FOREX Publication
Open Access | Rapid and quality publishing

International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 10, Issue 3 | Pages 716-721 | e-ISSN: 2347-470X

Controlling of Cascaded Voltage Source Two Level Inverter Based Grid Connected PV System by Using SVPWM and Quadratic Boost Converter

Shaik Masum Basha[1] and Dr. K. Nagaraju[2]

[1]Research Scholar, Department of Electrical and Electronics Engineering, JNTUA, Ananthapuramu, India, smasumbasha@gmail.com
[2]Professor, Department of Electrical and Electronics Engineering, Sir C V Raman Institute of technology and Sciences, Tadipatri, India, nagarajudr09@gmail.com

***Correspondence:** Shaik Masum Basha; smasumbasha@gmail.com

ABSTRACT- In this paper, two cascaded voltage source grid-connected inverters (VSI) with Quadratic boost converter (QBC) has been described and simulated as more attractive for a grid to interface with the PV system. The simulation is carried out by using the open loop control method to synchronize the grid with the photovoltaic system and these two inverters are controlled with the Sinusoidal Pulse Width Modulation (SPWM) approach and SV Pulse Width Modulation (SVPWM) skill technique for dynamic behavior. These two inverters individually operate as two-level inverters and after cascading with the transformer will get the three-level output voltage and it is interfaced to a three-phase ac grid. To interface PV system with Grid here using a two-stage method which includes DC to DC converter, three-phase voltage source inverters and cascaded transformer for analyzing dc output voltage, active power and harmonic distortion of current. The Quadratic Boost Converter (QBC) is used to convert from DC to DC for injecting DC supply voltage into the cascading three-phase inverters. In this paper, the entire system is carried out by using with QBC and without QBC and compares the output voltages and total harmonic distortion of current at the grid side.

General Terms: VSI, Sinusoidal pulse width modulation (SPWM), SV Pulse Width Modulation (SVPWM).

Keywords: Photovoltaic system; Cascaded voltage source two level inverter; DC to DC converter; Total harmonic distortion, QBC.

ARTICLE INFORMATION
Author(s): Shaik Masum Basha and Dr. K. Nagaraju;
Received: 18/08/2022; **Accepted**: 17/09/2022-; **Published**: 25/09/2022;
e-ISSN: 2347-470X;
Paper Id: IJEER 1808-35;
Citation: 10.37391/IJEER.100349
Webpage-link:
https://ijeer.forexjournal.co.in/archive/volume-10/ijeer-100349.html

crossref member
CROSSREF.ORG
THE CITATION LINKING BACKBONE

Publisher's Note: FOREX Publication stays neutral with regard to Jurisdictional claims in Published maps and institutional affiliations.

1. INTRODUCTION

Nowadays the most popular renewable energy resource is a photovoltaic system which can generate electricity for various applications. The generated electricity from the photovoltaic system is direct current (DC). Thus, inverters are employed to transform this DC electrical energy into an AC form. Stand-alone or grid-connected inverters are the two types of inverters utilized in this conversion process. [4], [5]. The three-phase grid-connected inverter transforms the DC power generated by DC power generators into appropriated three-phase AC power injected into the grid and additionally acts as active power compensation. The most efficient PWM method is Sinusoidal PWM (SPWM), and SV Pulse Width Modulation (SVPWM) has been employed to control the three-phase voltage source cascaded inverters. This type of controlling technique used for inverters is to lower the harmonic distortion at an output side of the grid while interfacing with the photovoltaic systems.

A three-phase two-voltage source grid-connected inverter with an inverter control unit that can control the grid and the PV side was introduced in this study. Designing and simulating the inverter system involves the usage of MATLAB/SIMULINK. Applications using renewable energy, and inverters linked to the grid are anticipated to offer more power quality, higher efficiency, and higher dependability. As a result, inverter technology and control strategies are crucial in grid-connected structures. These cascaded inverters are linked to the grid through LCL filters to lower the harmonics on the grid side.

The photovoltaic system is linked to a three-phase cascaded two-level inverter, and the converter output is linked to an LCL filter, which is linked to a three-phase transformer's open primary winding and finally, the transformer secondary winding is connected to Grid.

2. MODEL FOR PHOTOVOLTAIC SYSTEM

A standard photovoltaic (PV) cell is a straightforward basic P-N junction diode that produces electricity from solar radiation. *Figure 1* displays a simple equivalent circuit schematic for a photovoltaic cell. A current source, which represents the produced current from a PV cell, a diode connected in parallel, a shunt and series resistances make up this model.

