Solar PV Based Grid-Tied Multilevel Inverter Topology

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Abstract- The shape of the line current of the conventional converters/ inverters having line commutation is square-shaped in nature which posses harmonics of higher magnitude. Core of the distribution or power transformers became heated due to the presence of harmonics and it also creates Electro Magnetic Interference (EMI). Pulse Width Modulated converters/inverters having MOSFET/IGBT as switching devices contains greater switching losses, low power handling capacity and reliability if it compared to thyristors/ SCR. A thyristor converter/inverters with forced commutated circuit is costly as well as having problems of commutation, is not fit for PWM applications. Converters/inverters having pure sinusoidal output with low harmonics is required for dc-to-ac conversion. A multilevel inverter topology is proposed in this paper, in which 3-phase fully controlled converter is used in inversion mode by controlling the firing angle. This topology has an advantage of having no separate circuit for synchronization due to natural commutation. The proposed model is simulated analyzed initially by connecting an RLE load and later on solar PV array has been used in place of battery. The proposed model is analyzed for different firing angle to reduce the total harmonic distortion (THD).

***Index Terms*—Multilevel Inverter, AC-DC Converters, Total Harmonic Distortion.**

I. INTRODUCTION

Normally, a three phase system is employed for higher power levels which are above one kilowatt in rating. In comparison of single phase converter, the three phase converters provide higher output voltage due to which the ripples in frequency on the output voltage is higher. So there is a need of the filtering circuit for smoothing the load voltage and load current. Three phase converters are significantly used in high power variable speed drives [1].By reducing the harmonics content better output quality is generated by multilevel inveter topologies[2]. In high power application such as in AC transmission line system multilevel inverters are used[3]. Increasing in voltage level results in reducing the need of filters, on the other hand reduction in harmonics results in higher efficiency[4]. Earlier, single phase ac to dc converter are used as grid-tie inverters for harnessing solar energy and feeding it to grid[5][6]. However, these cases results in extensively high THD[7]. In this paper, 3-phase 6-pulse converter is used which work as an inverter by controlling the firing angle α. The proposed model is simulated in MATLAB/SIMULINK. THD and power transferred to grid at different condition is found for it.Figure1 shows a circuit diagram of the proposed model in which each phase conducts for line current for 120°. Converter work as an inverter when switching angle becomes higher than 90°. Later on battery is replaced by solar array in the proposed model which is

shown in figure 2and the results are compared for both the circuits.

