Performance Analysis of a Solar PV based Grid Tied Multilevel Inverter Scheme for Linear and Non Linear Load

Mohmmad Ahmad, Sheeraz Kirmani

Abstract: This paper presents the performance of Solar Photo Voltaic (SPV) based grid connected multilevel inverter scheme having linear and nonlinear load connected at the Point of Common Coupling (PCC). Initially the analysis was carried out for the complete inverter circuit resulting in a slightly higher harmonics in PCC voltage and current, which can be further reduced to a lower value by connecting a filter. For a linear RL load, due to the filter, the THD in PCC voltage is reduced from 13% to below 5% (IEEE standard) and the THD in grid current decreases to below 5% from 14.8%. Similarly for a nonlinear load at PCC, a Diode Bridge, the harmonics in PCC voltage and the grid current can be further reduced to the lower level by connecting filter. The results obtained from simulation using SIMULINK/MATLAB Software are tabulated for SPV based grid tied system and also explained graphically.

Keywords: Total Harmonic Distortion (THD), multilevel inverter, Power Quality, Grid connected Solar PV

I. INTRODUCTION

With more demand for electricity, continuously raising fuel costs and more concerns of global climate change have leads to more and more use of renewable energy sources. These energy resources have got more fame due to the depletion of non-renewable energy sources and their adverse impact on the environment. The energy extracted from Solar is one of the alternative renewable energy sources. In case of solar PV, the energy is collected as dc which, further can be converted into ac by the use of inverter and then subsequently fed to utility grid or it may be used in isolated load. The inverter output can be fed to the grid as well as standalone system. The main objective of Grid connected SPV system is to supply the local loads and any surplus power generation have to be injected into the grid [1].Nowadays solar photo voltaic power based grid connected system becomes more popular. The different types of grid-connection of SPV inverters have been elaborated and discussed in [2-5]. Grid integration of solar power generation system has the advantage of most effective utilization of the generated energy. But the technical requirements of both SPV system side as well as utility grid side need to be satisfied for the safety of the Solar PV installer as well as for the reliability of the grid [6].

Nowadays, the problems related to Power quality become of more concern in the distribution system due to the decrement in the efficiency of the system. These problems exist in the system because of more and more uses of non-linear loads such as renewable energy systems, solid-state devices, HVDC transmission etc., injecting the harmonics into the system leads to the degradation the power quality.

Various power electronics techniques are available for conversion of dc to ac with improved power quality. Multilevel inverter topologies have been introduced in literature [7-8], generating a staircase like voltage and current waveform.There are some considerable multi-level inverter types available like the cascaded H-Bridge, diode clamped, flying capacitor, magnetic coupled etc. The main feature of these inverters has to generate minimum harmonic components in load voltage as well as in load current. More the number of levels in the output voltage, lesser will be the harmonics and hence the THD. Further the level number can easily be increased resulting in the reduction of voltage stress. Hence, the output voltage wave shape shifts towards to the sinusoidal waveform. The power quality can be achieved better with the more number of levels in the voltage and current waveform [9-11].

In this paper a multi-level inverter circuit for the performance analysis of single phase SPV system is presented. The poor power quality waveform of PCC voltage and grid current, caused by injection of non-linear load, is improved, Further the harmonics are reduced again by using a filter so as to keep the harmonics content within the specified IEEE standard range (<5%).

II. MULTILEVEL INVERTER TOPOLOGY

This multi-level inverter circuit comprises of Solar PV array as input dc voltage source, Level Modules, a step up transformer, H-Bridge inverter, a grid through a small transmission line having negligible resistance along with small inductance in series. This inverter circuit with solar PV Module/Array as dc source with three level modules is shown in Fig 1. As shown in the figure, the grid along with small RL, is connected at the inverter output i.e. between point A and point B. A linear/nonlinear load has been connected between point A and B. The level of output voltage wave has the relationship with level modules connected in the inverter circuit [12-13].

