IJCTA, 9(14) 2016, pp. 6547-6555

Comparative Power Quality Analysis of Different Discontinuous Phase Control Grid-interactive Converter Systems

Satwinder Singh[1] and Akhil Gupta[2]

ABSTRACT

Employing multilevel inverters is a novel kind of converter used to reduce harmonic content of output voltage and current and Electromagnetic Interference (EMI) in high power applications. The conventional line commutated DC-AC inverters have square-shaped line current which contains higher-order harmonics. The line current with the high harmonic contents generates EMI and moreover it causes more heating of the core of distribution/power transformers. In the present work, a different line commutated inverter topology has been proposed and analyzed with discontinues phase control switching technique which improves the wave shape and hence reduces the Total Harmonic Distortion (THD) of the line current in a grid tie line commutated inverter. Proposed inverter circuit is supplied with a DC source at various levels which can be implemented by research engineers working in PV fed inverter and grid interactive systems.

Keywords: Power quality, harmonic distortion, multilevel inverter, grid, DC source

1. INTRODUCTION

A Multilevel converter is a power electronic system that synthesizes a sinusoidal AC output voltage from several DC sources. The basic aim of using MLI is to generate a staircase type sinusoidal voltage and current at the output by using thyristor or inverter switches in series [1]. The concept of MLIs does not depend on just two levels of voltage to create an AC signal. Instead, several voltage levels are added with each other in order to create a smooth stepped waveform at the output. The commonly used converter systems can be classified into various categories: flying capacitors, diode-clamped, and isolated H-bridge cell. Among them, an isolated H-bridge converter has various H-bridge modules at low voltage which are connected in series. Each converter module has its own independent source. Therefore, in [2], it is mentioned that to remove the shortcomings of an isolated H-bridge type converter, an isolated transformer is proposed which can be operated on single DC voltage source. Few high power applications are reported in [3] in which these converter systems have found its use are large motor drives, flexible AC transmission systems, and renewable energy sources. Additionally, this technology has been widely used for power quality improvements and reactive power compensation.

An important application of solar photovoltaic based power generation in reported in [4] in which it feeds the generated DC power into utility grid, after its conversion into AC power. To achieve this, the Pulse Width Modulation (PWM) inverters have been implemented for gate commutated devices. However, apart from higher switching losses, the power handling capability and reliability of these semiconductor devices are quite low in comparison to thyristors, as mentioned in [5]. Furthermore, the switching angles play an important role in order that the output voltage and current has low harmonic distortion. Various

[1] PG Scholar, Electrical Engineering, University Institute of Engineering, Chandigarh University, Mohali, India, *E-mail: satwindersingh416@yahoo.com*

[2] Associate Professor, Electrical Engineering, University Institute of Engineering, Chandigarh University, Mohali, India, *E-mail: akhilgupta1977@gmail.com*

renewable energy sources such as batteries, solar cells, and wind turbines can be connected through these MLI systems to feed a load. However, the solar photovoltaic arrays are restricted because its output mainly depends upon changing environmental conditions. Therefore, in this paper, the impact of the presence of a single DC voltage source on output power and harmonic distortion is studied. As described in [6], with an increase in the number of voltage levels on the DC side, the synthesized output voltage and current waveforms adds more steps, thus, producing a staircase waveform with minimum harmonic distortion. It has been found in [7] that multilevel converter topologies are integrated easily with photovoltaic applications because of their modular structure. Also, the different levels of DC voltage can easily be provided. The ability to operate MLI at very high input voltage is described in [8] in which the discussion on High Voltage Direct Current (HVDC) transmission with low distortion is presented. Also, the generation of voltages with low distortion reduces the *dv/dt* stresses. Due to their attractive features, multilevel converters are an interesting alternative for medium voltage and high power applications [9]. Multilevel converters are also employed for controlling the speed of single-phase and three-phase induction motors. For achieving low harmonic distortion at the output, the various types of multilevel topologies and multicarrier PWM have been mentioned in [10]. Multilevel inverter topology is implemented with reduced number of PWM controlled switches, which makes a reduction of the overall system cost and its size [11-12]. In [13], the multilevel inverters based on series and parallel connection of the DC voltage source are proposed. By using the series and parallel connections, the ability of multilevel inverter to increase the number of voltage levels and reduce the total harmonic distortion is demonstrated. In addition, it is proved that minimum number of switches and DC voltage sources are required. Therefore, from the literature survey, it is concluded that sufficient work on power quality concerns of MLI systems has not been addresses. Harmonic study is important when the semiconductor devices are implemented in any industrial application. Thus, the main scope of this paper is to address the harmonic concerns for various discontinuous phase control converter systems. The impact of changing levels of DC voltage and switching angles for phase-controlled converter systems on harmonic study is highlighted.

