing the fundamental sine waveform with high frequency triangular waveform. The theoretical gate signal waveforms can be seen below in Fig. 14.

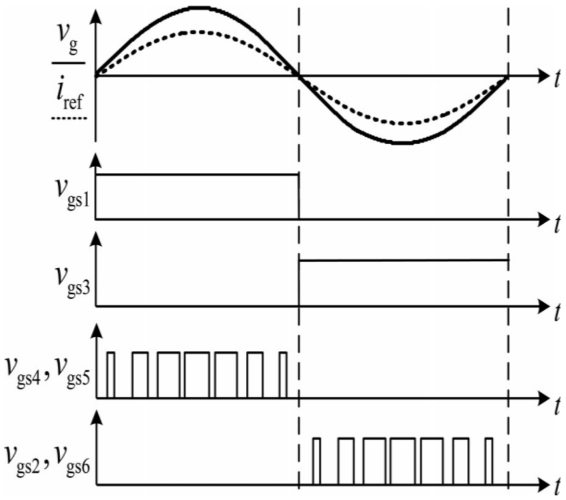

Figure 14. PWM Gate Signals for Switches S1-S6 of Proposed H6 Topology

V. SIMULINK MODELS AND RESULTS

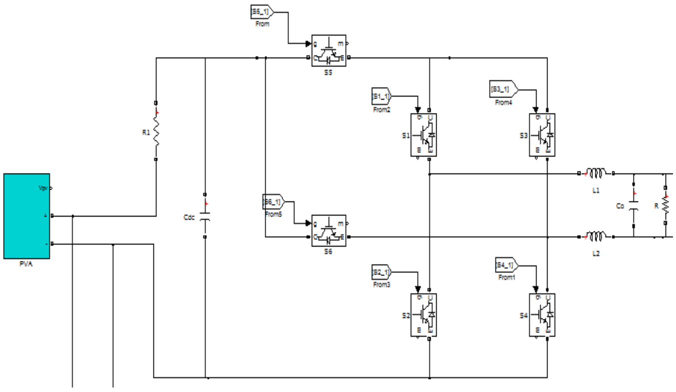

Figure 15. Proposed H6 Simulink Model with attached PVA

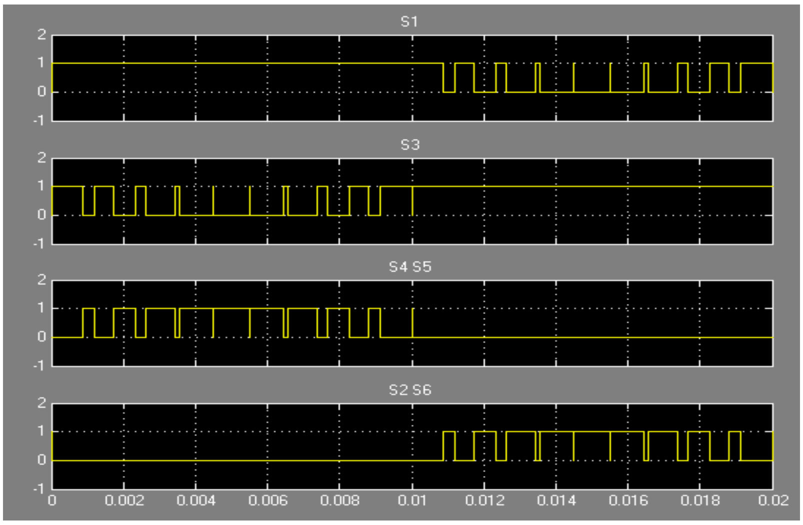

Figure 16. Pulse Waveforms of S1-S6 Switches for H6 Topology Simulink

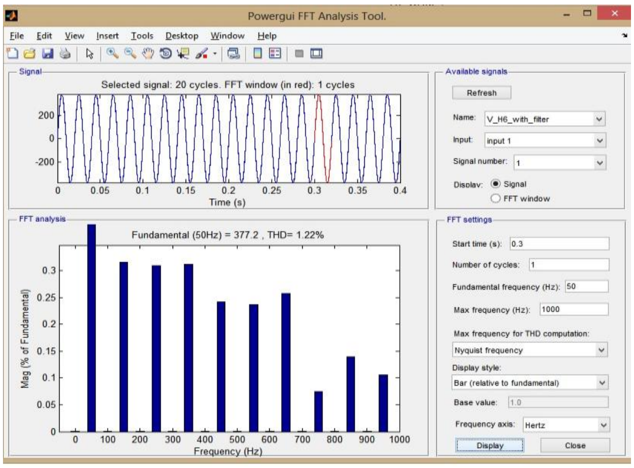

Figure 16. FFT Analysis of Phase-A Voltage (V_A)

