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Nine-level Inverter based Solar Power Generation for Micro Grid Application

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Abstract

This paper mainly focuses on to design a nine- level inverter for power generation using solar system to produce a nearly sine wave with reduced total harmonic distortion. The input from PV array is boosted using a dc-dc boost converter and fed into the nine-level inverter as three independent voltage sources. The capacitor selection circuit converts the three output voltage sources into a four-level dc voltage and it is further converted into nine-level ac voltage by full bridge converter. Hence the proposed system generates a sinusoidal output which is in phase with the utility voltage. The advantages of the proposed system is, it uses only nine power electronic switches, which results in reduced voltage stress and reduced total harmonic distortion without using any filter in utility side. Whereas, traditional system uses 16 power electronic switches and four independent dc voltage sources to produce a nine-level output voltage. By using minimum number of power electronic switches, the proposed system is compact and robust.

Keywords: Capacitor Selection Circuit, Nine-level AC Voltage, Nine-level Inverter, Sinusoidal Output, Total Harmonic Distortion

1. Introduction

The large amount of fossil fuel such as crude oil, coal, natural gas leads to the problem of green house gas emissions. Day by day the availability of it will be reduced which leads to increase in cost[1,2]. Therefore migrations to renewable energy sources are necessary. In which solar energy using PV array becomes popular while considering its eco friendly and cost nature. In rural areas, distributed generation using PV array will be maximum utilized for domestic consumers in future. In that aspect, converter plays a major role for DC – AC conversion when PV array output is converted to the direct use of consumers in the grid connected system[3–6]. When the inverter helps in converting DC to AC with the active devices such as power semiconductor switches and passive devices like capacitors, inductors, and resistors produce a power loss. The power loss which obtained due to transistor switches contains both conduction losses and switching losses. Let the conduction loss is due to the use of power semiconductor switches, whereas the switching loss is proportional to the current and voltage variations for each switching frequency[7].

A filter inductor is used to regulate the switching harmonics of an inverter; therefore the power loss is directly proportional to the amount of switching harmonics[8]. So, multi-level inverter technology has been the subject of best research over the past few decades. Theoretically, multilevel inverters should be developed with higher voltage levels in order to improve the power conversion efficiency and to reduce harmonics content and electromagnetic interference (EMI)[9].

Maharjan et al.[10] proposed an Active-power control of individual Converter cells for a battery energy storage system based on a multilevel cascade PWM converter in which a battery energy storage system based on a multilevel cascade Pulse Width-Modulated (PWM) converter was explained. Mastromauro et al.[11] explained control issues on implementation of photovoltaic system. Jinn-Chang Wu et al.[12] proposed A Solar Power Generation

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System with a Seven-Level Inverter which explains the working of a seven-level inverter and its advantages such as reduced switching losses and harmonic distortion compared to the traditional methods. With the help of all these studies and understanding on the scope of reducing harmonic distortion, the proposed study was carried out.

In the upcoming chapters, circuit diagram of the proposed system, modes of operation and simulation results are to be discussed.

2. Circuit Diagram of Nine-level Inverter

The Figure 1 represents the nine-level inverter. It consists of two stage of power conversion as dc to dc and DC to AC. DC to dc power conversion is done by the combination of boost converter and a transformer to convert PV array voltage into three different voltage sources[13]. The combination of capacitor selection circuit and full bridge voltage source inverter produce nine level ac voltages from three level dc voltages.

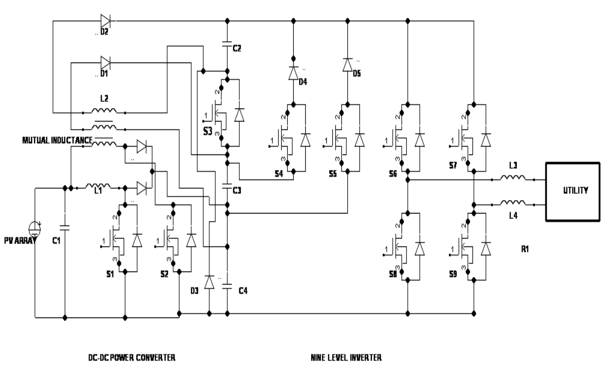

Figure 1. Circuit diagram of nine-level inverter.

3. Modes of Operation

First four modes are positive half cycle of voltage source inverter. Next four modes are negative half cycle of voltage source inverter. Switching operation and corresponding output voltages are shown in Table 1.