According to the properties of I-V cells, the values of these two resistances are used to determine [11].

FOREX Publication
Open Access | Rapid and quality publishing

International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 10, Issue 3 | Pages 716-721 | e-ISSN: 2347-470X

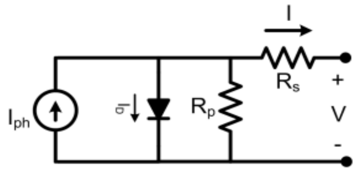


Figure 1: PV Cell Circuit Model

The following equation governs the relationship between a PV cell's output current and terminal voltage.

$$I = I_{ph} - I_D - \frac{V+IR_S}{R_P} \text{.................} (1)$$

Where $I_D = I_{01}\left\{\exp\left(\frac{q(V+IR_S)}{\alpha KT}\right) - 1\right\} \text{...} (2)$

Where I_{ph} = PV cell's Photo current
I_D = Diode current
α = Diode's ideal factor
K =Boltzmann constant (1.3806×10^{-23}J/K)
T = PV cell temperature in Kelvin
q = charge of electron ($1.60217\times10^{-19}C$)
I_{01}= Diode saturation current

This model, which has been utilized in several prior publications [9], [6] and [19] offers a fair balance between accuracy and model complexity. Combining the *equations (1) and (2)* we will get

$$I = I_{ph} - I_{01}\{\exp\left(\frac{q(V+IR_S)}{\alpha KT}\right) - 1\} - \frac{V+IR_S}{R_P} \text{.........} (3)$$

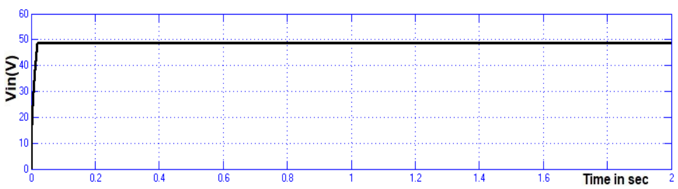


Figure 2: Output voltage of PV array (Vpv) at 1000W/m^2 at 25°

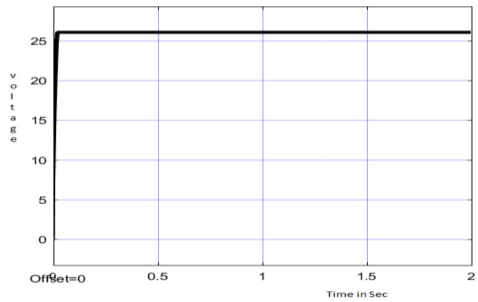


Figure 3: Output voltage of PV array (Vpv) at 1000W/m^2 at 35°

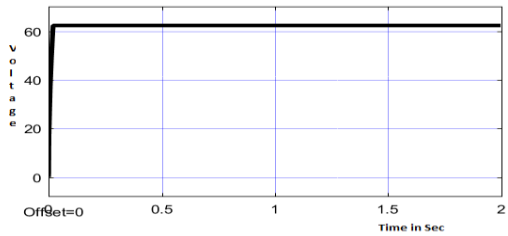


Figure 4: Output voltage of PV array (Vpv) at 3000W/m^2 at 25°

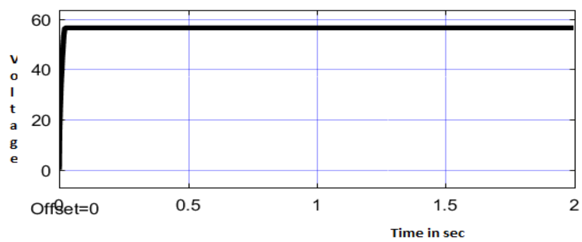


Figure 5: Output voltage of PV array (Vpv) at 3000W/m^2 at 35°

By observing the above figures, it is illustrated that as insolation increases with the same temperature the output voltage of PV is raised. As by seeing the figures due to rise in temperature with same insolation the PV voltage is dropped.

3. DC-DC CONVERTER

The grid-connected PV system comprises DC to DC converter. The DC-to-DC boost converter is coupled to a PV panel. To get a reasonably constant voltage DC bus for the three-phase voltage source inverter, a DC link capacitor is attached to the converter's output (VSI). A DC link voltage controller is used to maintain its voltage at a fixed value.