The number of output Levels will be represented as:

$$N = 2^{(m+1)} - 1 \quad \ldots\ldots\ldots\ldots \quad (1)$$

where m represents the Level Modules number.
And the number of connected switchesin the circuit is given by:

$$n_s = 2 * m + 4 \quad \ldots\ldots\ldots (2)$$

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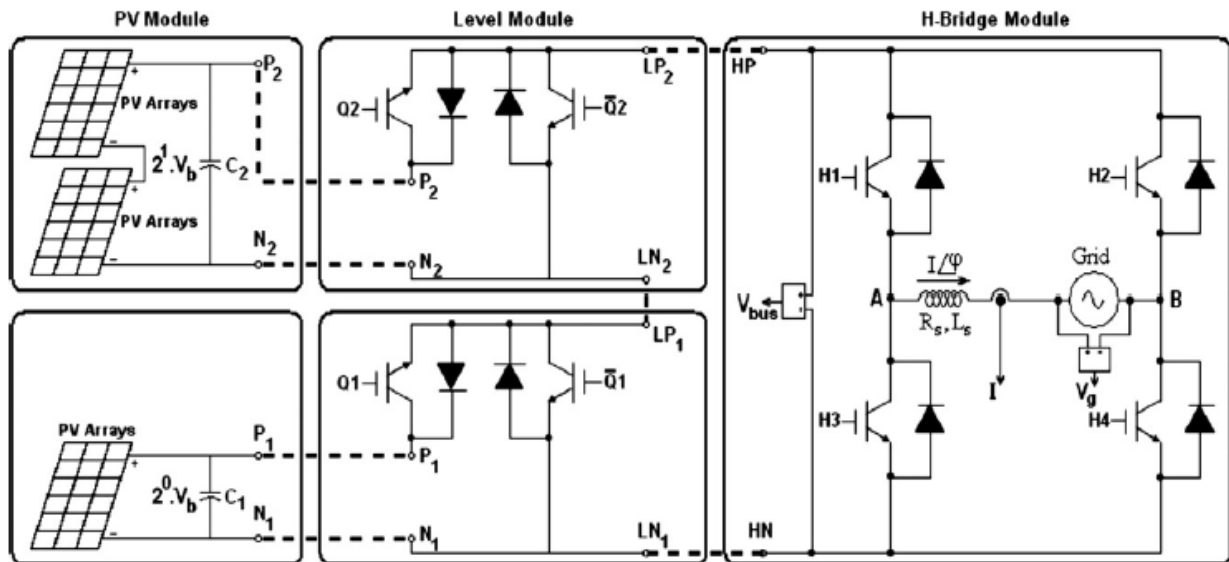

Fig 1.Multi-level Inverter circuit with two level module for grid connected solar PV system

The dc input voltage given to i^{th} module number varies with the particular module no. as:

$$V_i = 2^{(i-1)} \cdot V_b \dots\dots\dots\dots\dots (3)$$

where i = 1, 2, 3 …. m

In the inverter circuit, three Solar panel of output voltages $V_1 (= V_b)$, $V_2 (= 2 V_b)$ and $V_3 (= 4V_b)$, three Level modules (LM) and one H-Bridge inverter are used. Output voltage and current waveform has 15 levels and the total no. of connected switches are 10. The total input dc voltage given to the inverter circuit is $7 V_b$. The simulation has been carried out for the value of V_b as 18 Volt. A PV array is defined as a combination of series and parallel connection of solar PV cells [14].

III. RESULTS AND DISCUSSION

1.1 Grid connected inverter with linear load

3.1.1 Grid connected system without filter

The inverter output voltage, received across the ac load/grid, is now stepped up using a step-up transformer, of which the secondary winding connected to the utility grid (connected between point A and B in Fig. 1) with a small transmission line in series having small inductance along with negligible value of resistance. The linear (RL) load may be connected in parallel with the grid or at point of common coupling (PCC) [15].