In this paper, an effort has been made to demonstrate a power quality comparative analysis of different grid interactive discontinues phase-controlled converter systems. Both systems have been developed using thyristors which are controlled by varying phase delays under changing DC load voltages. Since a converter work as an inverter at switching angle greater than 90Ú, therefore, the switching angle of the thyristors are varied up to 165Ú for inversion operation to facilitate the commutation voltage for thyristor. Furthermore, the systems are tested at *RLE* load with changing level of DC voltages. In the present work, the level of DC voltage is varied from 24 V to 48 V to study its impact on harmonic level at various levels. Additionally, it is analyzed that real output power injected into the utility grid is increased under changing levels of DC voltage and switching angles.

2. PROPOSED COMPUTATION SCHEME FOR MLI SYSTEM

A converter systems, primarily consists of a PWM controlled thyristor, its switching scheme, a connected load and utility grid. For the optimal working of converter, the switching angle is varied in the range 90Ú to 165Ú for inversion purpose. The system generates sinusoidal waveform with less harmonic distortion at its output. The system validation of grid interactive discontinues phase-controlled converter systems are done in Matlab software [14].

2.1. Description for Grid interactive inverter with transformer

Here, a new grid interactive topology is proposed with centre-tapped transformer. The proposed scheme is a thyristor biased converter, which works in an inversion mode [15]. During operation of the converter, the real power output is transferred to the utility grid under changing levels of DC voltage source. In proposed topology, each load branch is connecting between one terminal of centre tapping on secondary side of the centre-tapped transformer. The line current on primary of centre-tapped transformer become continuous but current through the half winding of the secondary side of the centre- tapped transformer is discontinuous and its shape like a half-wave sinusoidal current. Thus, the THD of line current becomes very low.

2.1.1. Simulink model of Grid interactive inverter with transformer

Proposed topology works with RLE load connected on load side. When the switching angle is greater than 90Ú, it starts working as a inverter and inject power to grid from DC source. During positive half cycle thyristor T_1 is triggered at switching angle greater than 90Ú with RLE load as shown in Fig. 1(a).

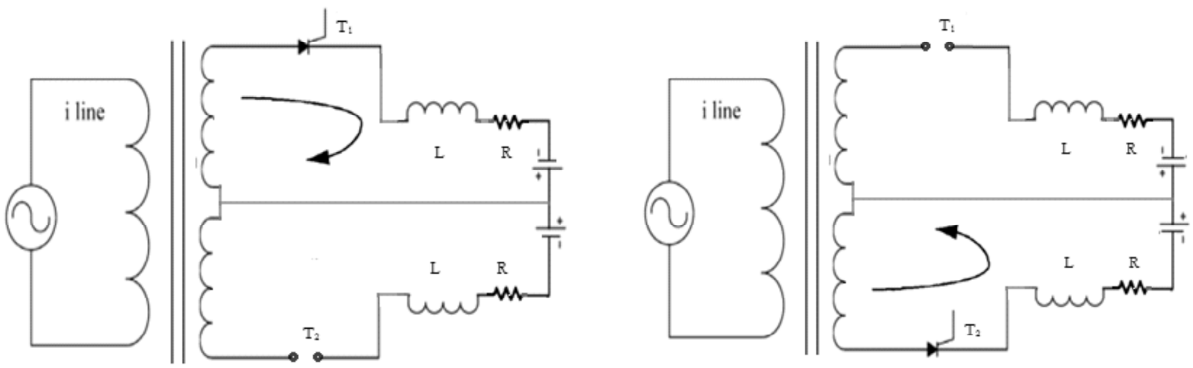


Figure 1: Operating mode of proposed topology during (a) positive half cycle and (b) negative half cycle

During negative half cycle thyristor T_2 is triggered at switching angle greater than (90°+180°) with RLE load as shown in Fig. 1(b). From both half cycle diagrams, it looks that during positive half cycle, thyrsitor T_1 transfer power from DC source to AC grid in Positive branch and similarly during negative half cycle, thyristor T-$_2$ transfer power from DC source to AC grid in negative branch of proposed converter. Simulink model of grid-interactive inverter with transformer is shown in Fig. 2. In this model two thyristors are used and triggered with the help of pulse generator block set of simulink library. Series resistance and inductance are connected in series with DC source. Resistance is connected in series with the inductance to