A quadratic boost converter is used in this research (QBC) [1] prefers to boost a fixed DC voltage for an inverter to operate and to get the specified AC output voltage from the inverter which is to be synchronized with the Grid. In this study, DC to DC converter architecture is used to increase the output voltage of renewable energy sources. In essence, boost converters are used to raise voltage gain. The output voltage is decreased in this converter due to restricted switching frequency. To solve this problem a quadratic boost converter (QBC) [12] is used for improving the switching frequency and output voltage.

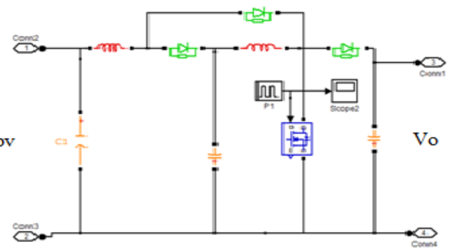


Figure 6: Quadratic Boost converter circuit (QBC) illustration

Where Vpv is the PV array output voltage as illustrated in *figure 2* and input to the QBC and V_o is the output voltage of the QB converter which is shown in *figure 6*.

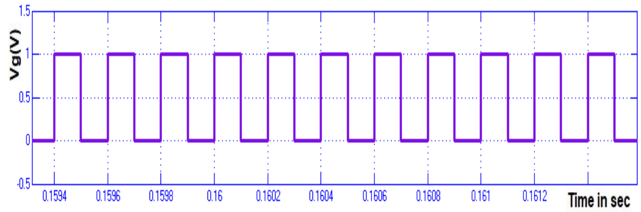


Figure 7: Switching pulse for QBC

Research Article | Volume 10, Issue 3 | Pages 716-721 | e-ISSN: 2347-470X

The voltage generated by the PV array is giving to as input to the quadratic boost converter. The PV array provides 48V as the input to the QB converter which is shown in *figure 6*. The corresponding switching pulses for the QB converter are shown in *figure 7*.

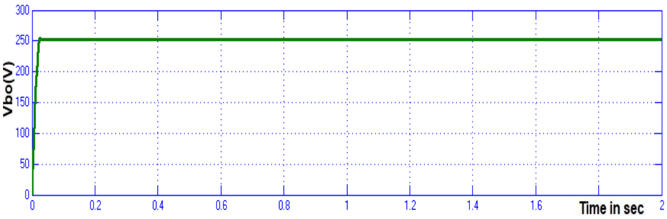


Figure 8: Voltage (V_o) across QBC

As seen in above *figure 8* voltage across the Quadratic boost converter is raised to 250V which is to be inserted into the cascaded to three-phase inverters as the voltage source.

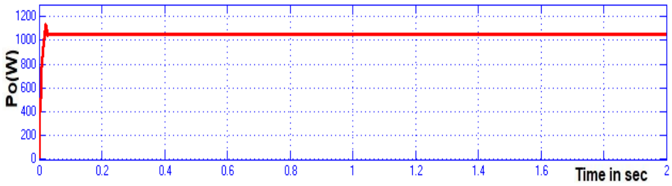


Figure 9: The output power across QBC

For conventional Boost converter the output voltage is

$$Vo = \frac{Vs}{1-K}$$

Vo = Output voltage of the Boost converter
Vs = Input voltage to the Boost converter from PV array.
K = Duty ratio of the switch in a Boost converter.

The output equation for the proposed Quadratic boost converter can be determined by turning the ON and OFF modes of operation of the switch
During the switch turn ON The currents in the inductors of the QB converter shown in *figure 6* increase and they can be written by

$$(\Delta I_{L1})On = \frac{VsKT}{L1} \quad (4)$$

$$(\Delta I_{L2})On = \frac{Vc1KT}{L2} \quad (5)$$

During the switch turn OFF The currents in the inductors of the QB converter shown in *Figure 6* decrease and they can be written by

$$(\Delta I_{L1})Off = \frac{(V_S - V_{C1})(1-K)T}{L1} \quad (6)$$

$$(\Delta I_{L2})Off = \frac{(V_{C1} - V_O)(1-K)T}{L2} \quad (7)$$

By solving the above equations of turn ON and OFF modes the output voltage of the QB converter can be written as

$$Vo = \frac{Vs}{(1-K)^2}$$

From the output voltage equations of the Boost and Quadratic Boost converters for the same input voltage and same duty ratio, the output voltage is raised in the case of the QB converter by comparing it with a conventional boost converter. The *table 1* shows the comparison values of boost and quadratic boost converter.

