Vol. 2 Issue 2, Feb.2012, pp.191-196

Modeling and Simulation Analysis of Seven Level Cascaded Multi String Inverters for Grid Integrated Systems

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Abstract: This paper presents the performance analysis of five levels and seven levels multi-string inverter using different PWM method. The proposed system components are modeled and simulated through computer software tool using MATLAB/SIMULINK. This work also describes the development of design, modeling and simulation of seven level multi-string inverters topology for industrial drive systems. The multi-string inverter based system gives better voltage regulation and efficiency compared to multi-level inverters. The output voltage of the drive system can be controlled and the THD reduced by using space vector modulation method. The advanced switching technique can be implemented for reducing the THD. A filter is also used in the output side to further reduce the harmonic values.

Keywords: Pulse Width modulation (PWM), Space Vector Modulation (SVM), Total Harmonic Distortion (THD), Photo Voltaic (PV) Source, Maximum Power Point (MPP).

1. Introduction

As the world is concerned with the fossil fuel exhaustion and environmental problem caused by conventional power generation, particularly solar have become very popular and demanding. PV sources are used in many applications because they have advantage of being maintenance and pollution free. It is used to convert the dc power from solar module to ac power to feed into load or grid. Multi-string inverter is used for PV application[3]. The multi-string inverter is a further development of string inverter. This report is the study of improvement of five level multi-string inverter to seven level multi-string inverter and the conventional and proposed multi-string inverters are implemented in different PWM techniques and its results are analyzed to get best PWM techniques for 5 level and 7 level multi-string inverter. The PWM techniques implemented in this paper are novel PWM technique and space vector modulation technique. These 5 levels and 7 levels multi-string inverter are connected to the grid load and its harmonics are calculated and it is tabulated [2]. The purpose of work is to provide the capability of design, modeling, simulating and analyzing the dynamic performance of 5 level and 7 level multi string inverter using two different PWM techniques using MATLAB/SIMULINK. The multi-string inverter is more advantageous than multi-level inverter while using in PV application. The advantage of multi-string inverter is it is low cost, high efficient, easy to work with PV application[1]. The auxiliary switch plays a major role in the proposed work. The objective of the project is to, improve the five level multi-string inverter to seven level multi-string inverter, comparison and analysis are made for grid connected. Two different PWM technique 1) novel PWM 2) space vector PWM are used in the 5 level and 7 level multi-string inverters and finding out best PWM technique which gives less total harmonic distortion, better load voltage and current.

2. Circuit Description of the Proposed System

This proposed circuit consists of a PV string, DC bus, Auxiliary circuit and single-phase multi-string five-level inverter. It consists of three strings of PV arrays connected to their own DC - DC boost converter. An auxiliary circuit comprising four diodes and a switch is configured together with a conventional full-bridge inverter to form this topology[4]. The block diagram of the proposed circuit is shown in Fig 2.1. The proposed inverter is used in a grid-connected PV system; the utility grid is used instead of a load. The dc–dc boost converters are used to track the Maximum power point (MPP) independently and to step up inverter output voltage. The multi-string approach is adopted because each dc–dc converter can independently perform MPP tracking (MPPT) for its PV strings. This will compensate for mismatches in panels of like manufacture, which can be up to 2.5%.

The dc–dc boost converters are connected in parallel to avoid high dc-bus voltage, which will eventually increase the size of the capacitors and the inverter's cost[6]. Therefore, only two capacitors with equal capacitance rating are used as the dc bus, and the other dc–dc boost converters are connected to this dc bus.

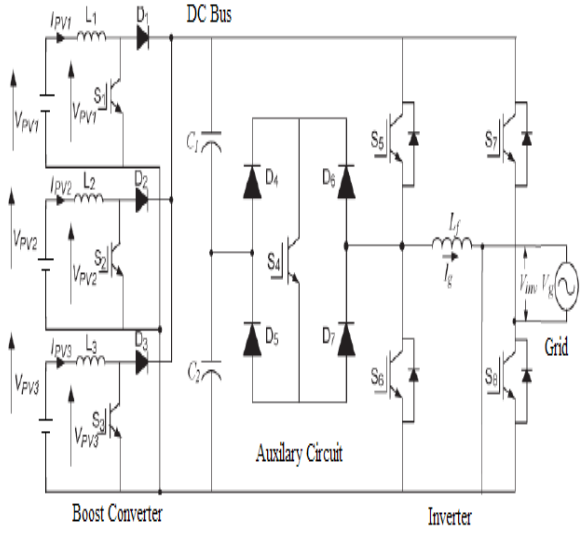

Fig 2.1 Circuit diagram of multi-string inverter

3. Seven Level Multi-String Inverter Topology

The five levels multi-string inverter will have lot of drawbacks like large size filter, high harmonics and high electromagnetic interference. This can be reduced by using 7 levels multi-string inverter. The seven levels multi-string inverter consists of two auxiliary switches. The auxiliary switching of seven levels multi-string inverter is given below figure 3.1.