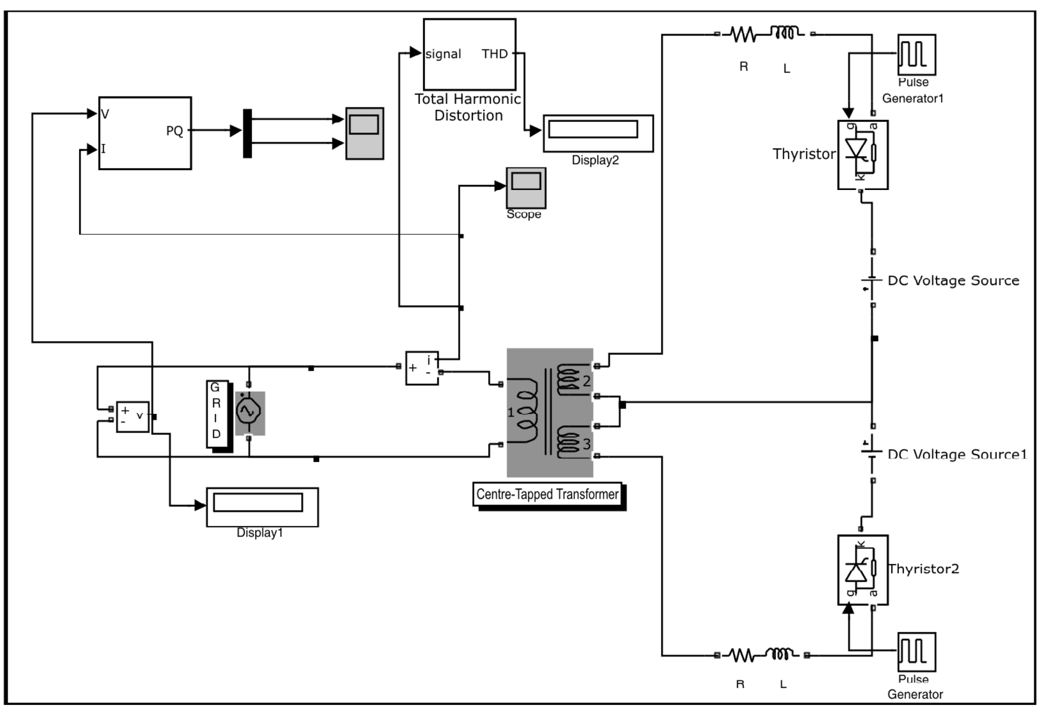


Figure 2: Simulink model of grid-interactive inverter with transformer

simulate the real inductor. The value of series connected resistance is 0.2 Ω and inductance value is 0.05 H. The centre tapped transformer has a ratio 230:150-0-150 V. Switching pulses generated from pulse generator is varied from in the range 90° to 165°. DC battery is used as a DC voltage source and DC battery voltage is varied from 24 V to 48 V.

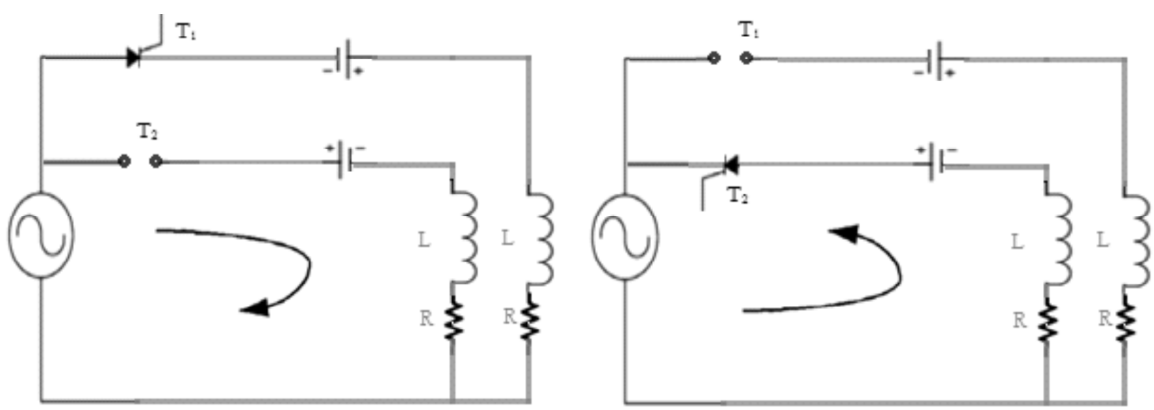
2.2. Description for Grid interactive inverter without transformer

Proposed scheme is operate without transformer [16] and a thyristor based converter, which works in inversion mode. Similarly as first topology, during operation of the converter, the real power output is transferred to the utility grid under changing levels of DC voltage source.

In proposed topology, two thyrsitors with DC source and series resistance-inductance branch are operating. The first thyristor and DC source with series resistance-inductance form a positive half cycle and similarly another thyrsitor and DC source with series resistance-inductance form a negative half cycle.

2.2.1. Simulink model of Grid interactive inverter without transformer

The pulse generator supplies switching to each thyristor during positive half cycle and negative half cycle. In the positive half cycle thyristor is switched at angle, say α. Thus, in negative half cycle, thyristor is switched at angle (α+180°). During operation, a half wave current flow through each branch. Therefore, the line current of both half cycles are resemble a sine wave with lower harmonics. During positive half cycle, thyristor T_1 triggered with DC source and series resistance-inductance at angle greater than 90°. Fig. 3 (a) shows the direction of current flowing during positive half cycle. Similarly in negative half cycle, thyristor T_2 triggered with DC source and series resistance-inductance at angle greater than (90°+180°). Fig. 3 (b) shows the direction of current flowing during negative half cycle.