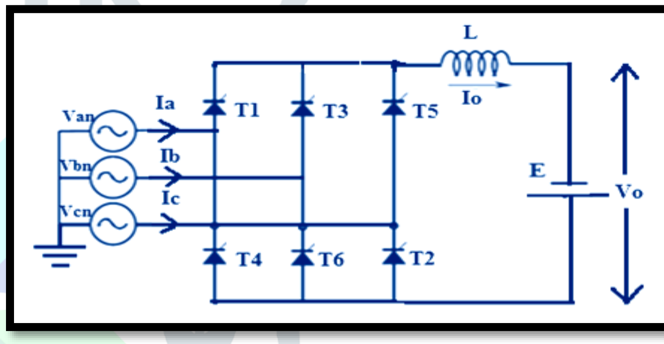


Figure1: Circuit diagram of proposed model with battery

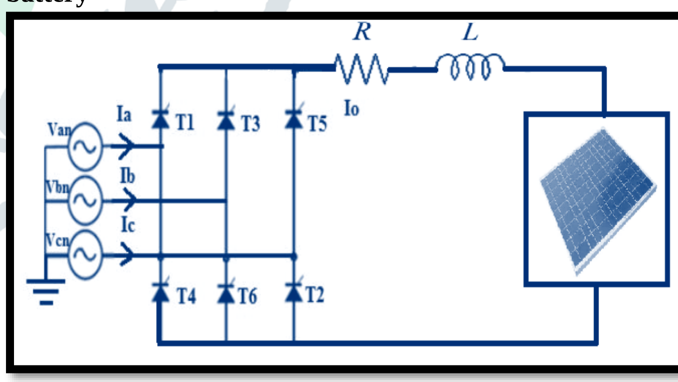


Figure2: Circuit diagram of proposed model with solar array

Solar PV cell

Practically, in the PV cell there is series of resistance in the current path through the metal grid, contacts etc, and these resistive losses are gathered together as series resistor. In PV module the effect become very specific which consist of several chain connected cell and the value of resistance is multiplied by the number of cell. In a parallel resistance the shunt resistance losses associated with the small leakage of current through the resistive path in parallel with the intrinsic device. Parallel resister is represented by (R_P). As compared to series resistance the effect is much less specific in PV module. It will only be noticeable for a larger system when numbers of PV module are connected in parallel.

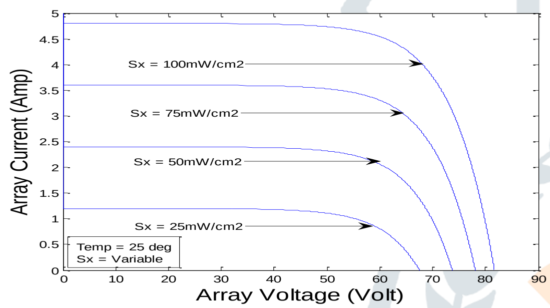
A current-voltage relationship of PV cell is given as:

$$I_C = I_{Ph} - I_0\left[e^{q\left(\frac{V_C + I_C R_S}{AkT_c}\right)} - 1\right] - \left(\frac{V_C + I_C R_S}{R_P}\right)$$

Where 'A' is known as the ideality factor of the junction

After rearranging the above equation the voltage-current equation is written as:

$$V_C = \frac{AkT_C}{q}\ln\left(\frac{I_{Ph} + I_O - I_C}{I_O}\right) - \left(\frac{V_C + I_C R_S}{I_O R_P}\right) - I_C R_S$$



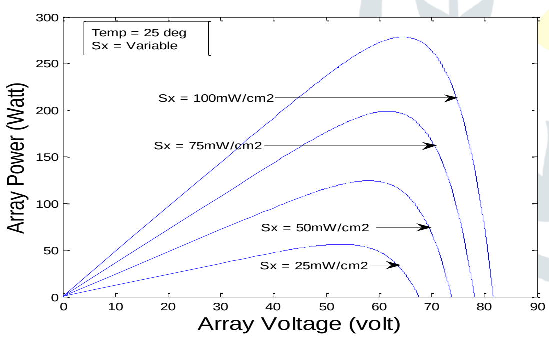
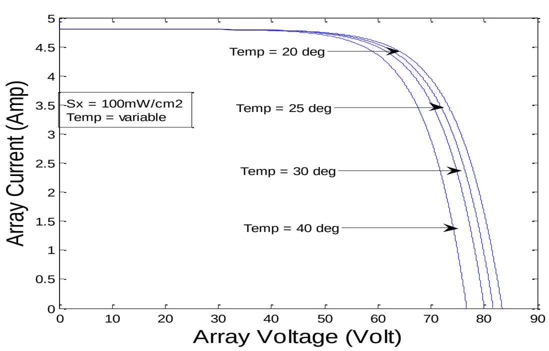


Figure (a) *i-v* Characteristics (b) *p-v* Characteristics of PV array with variable insolation at Tx = 25 ºC.



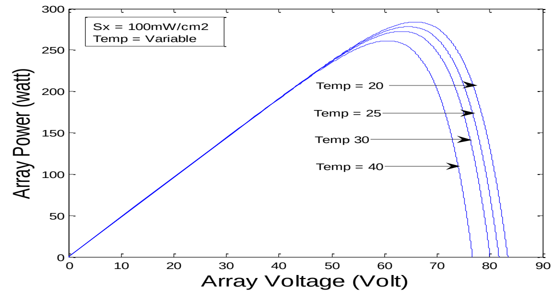


Figure (a) *i-v* Characteristics (b) *p-v* Characteristics of PV array with variable temperature at Sx = 100mW\cm^2.