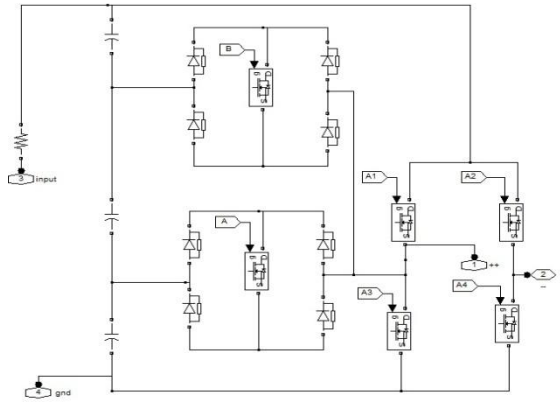

Fig 3.1 Auxiliary switch of the proposed multi-string inverter

The seven level multi-string inverter will gives better operation and efficiency compared to the five level multi-string inverters[8]. The improvement of level will improve the efficiency of the system and reduce the total harmonic distortion .the block diagram of seven level multi-string inverter is given below fig 3.2

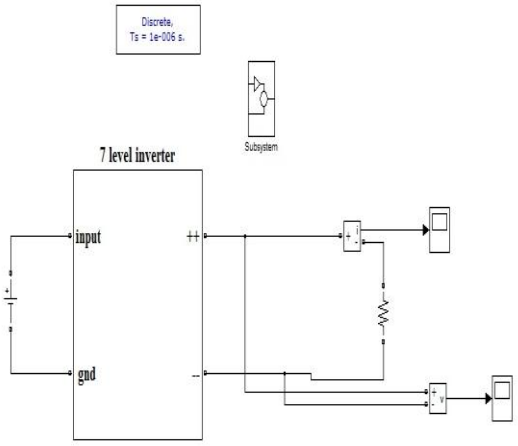

Fig 3.2 Block diagram of proposed multi-string inverter

	S4	S5	S6	S7	S8	S9
VS	off	off	on	off	Off	on
VS/3	off	on	off	off	Off	on
2VS/3	on	off	off	off	Off	on
0	off	off	on	on	Off	off
-VS/3	off	off	off	on	On	off
-2VS/3	off	on	off	off	On	off
-VS	on	off	off	off	On	off

Table 3.1 Truth table for the seven levels multi-string inverter

The truth table 3.1 is given the switching operation of the seven levels inverter. The switching time taken in this truth table is V_S, $V_S/3$, $2V_S/3$,0,$-V_S/3$,$-2V_S/3$,$-V_S$. The switching operation of the above period will be on and off according to the input need to be given. In space vector modulation the input can be given as the truth table[5]. The on and off can be done according the output required.

4. Space Vector Modulation Control Strategy

Space vector modulation (SVM) is an algorithm for the control of pulse width modulation (PWM). It is used for the creation of alternating waveform (AC) waveform. It most commonly used in inverters, 3 phase ac powered motors [7]. There are various types of SVM that result in different quality and computational requirements. One active area of development is in the reduction of total harmonic distortion (THD) created by the rapid switching inherent to these algorithms. With the increase of levels, traditional approaches of SVM based on five-level or seven level inverters are hardly realized. Some modified methods have been proposed to approach the SVM of inverter with any levels. One of them is carrying out the SVM in 60-degree coordinates. This section will outline this SVM scheme. Any three-phase system (defined by ax(t), ay(t) az(t)) can be represented uniquely by a rotating vector as ,

$$a_S = \frac{2}{3}\cdot\left[a_X(t) + a\cdot a_Y(t) + a^2\cdot a_Z(t)\right] \quad (1)$$

Given a three-phase system, the vectorial representation is achieved by the following 3/2 transformation:

$$\begin{bmatrix} A_\alpha \\ A_\beta \end{bmatrix} = \frac{2}{3}\cdot\begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix}\cdot\begin{bmatrix} a_X \\ a_Y \\ a_Z \end{bmatrix} \quad (2)$$

Where (Aα, *A*β) are forming an orthogonal 2-phase system and *aS* = *A*α + *j* . *A*β . A vector can be uniquely defined in the complex plane by these components. The reverse transformation (2/3 Transformation) is given by

$$\begin{cases} a_X(t) = \mathrm{Re}\left[a_S\right] + a_0(t) \\ a_Y(t) = \mathrm{Re}\left[a^2\cdot a_S\right] + a_0(t) \\ a_Z(t) = \mathrm{Re}\left[a\cdot a_S\right] + a_0(t) \end{cases}$$

$$a_0(t) = \frac{1}{3}\cdot\left[a_X(t) + a_Y(t) + a_Z(t)\right] \quad (3)$$

It represents the homopolar component. It results a unique correspondence between a Space Vector in the complex plane and a three-phase system. The method of choosing active vectors is the same regardless of which SVM algorithm is used.