(a) **(b)**

Figure 3: Operating mode of proposed topology during (a) positive half cycle and (b) negative half cycle

Simulink model of grid-interactive inverter without transformer is shown in Fig. 4. In this model two DC sources and two thyristors are used and triggered with the help of pulse generator block set of simulink library. Series resistance and inductance are connected in series with DC source. Resistance is connected in series with the inductance to simulate the real inductor. The value of series connected resistance is 0.2 Ω and inductance value is 0.05 H. Switching pulses generated from pulse generator are varied from in the range 90° to 150°. DC battery is used as a DC voltage source and DC battery voltage is varied from 24 V to 48 V. During positive half cycle thyristor T_1, battery B_1 and series resistance- inductance L_1-R_1 are conducting and during negative half cycle thyristor T_2, battery B_2 and series resistance- inductance L_2-R_2 are conducting.

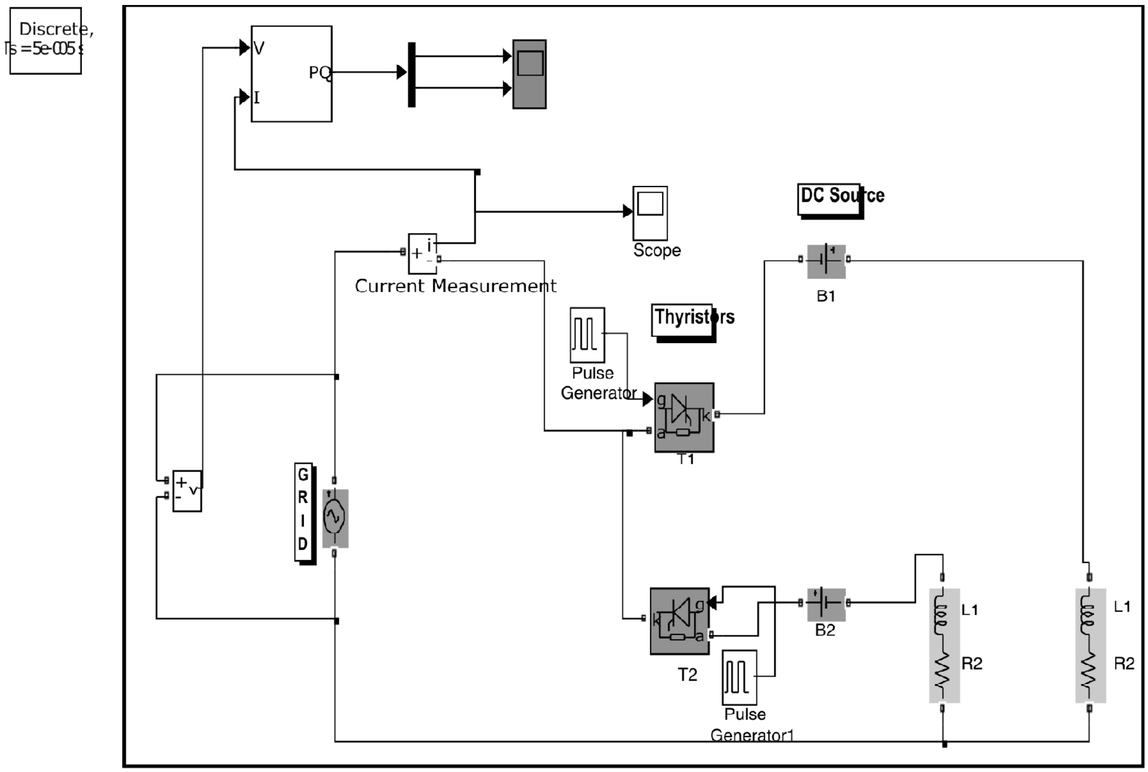


Figure 4: Simulink model of grid-interactive inverter without transformer

3. MATHEMATICAL ANALYSIS OF CONTROL STRATEGY

In general, the load current of MLI system can be either continuous or discontinuous. During continuous conduction mode, the current in the converter never reaches zero value. During discontinuous conduction mode, the load current falls to zero level. Overall operation of the converter is dependent upon the DC source voltage, switching angle, and phase angle between inductance and resistance load. The expression for both convertor schemes are obtained by solving the following Equation (1):

$$L\frac{di}{dt} + iR = V_m \cos \omega t + E \tag{1}$$

where, L= Load inductance (H), R= Load resistance (Ω), E = DC voltage level connected in load (V), V_m = Maximum value of sine voltage (V), i = instantaneous value of positive half current current (A).