II. PROPOSED SCHEME

Rectification and inversion are the two modes of operation of a fully controlled converter with RLE load. When firing angle of the converter exceeds 90º, converter circuit works as an inverter and below 90º it works as a rectifier [8]. By connecting dc source with RL load, converter operates in inversion mode by controlling the firing angle. A multilevel circuit topology is proposed in which3-phase 6-pulse converter circuits are used as multi-level inverter by controlling the firing angle. Later on battery is replaced by solar PV array in the proposed model. The proposed model is three level multilevel inverter which is analyzed form 3-level of line current, which can further extended to higher levels for better performance[9]. However, as the level increases cost of the multilevel inverter increases due to increase in the cost of additional hardware. Hence, a suitable adjustment is to be made between THD of line current and levels of multilevel inverter.

III. CONTROL STRATEGY

The output current of phase controlled converter can either be continuous or discontinuous. The current of conducting thyristor for continuous current mode does not come to zero level. The conduction depends upon DC source voltage, load angle and the firing angle. For 3-level line current, 3-phase 6-pulse converter is used for the proposed topology [11].In order to flow a current in a circuit at least one thyristor from the upper group and one from the lower group must conduct. Each one of the thyristor conducts for 120° in one cycle. Firing of thyristors has been done in a sequence with a firing sequence delay of 60°. Hence, thyristors of the same phase leg are fired at 180° interval but they cannot be conducted simultaneously. In continuous conduction mode there are six possible modes of operation (S1S2, S2S3, S3S4, S4S5, S5S6, and S6S1). Duration between each conduction mode is 60°.S1 is fired when conduction of S5S6 is closed. The voltage across S1 is V_{ac} in this period.S1 is fired at an angle'α' after the positive going zero crossing of 'V_{ac}'. Similar observations can also be made for other thyristors. Table 3.1 shows the switching sequence of different thyristors of the proposed model.

Table 3.1: Switching sequence of Thyristors

S.No	Switching Device	Switching Angle
1	T1	90 + α
2	T2	90 + 60 + α
3	T3	90 + 120 + α
4	T4	90 + 180 + α
5	T5	90 + 240 + α
6	T6	90 + 300 + α

IV. SIMULATION OF PROPOSED TOPOLOGY

The simulink model of the proposed topology has been shown in figure 3. It consists of three AC voltage source one for each phase, six thyristors (S1 to S6) which are triggered at an angle of 60°. The pulses are obtained for triggering from pulse generator using simulink library for each thyristors. The DC source voltage of 24 V is taken with negative polarity for inversion mode of operation. The R-L load is given as R=5Ω and L=0.1H respectively. Initially a proposed model is simulated by simulating the circuit by connecting RLE load. Later on solar PV array has been used in place of batteries. The commutation of SCR is promoted by varying the firing angle up to 165° for inversion operation.[11]. The output of the solar PV array which is about 24 Vis connected at the load end of the converter. Switching of S1 is done at an angle of 95° and the rest switches are triggered with phase delay of 60°. For different combinations of switching angles, total harmonic distortion (THD) and power transfer analysis has been done.