Table 1. Modes of operation

Levels	Switching Operation	Output Vg
1	S3, S4, S5 – OFF S6, S9 – ON	Vdc/4
2	S5 – ON S6, S9 – ON	2Vdc/4
3	S5, S4 – ON S6, S9 – ON	3Vdc/4
4	S5, S4, S3 – ON S6, S9 – ON	Vdc
5	Switches OFF; Capacitors Charging	0
6	S3, S4, S5 – OFF S7, S8 – ON	-Vdc/4
7	S5 – ON S7, S8 – ON	-2Vdc/4
8	S5, S4 – ON S7, S8 – ON	-3Vdc/4
9	S5, S4, S3 – ON S7, S8 – ON	-Vdc

Mode 1: ***DC to DC power converter and full bridge inverter operate in first half cycle with no capacitor switches turned ON.***

During this mode switch S1 in the dc to dc converter is turned ON and inductor L1 and capacitor C4 also charging. Capacitor switches S3, S4 and S5 are turned off. The capacitor C2 delivers its stored energy to the load. Voltage source inverter is operated in positive half cycle. During this mode output voltage of Vdc/4 is produced.

Mode 2: ***DC to DC power converter and full bridge inverter operate in first half cycle with one capacitor switches turned ON.***

The only difference between mode 1 and mode 2 is switch S5 turned ON during this mode. The output voltage is Vdc/2 because capacitor C4 also delivers its stored energy to the load via transistor switch S5.

Mode 3: ***DC to DC power converter and full bridge inverter operate in first half cycle with two capacitor switches turned ON.***

In addition to mode 2 switch S4 also turned ON during this mode so the Capacitor C3 also deliver its stored energy to the load. The ouput voltage 3Vdc/4 is produced.

Mode 4: ***DC to DC power converter and full bridge inverter operate in first half cycle with three capacitor switches turned ON.***

In addition to mode 3 switch S3 also turned ON during this mode so the Capacitor C3 and C4 also deliver its stored energy to the load. The ouput voltage Vdc is produced.

Mode 5: ***DC to DC power converter and full bridge inverter operate in second half cycle with no capacitor switches turned ON.***

During this mode Switch S1 in the dc to dc converter is turned OFF and switch S2 turned ON. Inductor L1 and coupled inductor discharging its energy to restore the capacitors C2, C3, and C4. Switches S7 and S8 are turned ON to provide negative cycle for ac load.

Dc to dc converter operation of next three modes is similar to this mode. Capacitor switching of next three modes are similar to Mode 2, Mode 3, Mode 4 respectively. The only difference is here switch S7 and S8 turned ON instead of S6 and S9.

4. Simulation Results and Discussion

The simulation was done using Matlab/Simulink. Switching frequency of the power semiconductor switches used in the capacitor selection circuit, boost converter and full bridge inverter is 100 Hz, 10 KHz, and 20 KHz respectively. The total simulation time is 1 second. The PV array is designed in the simulation using electrical characteristics of solar cell[14]. Solar cells are connected in series to add the voltage and it is connected in parallel to add the current. Powergui block is used to run simpower system elements. Scope and display is used to show the output in graphical and digital values respectively.

4.1 Input Voltage from PV

The PV array produces dc voltage using photovoltaic effect. The PV system produces 90V dc which is shown in the graph (Figure 2). X-axis and Y-axis of the below input and output waveform represents time duration and amplitude respectively.

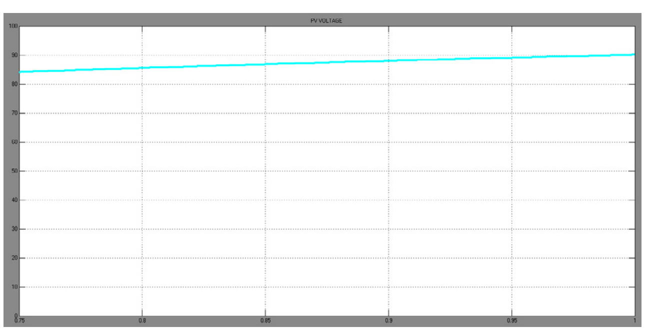

Figure 2. Voltage obtained from solar panel.

4.2 Output Voltage of Capacitor Selection Circuit

Figure 3 represents four level dc voltage obtained from three different voltage sources of dc to dc boost converter using three capacitors and three transistor switches.