For ωt = θ and $m = \left(\frac{E}{V_{leg1}}\right)$, it gives i_{leg1} for conducting through T_1 in positive half cycle in upper leg of the converter,

$$i_{leg1} = \cos(\theta - \psi) + \frac{m}{\cos(\psi)} * (1 - e^{\frac{1(\theta-\alpha)}{\tan(\psi)}}) - \cos(\psi - \phi) * (1 - e^{\frac{1(\theta-\alpha)}{\tan(\psi)}}) \tag{2}$$

For conduction through T_2 during negative half cycle in lower leg of converter,

$$i_{leg2} = \cos(\theta - \psi - \prod) + \frac{m}{\cos(\psi)} * (1 - e^{\frac{1(\theta-\alpha-\prod)}{\tan(\psi)}}) - \cos(\psi - \alpha) * (1 - e^{\frac{-1(\theta-\alpha-\prod)}{\tan(\psi)}}) \tag{3}$$

where each converter contributes to the line current and the net line current i_{line} is equal to sum of currents of both legs (i_{leg1} + i_{leg2}).

4. SIMULATION RESULTS AND DISCUSSION

4.1. Case I. Power quality study for Grid interactive inverter with transformer

The simulation work is basically done for study the variation of THD of line current and power transfer to the grid with different switching angles. Fig. 5 shows the line current with THD. From the Fast Fourier Transform (FFT) analysis, it has been found that the THD level of grid current is 17.09% at frequency 50 Hz.

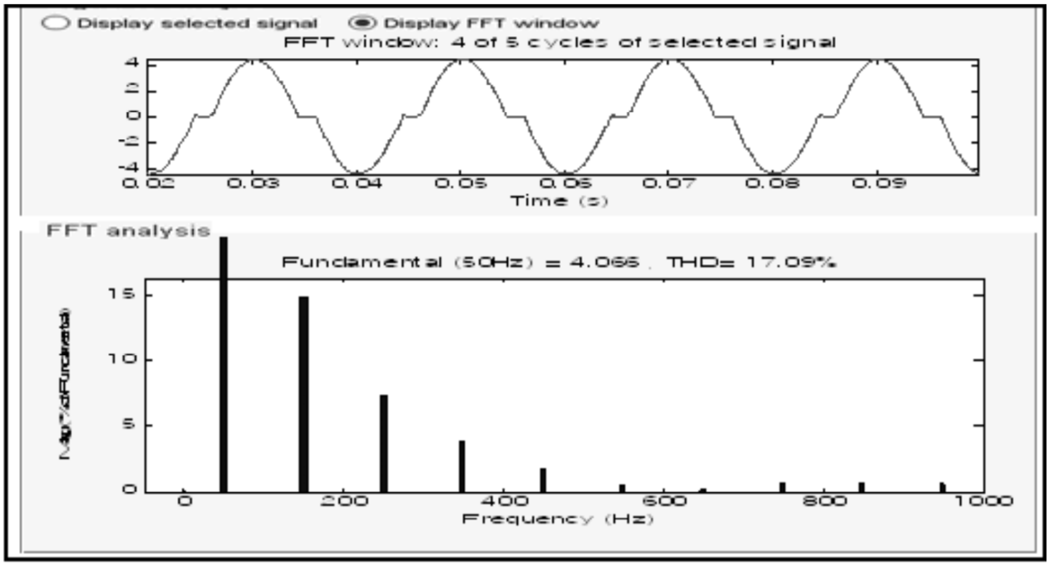
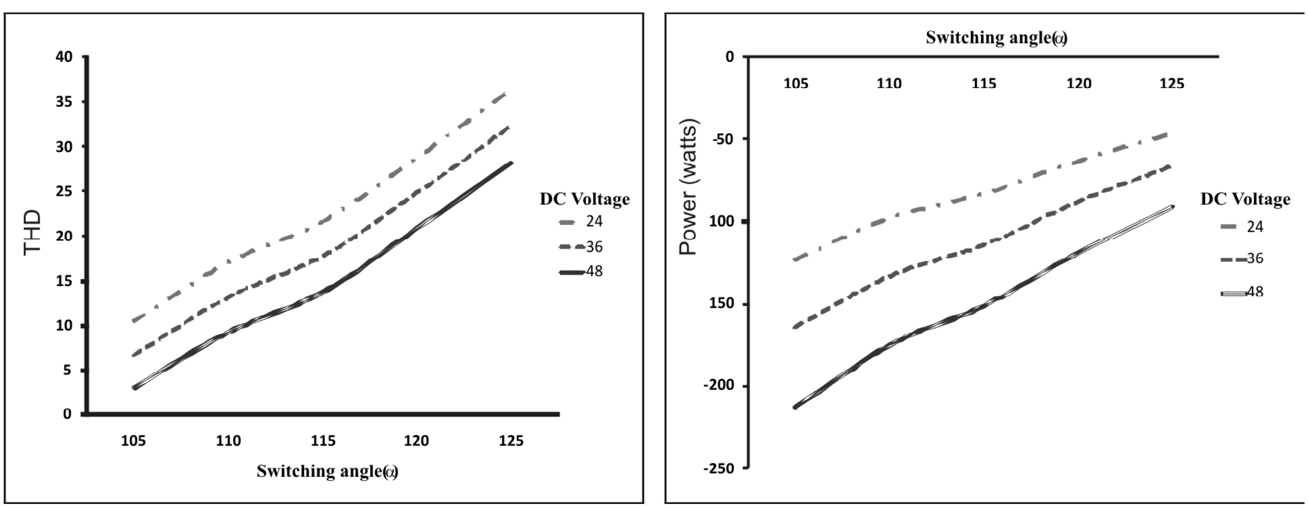