The ratings and different parameters values are as follows:
Solar PV Voltages: $V_1 = 18V$, $V_2 = 36V$, $V_3 = 72V$,
Grid Data: RMS grid voltage Vg = 230 V, small RL in series with grid: L = 25 mH, R = 0.5 Ω.
Impedance of Linear RL load taken as Z=25 Ω.
Transformer rating: Single phase, 50 Hz, 500 kVA, 200/600 V.

The inverter output voltage at transformer's secondary side is kept slightly greater than the rms value of grid voltage so as to ensure the power transfer from inverter side to the grid side.

Table 1 shows the variations of THD along with the RMS values of grid voltage/PCC voltage, load current and grid current with the variation of power factor of the load. This can be said from the table that the THD in PCC voltage (13%) and grid current (14.8%) are found almost constant with the variation of power factor, whereas the load current THD becomes worsened with the increment in load power factor. This above harmonics values are obtained when the system does not have a filter.

The variation of inverter output voltage, load voltage and current, grid voltage and current has shown graphically in Fig 2 at 0.8 load power factor with a load disconnection from 0.04 s to 0.08 second.

Table 1. Simulation results for grid tied inverter having linear load without filter

S. No.	Load Power Factor	Load/PCC Voltage		Load Current		Grid current		DC Input Power	Power to Load		Power to Grid	
		RMS (V)	THD (%)	RMS (A)	THD (%)	RMS (A)	THD (%)	P_{dc} (W)	P_L (W)	Q_L (VAr)	P_g (W)	Q_g (VAr)
1	0.7	239.4	13.2	9.5	4.5	6.9	14.8	6075	1577	1608	3404	861

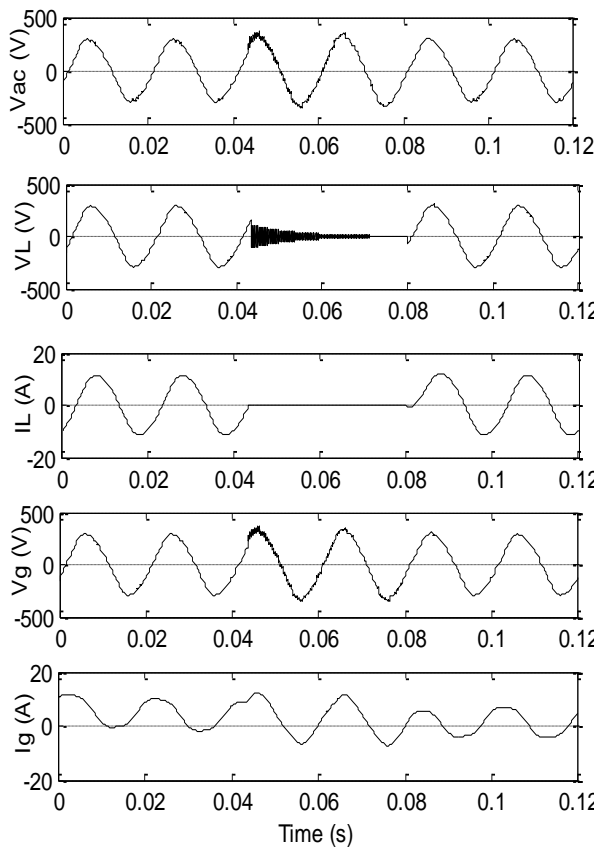| 2 | 0.8 | 239.4 | 13.2 | 9.5 | 5.1 | 6.9 | 14.8 | 6296 | 1803 | 1351 | 3399 | 858 |
| 3 | 0.9 | 239.4 | 13.2 | 9.5 | 6.4 | 6.9 | 14.8 | 6508 | 2028 | 982 | 3411 | 856 |
| 4 | 1 | 239.4 | 13.1 | 9.5 | 13.1 | 6.9 | 14.8 | 6695 | 2260 | 0 | 3405 | 863 |

Fig 2. Waveforms at 0.8 load power factor Without LC filter

3.1.2   Grid connected system with Filter

The same solar PV based grid tied inverter circuit, having R-L load at PCC, has been again analyzed after connecting LC filter between inverter and PCC. Table 2 shows the results obtained from simulation with the variation of load power factor. It can be concluded from the table that the THD in grid current, load current and PCC voltage falls down below 5 %, and the minimum harmonics in the grid current is achieved at around 0.9 power factor. This can be seen from the table that as the LC filter is connected, the transfer of power is from grid to inverter instead of injecting into the grid from inverter, as the sign of active power and reactive power becomes negative.