Table 1: Output voltage Comparison for Boost Converter and Quadratic Boost Converter

Converter	Input voltage Vs (Volts)	Duty ratio K	Output voltage Vo (Volts)
Boost Converter	10	0.8	50
Quadratic Boost converter	10	0.8	250

4. SYSTEM DESCRIPTION

4.1 Grid Connected Three-Phase Cascade Inverters Interfacing with PV System without QBC

Figure 10 illustrates a Grid-connected PV system by using the two three-phase cascaded two-level inverters and without a Quadratic boost converter. That is directly the PV cells are connected with the three-phase cascaded inverters to produce ac output to interface with the grid. The voltage injected into the inverters is limited which is 48 volts that come from PV is shown in *figure 2*. The corresponding grid side voltages and currents are shown in *figure 11* and *figure 12*.

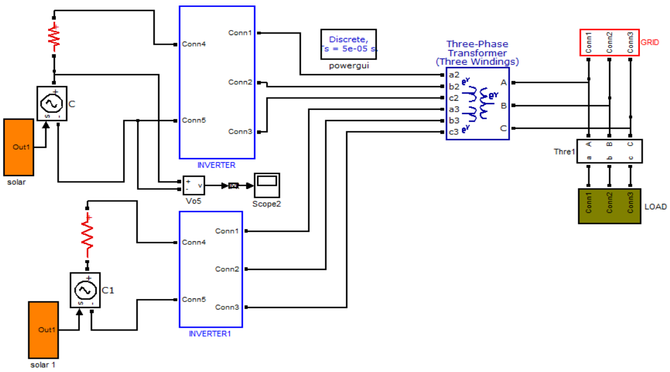


Figure 10: Block diagram of two three phase inverters in cascading manner with PV system without QBC

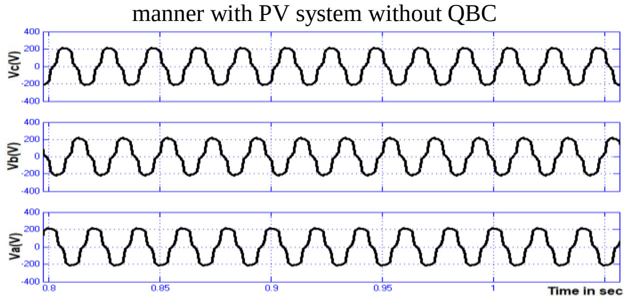


Figure 11: Line Voltages injected to Grid without QBC

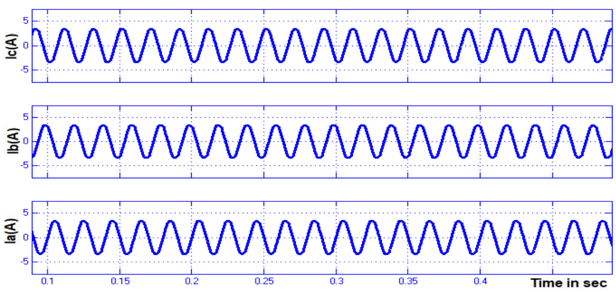


Figure 12: Line currents injected to Grid without QBC

FOREX Publication
Open Access | Rapid and quality publishing
International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 10, Issue 3 | Pages 716-721 | e-ISSN: 2347-470X

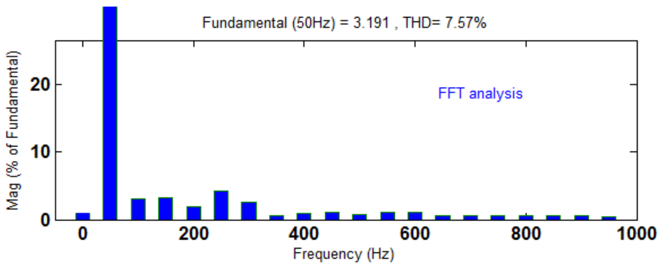


Figure 13: Harmonic distortion (THD) of current at Grid side without QBC

4.2 Grid Connected Three-Phase Cascade Inverters Interfacing with PV System with QBC

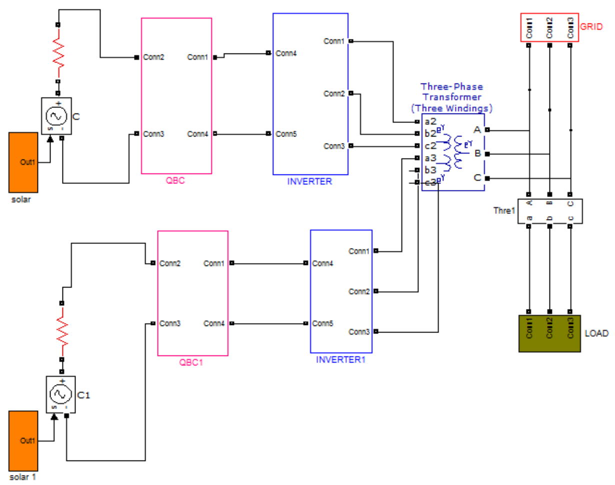


Figure 14: Block diagram of two three phase inverters in cascading manner with PV system