Figure 5: Harmonic spectrum of grid injected current

Further, Fig. 6 (a) Depicts the variation of THD whereas Fig. 6 (b) depicts the change in power, with different switching angles (α*)*. The chosen values of switching angles are (α =105°), (α =110°), (α =115°), (α =120°), (α_1=125°) etc.



(a) **(b)**

Figure 6: With DC Voltage kept at 24 V, 36 V and 48 V, (a) Variation of THD, (b) Variation of power, with different switching angles

The level of DC voltage at load is varied from 24 V to 48 V. It is evident that, the level of THD for line current injected into the grid Increases with increase in switching angle. However, as the increase in DC voltage level, the THD level of grid injected current decreases. In addition, the real output power is negative which means that the real power is being supplied from DC source connected at *RLE* load and being fed to utility grid through a multi-winding transformer. From the waveform, it is also clear that as the value of switching angle increases, the real output power supply to the utility grid decreases. Thus, instead that RLE load consumes power; it supplies real power to the utility grid. This supply of power decreases the overall burden on utility grid.

4.2. Case II. Power quality study for Grid interactive inverter without transformer

Figure 7 shows the line current with THD. From the FFT analysis, it has been found that the THD level of grid current is 14.52% at frequency 50 Hz.

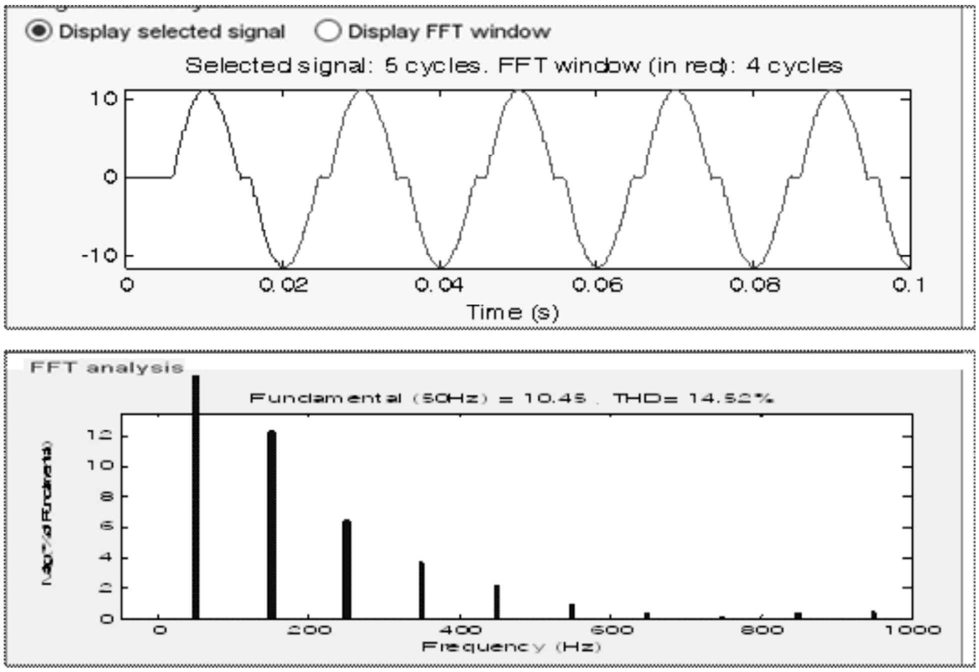
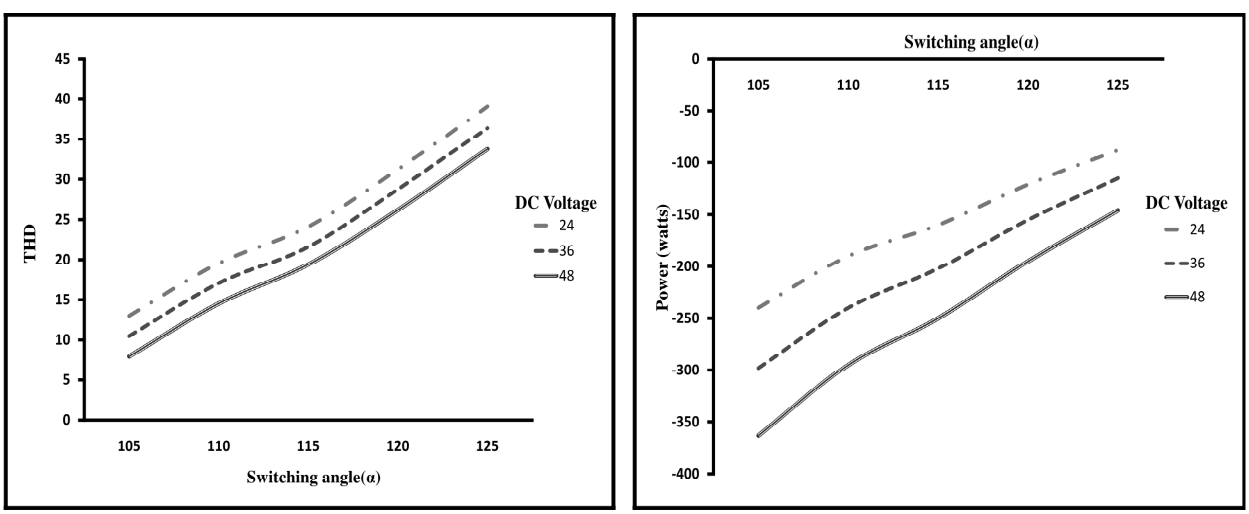