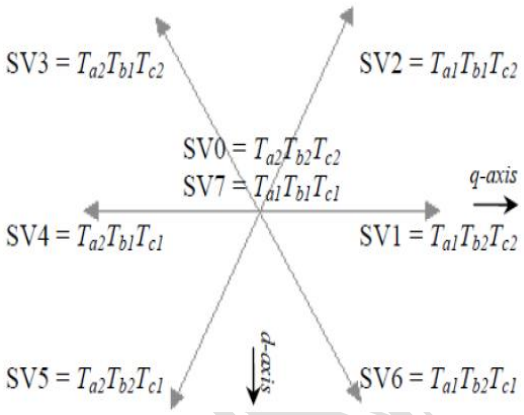

Fig. 4.1 Space vector d,q-axis locations and their corresponding closed switches

The MATLAB/ SIMULINK for the space vector modulation is designed as subsystem and it is implemented in seven level multi-string inverter. The subsystem of the space vector system is given below figure 4.2. The subsystem explains about the truth table developed for the seven levels multi-string inverter. The 1 will mention switch is in on state and if it is 0 then the switch is in off condition. According the output required the switching is done. As mentioned in below diagram.

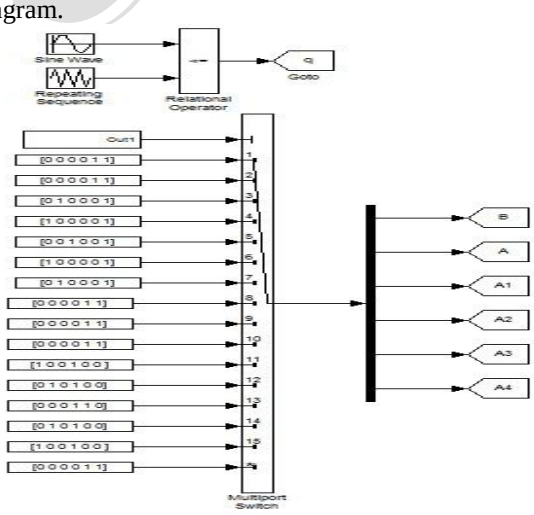

Fig 4.2 Simulink for space vector modulation

5. Results and Discussion

The seven level multi-string inverters operation and its results at various load condition like R, RL, RLE are studied and discussed below. The operation of various PWM techniques is implemented and its operation also studied below. The block diagram of seven level multi-string inverter using RLE load simulink is given in below figure 5.1.

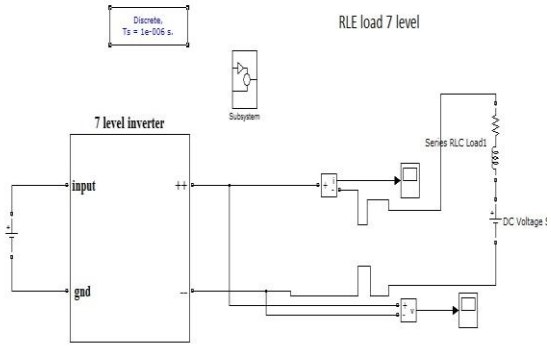

Fig 5.1 Simulink model of the proposed seven level multi-string inverters

The simulink output voltage and current are taken for the seven levels multi-string inverter is taken and its graph is taken and its waveform is given below figure 5.2 and 5.3. The seven level multi-strings which convert the input voltage 230v dc input to the 230v ac output with reduced amount of harmonics compared to the multi-level inverter.

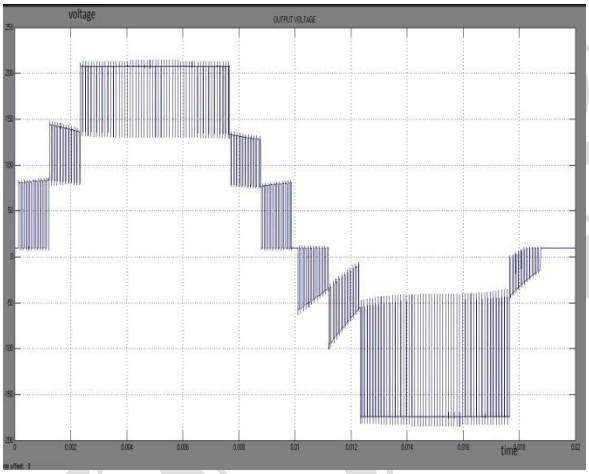

Fig 5.2 Output voltage for RLE load seven level multi-string inverter

The current waveform for the seven level multi-string inverter are given as below