Utilizing the two voltage source inverters operating in three-phase in a cascaded manner can improve the line voltage, which tends to diminish the voltage stress on switching devices of the inverters of each unit, which causes the reduction in harmonics in the synthesized current. Meanwhile, the three-phase two voltage source inverters are associated in parallel using the linear transformer which helps to increase the voltage levels to interface with grid voltages. A linear transformer is used to cascade two three-phase voltage source inverters to increase the output voltage level. The increased output voltage can be taken from the secondary of the transformer where as the primary of the transformers are cascaded the two three phase inverters. Unlike normal voltage source inverters, these cascaded voltage source inverters [7] increase power levels.

5. SWPM BASED CASCADE TWO LEVEL INVERTER GRID CONNECTED PV SYSTEM

The SPWM technique is approached with two three-phase voltage source inverters which are cascaded to supply the output voltage to the grid [20]. One of the inverters of cascaded two-level inverters and its switching pattern is shown below *figure 15* and *figure 16.*

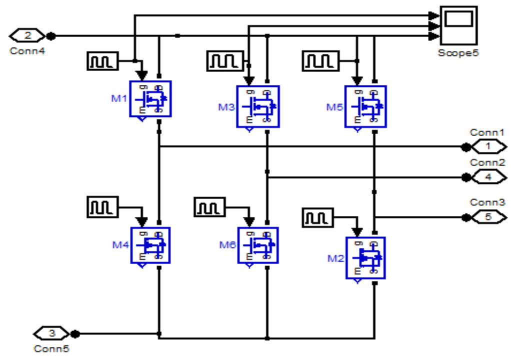


Figure 15: Circuit schematic for a three-phase inverter

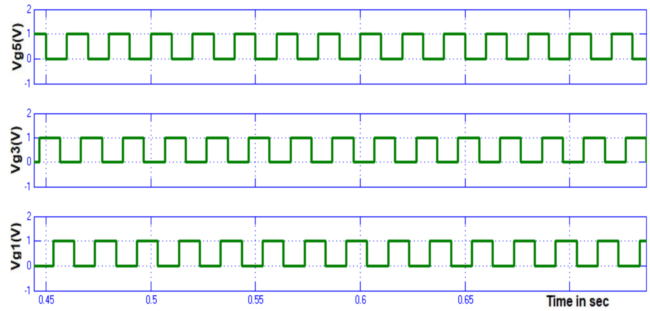


Figure 16: Switching pulse pattern for three phase inverter M1, M3 and M5 by using SPWM approach

6. SVWPM BASED CASCADE THREE PHASE TWO LEVEL INVERTER GRID CONNECTED PV SYSTEM

As of using the SPWM technique to the dual inverter that is cascaded three phases two-level inverter, the current at output side is getting more harmonic distortion which tends to subject into the grid may cause problems. Avoiding such type of in occurrences in the system can be overcome by using the space vector modulation technique for the three-phase cascaded inverter to get appropriate output voltage into the grid. With that, it may be possible to abate the harmonic distortion in the current which is injected into the grid in open loop control manner by adopting a two-level space vector control method.

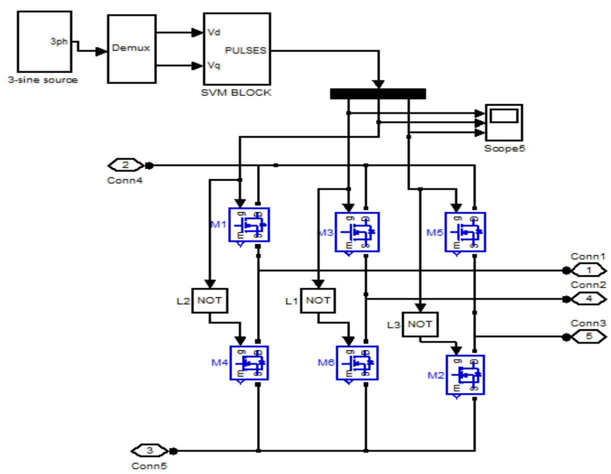


Figure 17: Circuit diagram of three phase inverter1 using SVPWM

FOREX Publication
Open Access | Rapid and quality publishing

International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 10, Issue 3 | Pages 716-721 | e-ISSN: 2347-470X