Figure 7: Harmonic spectrum of grid injected current

Further, Fig. 8 (a) Depicts the variation of THD whereas Fig. 8 (b) depicts the change in power, with different switching angles (α). The chosen values of switching angles are (α = 105°), (α =110°), (α = 115°), (α =120°), (α_1=125°) etc. The level of DC voltage at load is varied from 24 V to 48 V. It is evident that, the



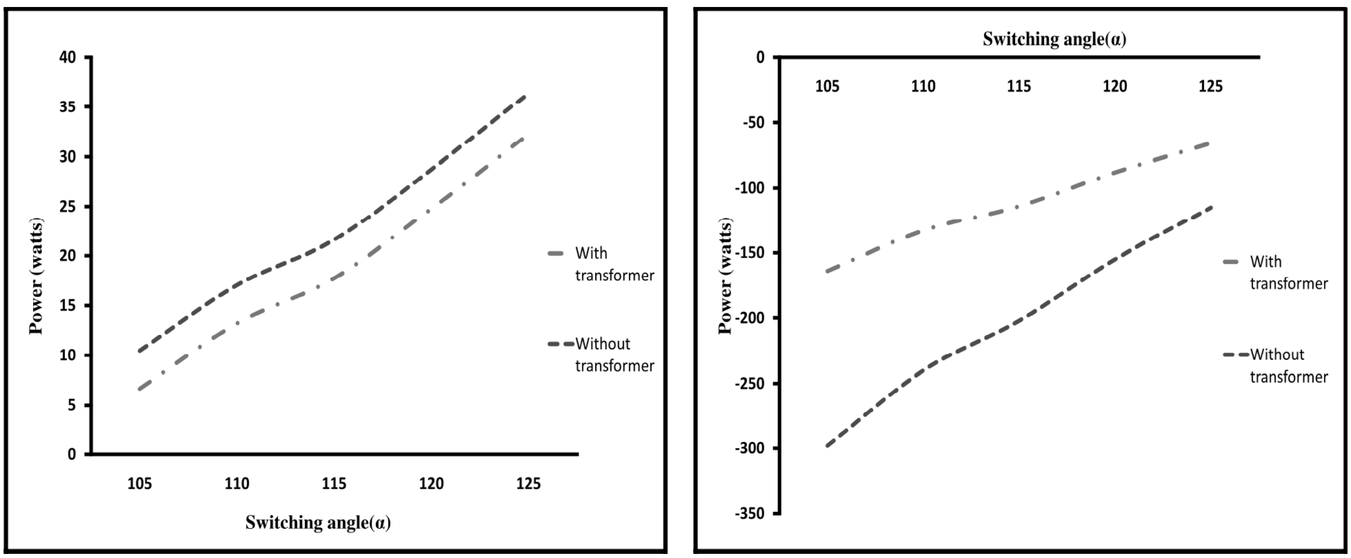
(a) **(b)**

Figure 8: With DC Voltage kept at 24 V, 36 V and 48 V, (a) Variation of THD, (b) Variation of power, with different switching angles

level of THD for line current injected into the grid Increases with increase in switching angle. However, as the increase in DC voltage level, the THD level of grid injected current decreases. In addition, the real output power is negative which means that the real power is being supplied from DC source connected at *RLE* load and being fed to utility grid through a multi-winding transformer.