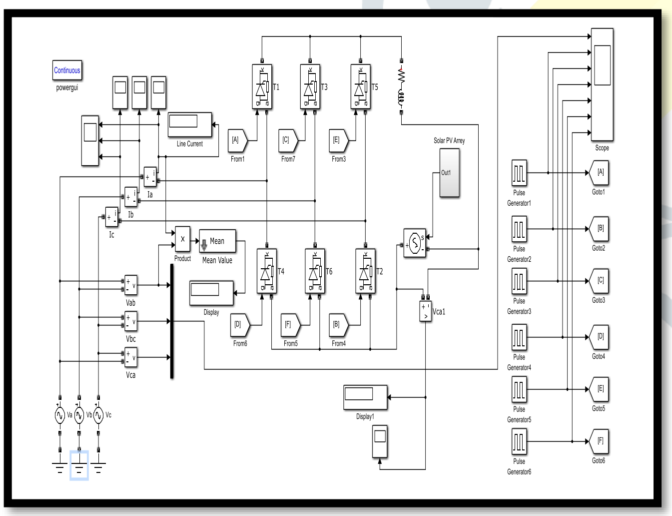


Figure 3: Simulink model of Proposed Topology

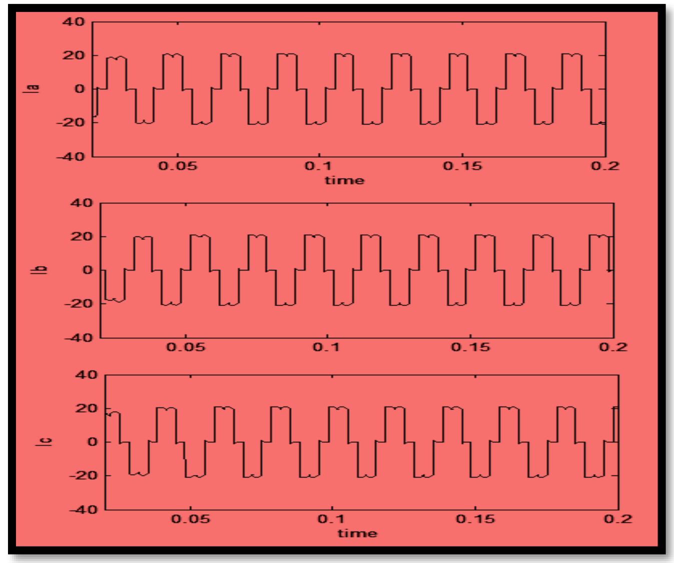


Figure 4: Output waveform of line current of Proposed Model

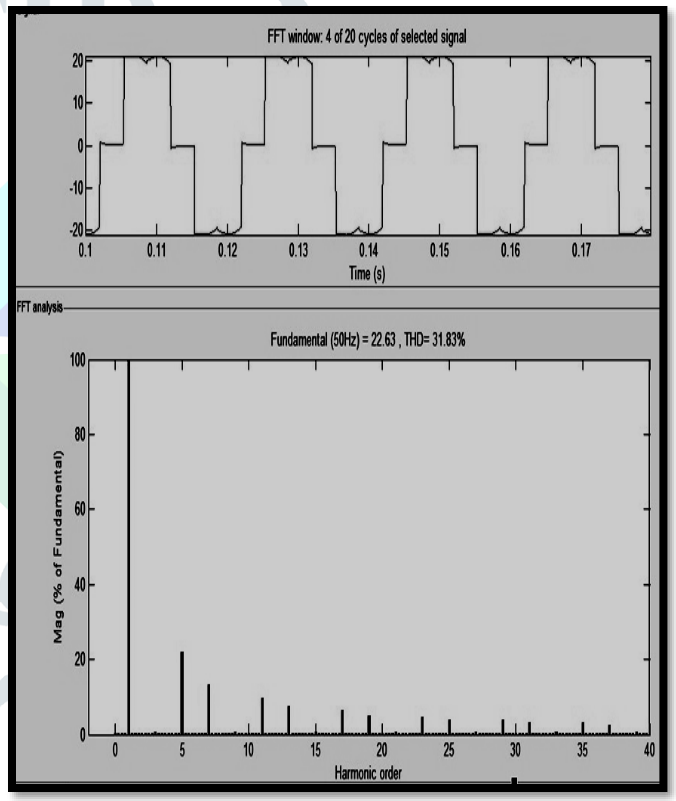


Figure 5: Line current with THD and harmonics of proposed model at firing angle α=95º