The variation of inverter output voltage, load voltage/PCC voltage and current, grid voltage and current has been shown in Fig 3 at 0.8 power factor load with a load disconnection from 0.04 s to 0.08 s.

3.2   Grid tied inverter having nonlinear load at PCC

3.2.1 Grid connected system without filter

The grid tied solar pv system is now analyzed having a nonlinear load of diode bridge, which is connected at the PCC without the LC filter. The nonlinear load of Diode Bridge consists of R and L on its dc side with the values of 20 Ω and 5 mH respectively. Fig 4 depicts the variation of load voltage, load current, PCC voltage, grid current when the load is disconnected from 0.04 to 0.08 second.

3.2.2   Grid connected system with filter

If a filter is connected in the grid connected system having nonlinear load, then the harmonics in the voltage across grid and the current through grid become too low resulting in a better power quality.

The different waveforms are shown in Fig 5 with a load disconnection. It can be seen from the figure that there are some fluctuations measured during the load disconnection.

Table 2. Simulation results for grid tied inverter having linear load with filter

S. No.	Load Power Factor	Load/PCC Voltage		Load Current		Grid current		DC Input Power Pdc(W)	Power to Linear Load		Power to Grid	
		RMS (V)	THD (%)	RMS (A)	THD (%)	RMS (A)	THD (%)		P (W)	Q (VAr)	P (W)	Q (VAr)
1	0.7	195	9.6	7.8	1.9	5	7.8	1260	1057	1081	-123	-867
2	0.8	199	5.8	7.9	1.6	4.7	6.6	1323	1267	943	-270	-780
3	0.9	204	3	8.1	1.5	4.4	5.8	1404	1503	729	-432	-630
4	1	223	2.4	8.9	2.4	4.1	7.1	1595	1995	0	-744	-104

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14.8 % in grid current, but with filter it falls down to 2.4 % in load voltage and 5.8 % in grid current respectively.
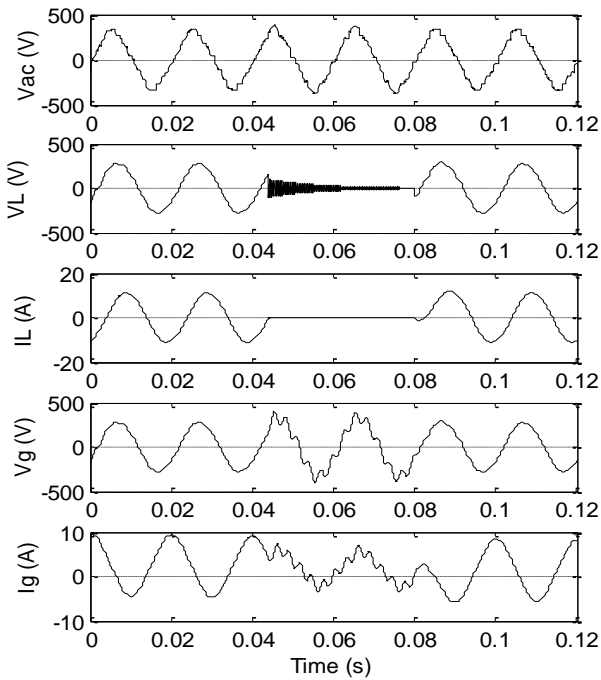