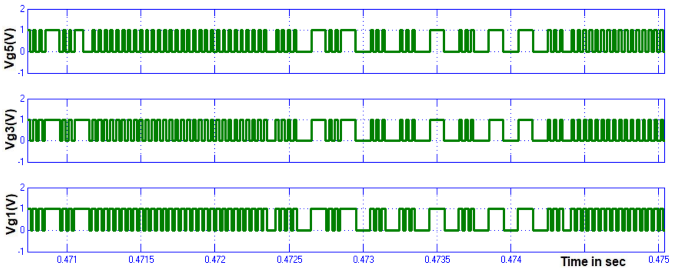


Figure 18: Switching pulse of three phase inverter M1, M3 and M5 using SVPWM

7. SIMULATION RESULTS

The cascaded two three-phase voltage source inverters and quadratic boost converter with PV system interfaced with a grid in an open loop manner are simulated by using MATLAB environment.

7.1 SPWM technique

The line voltages and currents of the two inverters after cascading through the linear transformer to the grid by adopting the sinusoidal pulse width modulation technique are shown in the corresponding figures.

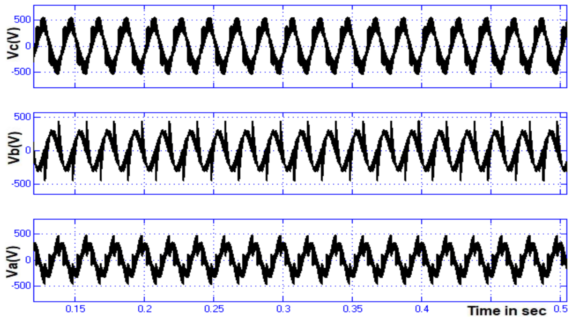


Figure 19: Line Voltages of inverter after cascading by using SPWM Method to the Grid

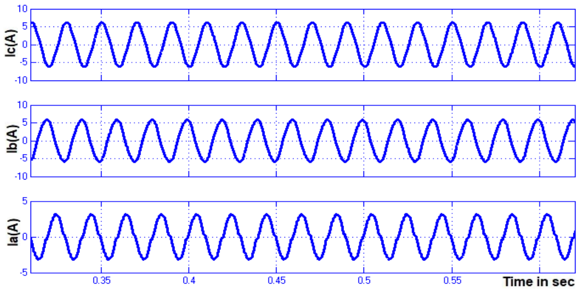


Figure 20: Line Currents injected to grid by using SPWM

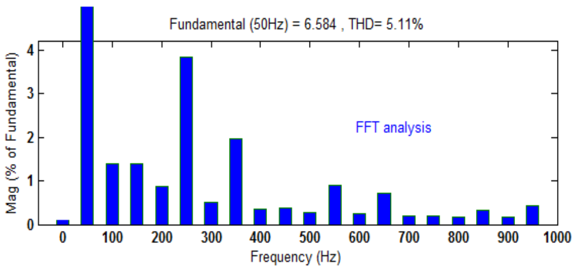


Figure 21: Harmonic distortion (THD) of current at Grid side with SPWM

7.2 SVPWM Technique

The line voltages and currents of the two inverters after cascading through the linear transformer to the grid by using the SV pulse width modulation recipe [14] are shown in the corresponding figures.