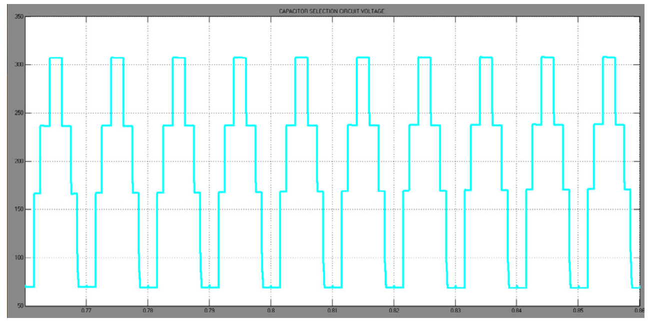

Figure 3. Voltage obtained from capacitor selection circuit.

4.3 Pulse Signal Given to Switches in the Capacitor Selection Circuit

The switch S5 need to turn ON for more time compared with switch S4, The switch S4 need to turn ON for more time compared with switch S3 to produce four level dc voltages. Therefore pulse width of switch S5 is 80%, switch S4 is 60%, and switch S3 is 40% which is shown in Figure 4.

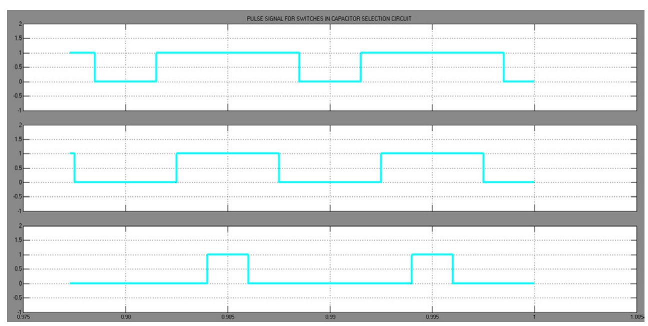

Figure 4. Gate pulse signal given to three switches used in the capacitor selection circuit.

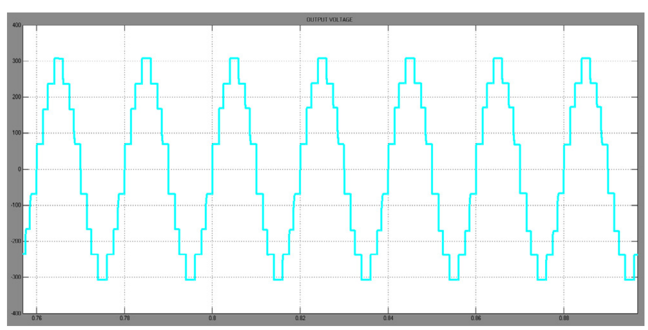

Figure 5. Nine level AC output voltage.

4.4 Output Voltage

The full bridge voltage source inverter converts four level dc voltages into nine level ac voltages as shown in Figure 5. The magnitude of this ac voltage is 300V.

4.5 Output Current

The full bridge voltage source inverter converts four level dc current into nine level ac current, shown in Figure 6. The magnitude of this ac current is 0.5A.

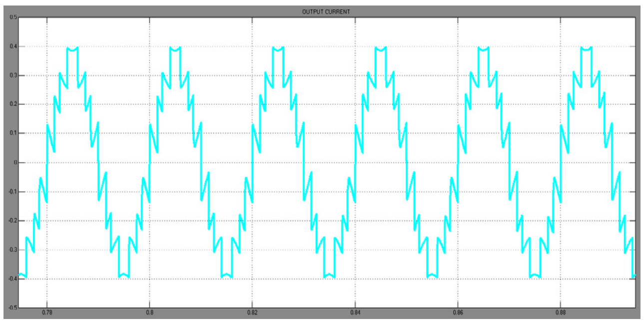

Figure 6. Sinusoidal AC output current.

4.6 Total Harmonic Distortion

The THD of proposed system is only 13.9 percentage compared with existing system which has 22 percentage as shown in Figure 7.