VI. CONCLUSION

We observed in Simulink results of the proposed H6 topology, graphical representations of the output voltage waveform can be seen with LCL filter attached. The output of the inverter is a sinusoidal waveform with a THD of 1.22%

during fully loaded condition, and is in limit of IEEE standard. The proposed H6 topology can be connected to the grid with reduced THD and increased efficiency of the converter.

REFERENCES

[1] S. B. Kjaer, J. K. Pedersen, F. Blaabjerg, "A review of single-phase grid-connected inverters for photovoltaic modules," IEEE Trans. Industry Applications., vol. 41, no. 5, pp. 1292 – 1306, Sep/Oct. 2005.

[2] M. Calais, J. Myrzik, T. Spooner, V. G. Agelidis, "Inverters for singlephase grid connected photovoltaic systems - an overview," in Proc. IEEE PESC'02, vol. 4, 2002, pp. 1995 – 2000.

[3] E. Gubía, P. Sanchis, A. Ursúa, et al; "Ground currents in Single-phase Transformer less Photovoltaic Systems"; Progress in Photovoltaics: Research and Applications; 2007, pp: 629-650

[4] Li Zhang, Kai Sun, Yan Xing, and Mu Xing, "H6 Transformerless Full-Bridge PV Grid-Tied Inverters" IEEE Trans On Power Electronics, Vol. 29, No. 3, March 2014.

[5] M.Victor, F.Greizer, S.Bremicker and U.Hubler,"Method of converting a direct current voltage from a source of direct current voltage, more specifically from a photovoltaic source of direct current voltage, into a alternating current voltage," U.S.Patent7411802, Aug.12,2008.

[6] S. Heribert, S. Christoph, and K. Jurgen, "Inverter for transforming a DC voltage into an AC current or an AC voltage," Europe Patent 1 369 985 (A2), May 13, 2003.

[7] O. Lopez, F.D. Freijedo, A.G.Yepes, P.Fernandez- Comesana, J.Malvar, R.Teodorescu and J.Doval Gandoy, "Eliminating ground current in a transformer-less photovoltaic application," IEEE Trans. Energy Converse., Vol.25, no.1, pp.140-147, March-2010.

[8] W. Yu, J. Lai, H. Qian, and C. Hutchens, "High-efficiency MOSFET inverter with H6-type configuration for photovoltaic non isolated ac-module applications," *IEEE Trans. Power Electron.*, vol. 26, no. 4, pp. 1253–1260, Apr. 2011.

[9] Dr. Abu Tariq, Mohammed Asim and Mohd.Tariq, "Simulink Based Modeling simulation and Performance Evaluation of an MPPT for maximum power generation on resistive load", 2011 IPCBEE vol.6 (2011) IACSIT Press, Singapore

[10] Huafeng Xiao, Shaojun Xie, Yang Chen, and Ruhai Huang, "An Optimized Transformerless Photovoltaic Grid-Connected Inverter", IEEE TRANS. On Industrial Electronics, Vol. 58, No. 5, May 2011.

[11] L. Marroyo, "Transformerless single-phase multi level-based photovoltaic inverter" IEEE Trans. Ind.Electron., vol.55, no.7, pp.2694–2702, Jul.2008.

[12] H.Xiao and S.Xie, "Transformerless split-inductor neutral point clamped three-level PV grid-connected inverter" IEEE Trans. Power Electron., vol.27, no.4, pp.1799–1808, Apr.2012.

[13] L.Zhang, K.Sun, L.Feng, H.Wu and Y.Xing, "A family of neutral point clamped full-bridge topologies for transformer-less photovoltaic grid-tied inverters" IEEE Trans. PowerElectron., vol.28, no.2, pp.730–739, Feb. 2012.