4.3. Case III. Comparative analysis of THD and Output power for converter schemes

Fig. 8 shows the comparison of grid interactive inverter schemes with transformer and without transformer. As evident from waveform THD level in with transformer scheme is less as compare to without transformer scheme and grid output power level is more in without transformer inverter scheme as compare to with transformer.



(a) (b)

Figure 8: With DC Voltage kept at 36 V, Comparative analysis of (a) THD and (b) Output power for converter schemes

5. CONCLUSION

This paper has emphasized the analysis and a comparative power quality study of two different discontinuous phase control inverter systems. The simulation of both the systems has been carried out thoroughly when operating thyristors as inverters by varying the switching angle in the range of 90° to 165°.The performance of both these systems has been tested at *RLE* load, where the level of DC voltage is varied between 24 V to 48 V. It has been found that as the DC voltage increases, the real output power injected into the utility grid increases. This increase in power with reduced level of harmonics reduces the overall burden of utility grid. Meanwhile, the study of THD levels for the grid injected current has been carried out. It has been found that there is improvement in harmonic levels during changing DC voltage and switching angles at all levels.

REFERENCES

[1] Rashid M. H (2009). Power Electronics- Devices, Circuits and Applications. 3rd ed. Pearson Publishing. India

[2] Rodriguez J., Lai JS and Peng F. Z. Multilevel Inverters: A survey of topologies, controls, and applications. IEEE Transactions on Industrial Electronics, 2002, 49(4): 724-38.

[3] Zen P. F., Ming Q. Z. Applications of Cascade Multilevel Inverters. Journal of Zhejiang University science, 2003, 4(6): 658-665.

[4] Ahmad S., Johari S. H., Ahmad A., Halim M. F. M. A. Grid connected Multilevel Inverters for PV application. In: Proceeding of IEEE Conference On Energy Conversion (CENCON), Johor Bahru, 2015, 181-186.

[5] Lai JS, Peng F. Z. Multilevel Converters-A New Breed of Power Converters. IEEE Transaction on Industrial Application, 1996, 32(3): 509-17.

[6] Sarwar A., Asghar M. S. J., Imdadullah and Ahmed S. K. M. Development of Solar PV based Grid connected Inverters. In: Proceeding of IEEE international Conference on Electrical Energy System & Power Electronics, Chennai, 2009, 1172-1177.

[7] Myrzlk A. and Johanna M. A. Novel Inverter Topologies for Single-Phase Stand-Alone or Grid Connected Photo-Voltaic Systems. In: Proceeding of 4th IEEE International Conference on Power Electronics and Drive Systems. Denpas-sar, 2001, 103-10

[8] Sadigh A. K., Barakati S. M. Topologies and Control Strategies of Multilevel Converters. Modeling and Control, Green Energy and Technology. Springer-Verlag Berlin Heidelberg, 2012, 311-340.

[9] Sadigh A. K., Gharehpetian G. B., Hosseini S. H. New method for estimation of Flying Capacitor Voltages in stacked Multicell and Flying Capacitor Multicell converters. Journal of Zhejiang University-Science C, 2010, 11(8): 654-662.

[10] Singh S., Sharma P., Varshney A., Kumar A. Speed Control of Multilevel Inverter-based Induction Motor using V/F method. In: Proceedings of fourth International Conference on Soft Computing for Problem Solving, Advances in Intelligent Systems and Computing, Springer India, 2014, 1: 231-243.

[11] Santhiya R., Senthilnathan A., Chinnaiyan V. K., Priya R. N. Grid Connected Multilevel Inverter and MPPT for Photovoltaic System. Power Electronics and Renewable Energy Systems, Lecture Notes in Electrical Engineering 326, Springer India, 2015, 201-211.

[12] Karaca H. Analysis of a Multilevel Inverter Topology with Reduced Number of Switches. Transactions on Engineering Technologies, Springer Netherlands, 2014, 41-54.

[13] Babaei E., Zadeh S. S., Sabahi M. Improvement of Multilevel Inverters Topology using Series and Parallel connections of DC Voltage Source. Arabian Journal for Science and Engineering, 2014, 39(2): 1117-1127.

[14] The Mathworks. MATLAB/SIMULINK 7.10.0.499 (R2010a). 2010, *http://www.mathworks.in.*

[15] Singh S., Gupta A. Power Quality Analysis of Multilevel grid-interactive converter system with varying DC source and switching angle. Accepted in Proceedings of 1st IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems, July 2016, Delhi.

[16] Gupta A., Chanana S., Thakur T. Power quality improvement of solar photovoltaic transformer-less grid-connected system with maximum power point tracking control. International Journal of Sustainable Energy. vol. 33, Issue 4, 2014, pp. 921-936.