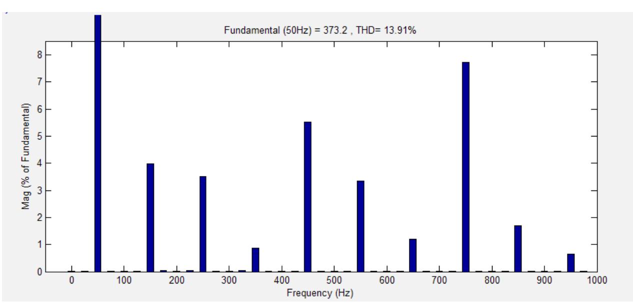

Figure 7. Total harmonic distortion in the proposed system.

5. Conclusion

The proposed work represents the conversion of PV cell generated DC output to the AC which is suitable for the consumer utilities in the grid system. It is achieved by using a DC to DC power converter and a nine level inverter. The circuit configuration is simplified by having seven transistor switches in the inverter proposed. Moreover, the nine level AC output is generated by switching only one metal oxide field effect transistor at high frequency. The improved efficiency and reduced switching loss will be guaranteed with the above setup. Natural balancing takes place in the voltage of the three dc capacitors used in the proposed inverter, which suits the compactness of the control circuit. The above results concludes that the proposed inverter setup helps in generating sinusoidal output is in phase with the utility supply promises to achieve nearby unity power factor.

6. References

1. Mohan N, Undeland TM, Robbins WP. Power electronics converters, applications and design. Media Enhanced 3rd ed. New York, NY, USA: Wiley; 2003.
2. Hasegawa K, Akagi H, Low-modulation-index operation of a five level diode-clamped pwm inverter with a DC-voltage-balancing circuit for a motor drive. IEEE Transactions on Power Electron. 2012; 27(8):3495–505. Crossref
3. Pouresmaeil E, Montesinos-Miracle D, Gomis-Bellmunt O. Control scheme of three-level NPC inverter for integration of renewable energy resources into AC grid. IEEE Systems Journal. 2012; 6(2):242–53. Crossref
4. Srikanthan S, Mishra MK. DC capacitor voltage equalization in neutral clamped inverters for DSTATCOM application. IEEE Transactions on Industrial Electronics. 2010; 57(8):2768–75. Crossref
5. Chaves M, Margato E, Silva JF, Pinto SF. New approach in back-to-back m-level diodeclamped multilevel converter modelling and direct current bus voltages balancing. IET Power Electron. 2010; 3(4):578–89. Crossref
6. Barros JD, Silva JFA, Jesus EGA. Fast-predictive optimal control of NPC multilevel converters, IEEE Transactions on Industrial Electronics. 2013; 60(2):619–27. Crossref
7. Sadigh K, Hosseini SH, Sabahi M, Gharehpetian GB, Double flying capacitor multicell converter based on modified phase-shifted pulse width modulation. IEEE Transactions on Power Electron. 2010; 25(6):1517–26. Crossref
8. Thielemans S, Ruderman A, Reznikov B, Melkebeek J. Improved natural balancing with modified phase-shifted PWM for single-leg five level flying-capacitor converters. IEEE Transactions on Power Electron. 2012; 27(4):1658–67. Crossref
9. Choi S, Saeedifard M. Capacitor voltage balancing of flying capacitor multilevel converters by space vector PWM. IEEE Transactions on Power Delivery. 2012; 27(3):1154–1161. Crossref
10. Maharjan L, Yamagishi T, Akagi H, Active-power control of individual converter cells for a battery energy storage system based on a multilevel cascade PWM converter. IEEE Transactions on Power Electron. 2012; 27(3):1099–107. Crossref

11. Wu J-C, Chou C-W. A solar power generation system with a seven-level inverter. IEEE Transactions on Power Electron. 2014; 29(7).
12. Mastromauro RA, Liserre M, Dell' Aquila A, Control issues in single-stage photovoltaic systems: MPPT, current and voltage control. IEEE Transactions on Industrial Informatics. 2012; 8(2):241–54. Crossref
13. Veeramani G, Kalanithi C, Padmanabhan B. A novel transformer-less three stage interleaved voltage quadrupler DC converter with low switching voltage stress. International Journal of Applied Engineering Research. 2014; 9(25):8704–10.
14. Pereda DJ. High-frequency link: A solution for using only one DC source in asymmetric cascaded multilevel inverters, IEEE Transactions on Industrial Electronics. 2011; 58(9):3884–92. Crossref
15. Pauline AA, Vijayakumar M, Padmanabhan B. Capacitor diode clamped LLC resonant converter for current limiting harmonic approximation. International Journal of Engineering Trends and Technology. 2016 Mar; 33(4):1–5.