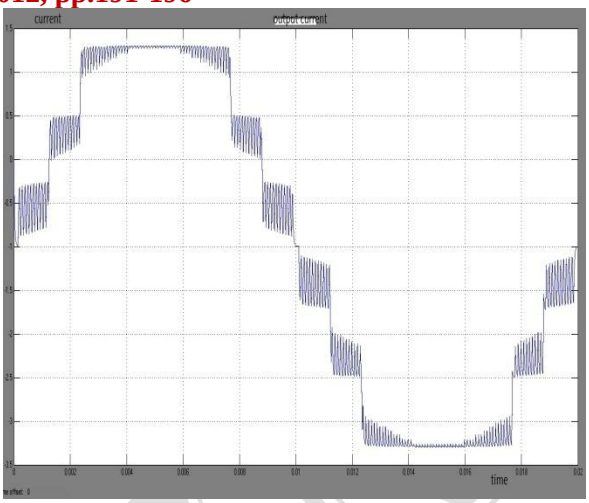

Fig 5.3 Output current for RLE load seven level multi-string inverter

The total harmonic distortion of the seven level multi-string inverters is taken for voltage and current harmonics, and its output is tabulated below. The total harmonic distortion for voltage, current, with filter and without filter is taken and their outputs are tabulated and its results are presented below.

Multi-string inverter	R Load	RL Load	RLE Load
5 Level	11.27%	15.79%	25.33%
7 Level	6.54%	8.79%	19.48%

Table 5.1 Comparison table for 5 level and 7 level multi-string inverter (for voltage)

Multi-string inverter	R Load	RL Load	RLE Load
5 level	9.76%	14.38%	26.61%
7 level	5.75%	9.36%	18.23%

Table 5.2 Comparison table for 5 level and 7 level multi-string inverter (for current)

The above tables 5.1 and 5.2 deals with the comparison of five levels and seven levels multi-string inverter without filter. While studying the table, we can justify that the seven level multi-string inverter will gives low harmonics compared to the five levels multi-string inverter. The THD simulink output waveform with for

the seven levels multi-string inverter is given below figure 5.4.

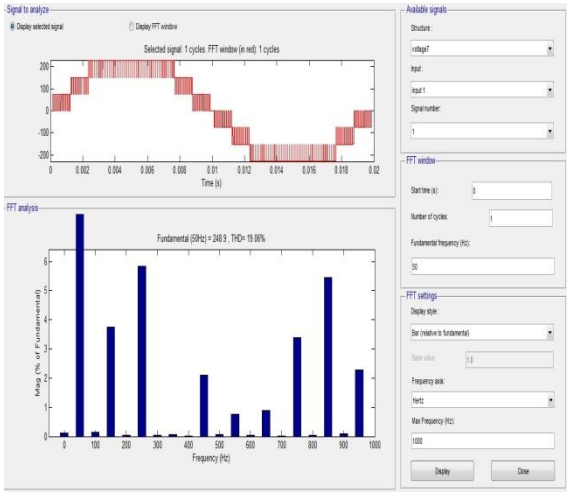

Fig 5.4 Voltage THD value for seven levels multi-string inverter (voltage)

The THD value of the seven level multi-string inverter for voltage is 19.06% , and the current THD value is 18.23%. These outputs are taken without the usage of the filter. When we use the filter the harmonics in the output will be still reduced. The output of the seven level multi-string inverter using filter we get 5.93%. The result of using filter is given below.

Multi-string inverter	R Load	RL Load	RLE Load
7 level	3.12%	4.75%	5.93%

Table 5.3 Tabulation for seven levels multi-string inverter with filter (for voltage)

Multi-string inverter	R Load	RL Load	RLE Load
7 level	3.75%	4.96%	6.21%

Table 5.4 Tabulation for seven levels multi-string inverter with filter (for current)

6. CONCLUSION

Seven level multi-string inverters is the best suited topology for the dc to ac conversion .space vector modulation technique is better PWM ,which gives low total harmonic distortion (THD) compared to novel PWM technique. The switching operation is sophisticated and gives better output in space vector modulation. In seven level multi-string inverters due to the better ac to dc conversion the harmonic losses will be totally reduced. The heating of industrial drives will also reduce, so that the industrial drive operates with the better efficiency. Both PWM compared and we get low harmonics for current and voltage in seven level multi-string inverter. Hence we require small size filter in proposed method. So it is better to prefer, seven levels multi-string inverter for industrial drives to get low cost, easy operation, high efficiency, and reduced THD.

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ACKNOWLEDGEMENT

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