V. ANALYSIS AND SIMULATION RESULTS

Simulation of the proposed model is done using MATLAB/ Simulink. The triggering pulses are taken from the pulse generator block of the simulink library. THD and power transfer analysis is done for various combinations of firing angles (α). It has been observed that for increasing switching angle, the power transfer to grid initially increases thereafter it decreases after 110 deg. (for Solar array connected system) and 105 deg.(for battery connected system). The THD is almost constant upto 120º then its increases rapidly. Therefore a suitable compromise is made for selecting switching angle. Figure 4 shows the output waveform of the line current of the proposed model. It has been shows in Figure 5 that THD of line current comes out to be 31.81 % at switching angle α=95º. Comparison of the power transfer analysis and THD for various combinations of switching angles (α) for battery and solar array connected system has been shown in table 5.1 and 5.2 respectively. Comparison of switching angle Vs THD for battery & Solar array connected with proposed model has been shown in figure 6 whereas Comparison of Switching angle Vs Power transfer for battery & solar array connected with proposed model has been shown in figure 7.

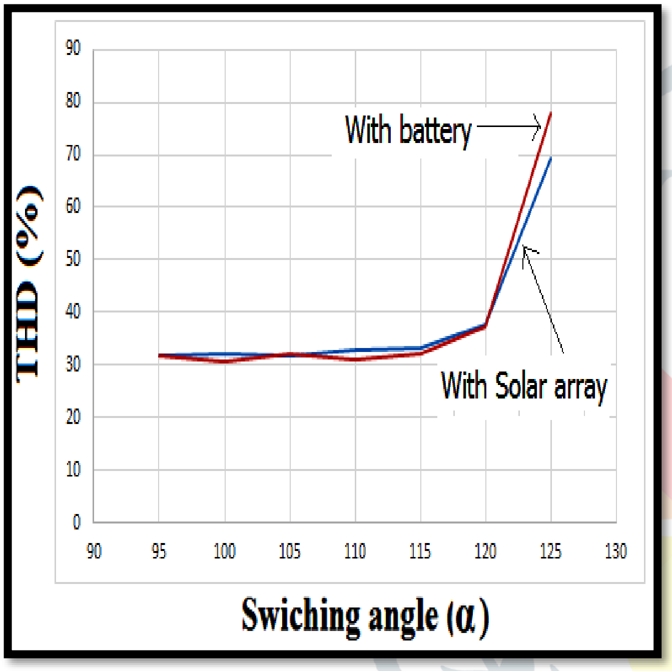


Figure 6: Comparison of Switching angle Vs THD with and without Solar Array connected with proposed model

Table 5.1: Comparison of results (Switching angle vs Power transfer)

Switching angle (Deg)	Power transfer (watt)	
	With battery	With Solar Array
95	-690.7	-349
100	-1145	-633.6
105	-1343	-776.5
110	-1281	-787.1
115	-979.2	-653.9
120	-426.3	-388.2
125	-47.36	-75.16

Table 5.2: Comparison of results (Switching angle vs THD)

Switching angle (Deg)	THD (%)	
	With battery	With Solar Array
95	31.82	31.81
100	30.68	32.1
105	32.05	31.81
110	30.99	32.9
115	32.24	33.25
120	37.2	37.62
125	77.63	69.37

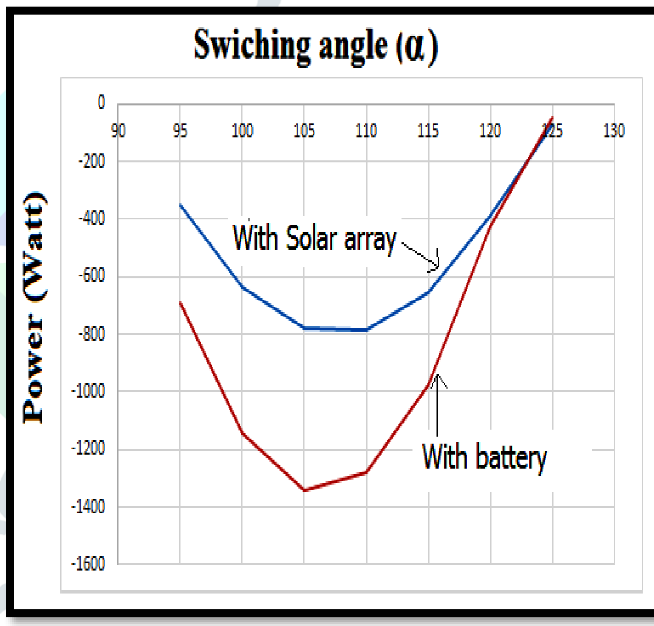


Figure 7Comparison of switching angle Vs Power transfer for battery & Solar Array connected 3-phase 6-pulse converter system