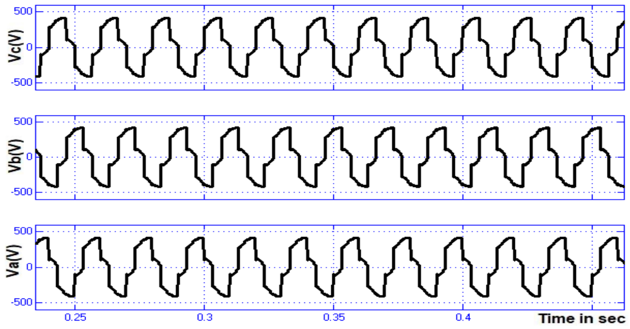


Figure 22: Line Voltages injected to Grid by using SVPWM

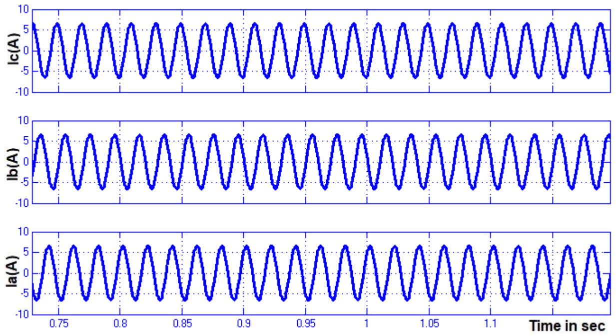


Figure 23: Line Currents injected to grid after Cascading by using SVPWM Method

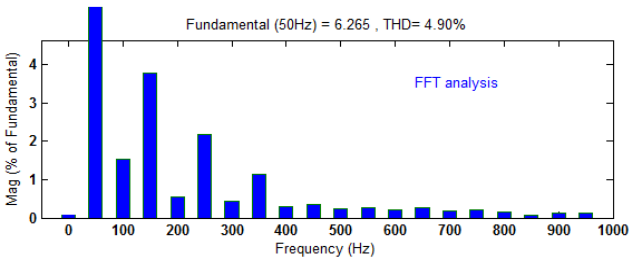


Figure 24: Harmonic distortion (THD) of current at Grid side with SVPWM

The performance across the QBC has been compared in terms of output voltage (Vo), percentage of current harmonic distortion (THD), and output power (Po) with and without a QBC grid-connected PV system. The comparison values are prescribed in *table 1*.

Table 2: Comparison of output voltage, output current THD and output power with QBC and without QBC

Grid connected system	Vin(V)	Vo(V)	Current THD (%)	Po(W)
PV – inverter without QBC	48	200	7.57	300
PV with QBC and inverter	48	415	5.11	1050

FOREX Publication
Open Access | Rapid and quality publishing
International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 10, Issue 3 | Pages 716-721 | e-ISSN: 2347-470X

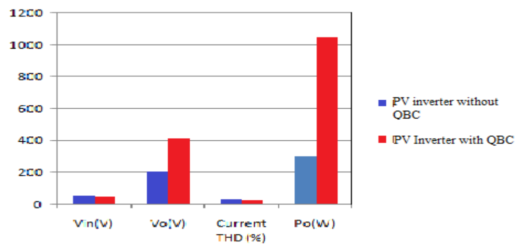
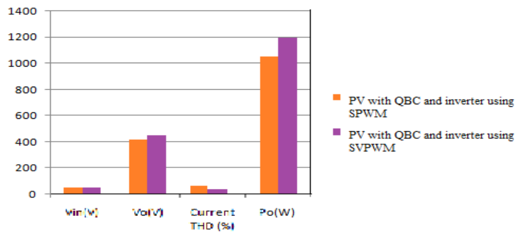


Table 3: Comparison of Vo (V), Total Harmonic distortion in Current and Po (w) of grid connected system

Grid connected system	Vin(V)	Vo(V)	Current THD (%)	Po(W)
PV-QBC and inverter SPWM	48	415	5.11	1050
PV- QBC and inverter SVPWM	48	450	4.90	1200



8. CONCLUSION

In this paper for the Grid-connected PV system, cascaded two level two three phase voltage source inverters are proposed by using quadratic boost converters which enhances the input voltages of the two inverters. With the increase of these voltages the output voltages, and output powers are enhanced and current harmonic distortion (THD) is lowered in the grid-connected system. The sinusoidal pulse width modulation and space vector pulse width modulation is used across the whole grid-connected PV system. By observing these two methods it came to conclude that the THD values are less than 5% by operating the inverters with space vector pulse width modulation and quadratic boost converter for grid-connected systems comparatively with the inverters operating with sinusoidal pulse width modulation approaches.

9. ACKNOWLEDGEMENT

Sincere thanks to my guide Dr. K. Nagaraju, Professor in the EEE department for encouraging and giving technical support for this study.

REFERENCES

[1] Oswaldo Lopez-Santos1, Jonathan C. Mayo-Maldonado2, Julio C. Rosas-Caro3 , Jesus E. Valdez- Resendiz2, David A. Zambrano-Prada1, Omar F. Ruiz-Martinez2 "Quadratic boost converter with low-output- voltage ripple" IET Power Electron., 2020, Vol. 13 Iss. 8, pp. 1605-1612 © The Institution of Engineering and Technology 2020

[2] Abdelkrim Thameur, Bouarroudj Noureddine, Borni Abdelhalim Particle Swarm Optimization of PI Controllers in Grid-Connected PV Conversion Cascade Based Three Levels NPC Inverter 978-1-7281-7455-6/20©2020 IEEE

[3] F. Alongea, M. Puccib, R. Rabbenia,b,∗, G. VitalebDynamic modelling of a quadratic DC/DC single-switch boost converter Electric Power Systems Research 152(2017) 130-139

[4] W. Xiao, M. S. El Moursi, O. Khan and D. Infield, "Review of grid tied converter topologies used in photovoltaic systems", IET Renewable Power Generation, vol. 10, pp. 1543-1551, 11 2016.