Fig 3. Waveforms at linear load at 0.8 load power factor With LC filter
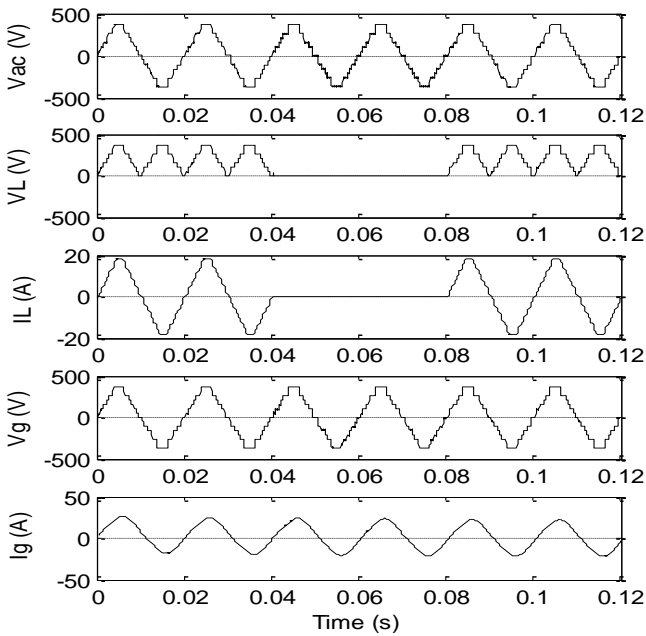
Fig 4. Waveforms without filter at non-linear load disconnecting from 0.04 s to 0.08 s
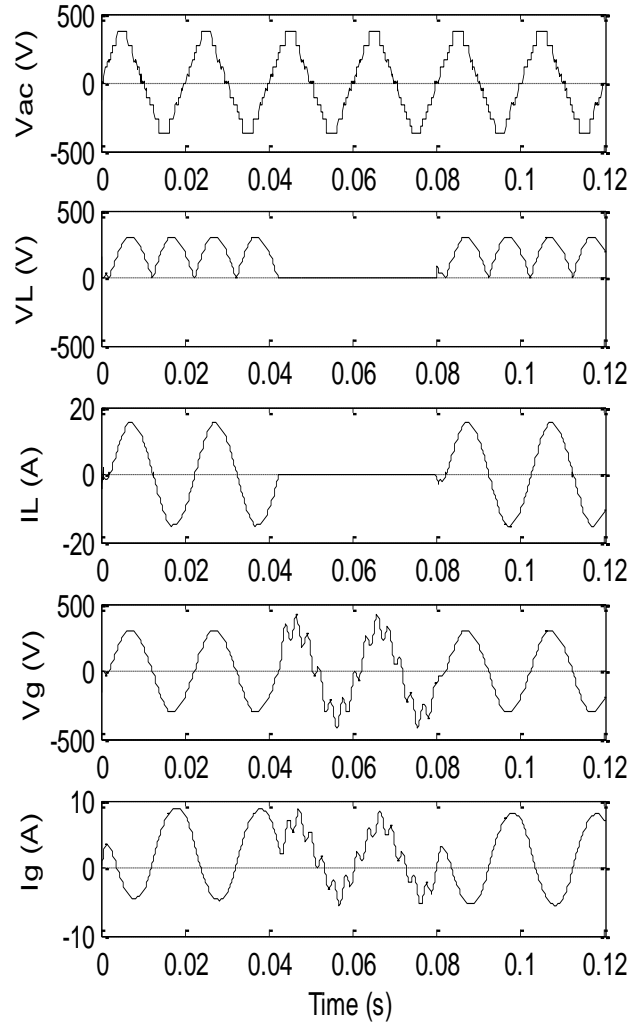