VI. CONCLUSION

Simulation and analysis of three-phase 6-pulse converter with battery as well as solar array is successfully done. THD and power transfer analysis is done for various combinations of firing angles α. It is evident from the results that on increasing the switching angle THD gradually increases for 6-pulse converter. It has been observed that for increasing switching angle the power transfer to grid initially increases thereafter it decreases after 110 deg. The THD is almost constant upto 120º then its increases rapidly. Therefore a suitable compromise is made for selecting switching angle. It is evident from graph that for increasing switching angle the power transfer to grid initially increases thereafter it decreases beyond 110 deg.(for Solar array connected system) and 105 deg.(for battery connected system). From the results shown in this paper, it is concluded that for three phase 6-pulse converter, THD of line current comes out to be 31.83 % at switching angle α=95º.This THD can be further reduced by adding filter to the circuit.

VII. REFERENCES

[1] Muhammad H. Rashid, "Power Electronics Circuits, Devices, and Applications", Pearson, Third Edition.

[2] Asim, M., Riyaz, A., Tiwari, S., & Verma, A. (2018). Performance evaluation of fuzzy controller for boost converter with active PFC. *Journal of Intelligent & Fuzzy Systems*, (Preprint), 1-8.

[3] Asim, M., Tariq, M., Mallick, M. A., & Ashraf, I. (2016). An improved constant voltage based MPPT technique for PMDC motor. *International Journal of Power Electronics and Drive Systems*, *7*(4).

[4] L. Sabari Nathan, S. Karthik, S. Ravi Krishna, "The 27-Level Multilevel Inverter for Solar PV Applications", 978-1-4673-0934-9/12/2012 IEEE.

[5] N. Hingorani and G. Gyugai, Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems, Wiley-IEEE Press, 1999.

[6] Adil Sarwar, Mohammad S. J. Asghar, "Simulation and Analysis of a Multilevel Converter Topology for Solar PV Based Grid Connected Inverter" Smart Grid and Renewable Energy, 2011, 2, 56-62, doi:10.4236/sgre.2011.21007 Published Online February 2011.

[7] Adil Sarwar, M.S. Jamil Asghar, "Multilevel Converter Topology for Solar PV Based Grid-Tie Inverters" 2010.

[8] M.S.J. Asghar "Power Electronics", PHI learning, India, chapter 6, 2004.

[9] Nakul Thombre, Ratika singh Rawat, Priyanka Rana, Umashankar S, "A Novel Topology of Multilevel Inverter with Reduced Number of Switches and DC Sources"International Journal of Power Electronics and Drive System(IJPEDS), Vol. 5, No. 1, July 2014, pp. 56-62

[10] Mirza Mohammad Shadab, Mohammad Arifuddin Mallick, Mohammad Tufail, M.S. Jamil Asghar, "Development of a Novel Three Phase Grid-Tied Multilevel Inverter Topology", International Journal of Power Electronics and Drive System (IJPEDS), Vol. 7, No. 3, September 2016, pp. 826~834, ISSN: 2088-8694, DOI: 10.11591/ijpeds.v7.i3.pp826-834

[11] Mirza Mohammad Shadab, Mohammad Tufail, Qamar Alam, Mohammad Ariffudin Mallick, "Simulation and analysis of a grid connected multi-level converter topologies and their comparison" Journal of Electrical Systemsand Information Technology-Elsevier, 2014,vol-1,issue-2, pp-166-174, doi.org/10.1016/j.jesit.2014.07.007