[5] Hintz A, Prasanna UR, Rajashekara K (2016) Comparative study of the three-phase grid-connected inverter sharing unbal- anced three-phase and/or single-phase systems. IEEE Trans Ind Appl 52(6):5156–5164

[6] N. Kumar, T. K. Saha and J. Dey, "Sliding-Mode Control of PWM Dual Inverter-Based Grid-Connected PV System: Modeling and Performance Analysis," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 4, no. 2, pp. 435-444, June 2016.

[7] S.Jain, A. Thopukara, R. Karampuri, and V. T. Somasekhar, "A Single-Stage Photovoltaic System for a Dual-Inverter-Fed Open-End Winding Induction Motor Drive for Pumping Applications", IEEE Transactions on Power Electronics, vol. 30, no. 9, pp. 4809-4818, September 2015

[8] F. Alonge, R. Rabbeni, M. Pucci, G. Vitale, Identification and robust control of a quadratic DC/DC boost converter by Hammerstein model, IEEE Trans. Ind. Appl. 51 (5) (2015) 3975–3985.

[9] N. Kumar, T. K. Saha and J. Dey, "Cascaded twolevel inverter based grid connected photovoltaic system:modelling and control", 2014 IEEE International Conference on Industrial Technology (ICIT), Busan, 2014, pp. 468-473.

[10] N. N. V. Surendra Babu and B. G. Fernandes, "Cascaded Two-Level Inverter-Based Multilevel STATCOM for High-Power Applications", IEEE Transactions on Power Delivery, vol. 29, no. 3, pp. 993-1001, June 2014.

[11] T. K. S. Freddy, N. A. Rahim, W. P. Hew and H. S. Che, "Comparison and Analysis of Single-Phase Transformerless Grid-Connected PV Inverters", IEEE Transactions on Power Electronics, vol. 29, no. 10, pp. 5358-5369, Oct. 2014.

[12] Selva Kumar.R, Vignesh C.J,Gayathri Devayanki V.P, Naveena.P Design and Comparision of Quadratic Boost Converter with Boost Converter in: intrtnational journal of Engineering & Technology,Vol. 5 Issue 01,2016

[13] Yang S, Lei Q, Peng FZ (2011) A robust control for grid- con- nected voltage-source inverters. IEEE Trans Ind Electron 58(1):202–212.

[14] B.Mirafzal, M.Saghaleini and A.K.Kaviani, "An SVPWM-based switching pattern for stand-alone and grid connected three-phase single-stage boost-inverters," IEEE Trans. On Power Electron., vol.pp, Oct 2010

[15] J.-P. Gaubert, G. Chanedeau, Evaluation of DC-to-DC converters topologies with quadratic conversion ratios for photovoltaic power systems, in: 13th European Conference on Power Electronics and Applications, 2009, EPE'09, IEEE, 2009, pp. 1–10.

[16] A.M. Hava and E. Ün, "Performance analysis of reduced common mode voltage PWM methods and comparison with standard PWM methods for three-phase voltage source inverters,"" IEEE Trans. Power Electron., vol. 24, no. 1, pp. 241–252, Jan. 2009.

[17] A. Cataliotti, F. Genduso, A. Raciti, and G.R. Galluzzo, "Generalized PWM–VSI control algorithm based on a universal duty-cycle expression: Theoretical analysis, simulation results, and experimental validations," IEEE Trans. Ind. Electron., vol. 54, pp. 1569 2007

[18] Z. Shu, J. Tang, Y. Guo and J. Lian, "An efficient SVPWM algorithm with low computational overhead for three-phase inverters", IEEE Trans. Power Electron., vol. 22, pp. 1797 2007.

[19] S. B. Kjaer, J. K. Pedersen, and F. Blaabjerg, "A Review of Single-Phase Grid-Connected Inverters for Photovoltaic Modules", IEEE Trans. Industry Applications, Vol. 41, no. 5, Sep. /Oct. 2005.

[20] Jin-Woo, "Various PWM control techniques for 3-phase inverters",IEEE Industrial Electronics Society, vol 2.pp 105-110, 2005