Fig 5. Waveforms with filter at non-linear load disconnecting from 0.04 s to 0.08 second
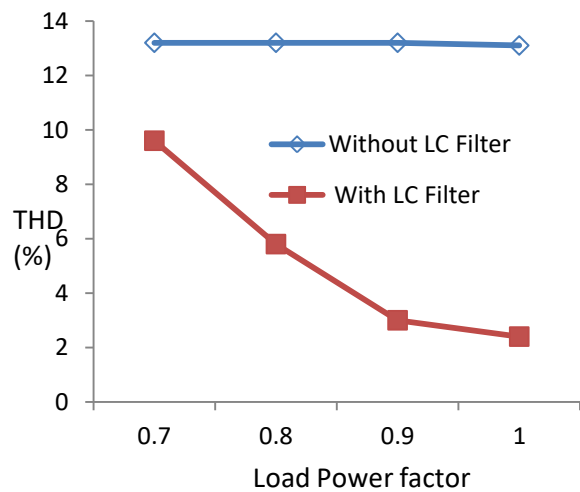
Fig 6. Variation of THD of PCC voltage with load power factor

IV.   HARMONIC COMPARISON

1.2 Grid connected PV system having linear load: With and without Filter

Table 1 & 2 demonstrates the circuit performance for Solar PV based grid tied system having linear RL load connected at PCC without and with filter respectively. Fig 6 and 7 shows the variation of THD in Load/PCC voltage and grid current of the circuit with and without filter respectively. These figures depict that the harmonics contents become very less when the LC filter is connected in the circuit. Without filter these figures were 13.2% in load voltage and
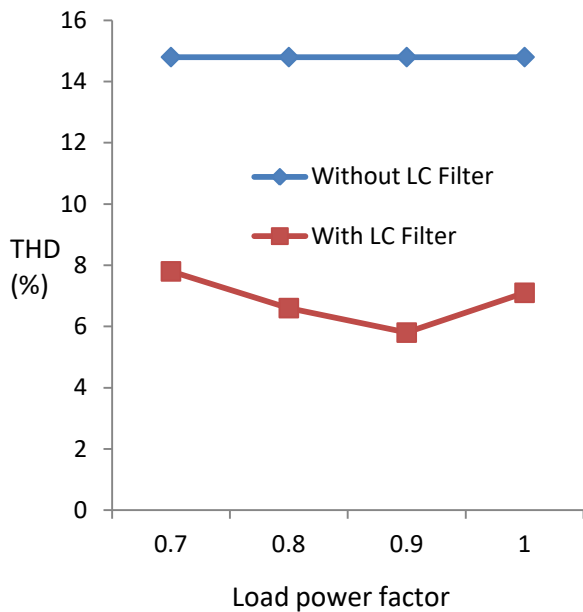
Fig 7.Variation of THD of grid current with load power factor

1.3 Grid Tied system having nonlinear load of diode bridge: With and without Filter

Table 3 shows the harmonics component analysis for the inverter circuit consisting filter and without the filter. There exist many significant changes in the THD of different parameters, as the filter is got connected. The Load/PCC voltage as well as grid current both the values reaches below 5 % and hence enhances the power quality at the grid side.

Table 3. Harmonic variation for grid tied inverter having non-linear load with and without filter

S. No.	Parameters	THD (%)	
		Without Filter	With filter
1	Inverter Output Voltage	13.1	13.3
2	Inverter Output current	6.9	4.6
3	Load / PCC voltage	13	3.2
4	Load current	10.8	2.3
5	Grid current	6.9	4.5

V. CONCLUSION

In this paper, harmonic analysis is described for grid tied multilevel inverter circuit (with and without filter) through step up transformer for Solar PV as dc source. Multilevel inverter topologies are used to generate high quality waveforms by forming higher number of levels.

For grid connected solar PV system having linear and nonlinear load connected at PCC, the variation of THD in inverter output voltage, PCC voltage, load voltage, load current and grid current along with the power send to the load as well as grid are shown graphically with the variation of power factor of the load. The THD in grid current, PCC voltage was found as large as 13 %. These harmonics further reduced to below 5 % (as per IEEE standard) by connecting a filter between inverter output and the grid. The obtained results are tabulated and also elaborated graphically.

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