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Research Article

Harmonic Analysis of Solar Power Based Grid Connected System using MATLAB/SIMULINK

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Abstract

The present work deals with the reduction of harmonics which is produced by non-linear loads when connected with PV integrated grid connected system. Two PV sources are considered and they are synchronized with grid where inverter control for a one PV is given with the use of PLL technique and another PV inverter control is not a PLL dependent. Two PVs grid integrated system is then tested by connecting linear and non-linear load. The harmonics created by non-linear load is reduced by using passive LC filter. The model is executed in simulation and the THD content is determined by FFT analysis in MATLAB/SIMULINK.

Keywords: Grid connection; PV integration; Harmonics; Simulation; Grid synchronization.

Introduction

Power Quality is an inevitable parameter to be considered when renewable energy sources are integrated to the grid. [1]. To supply a clean and stable power to the grid possess a great challenge by power quality issues. [2,3,4]. Among that harmonics gives a potential threat to grid stability by causing poor power factor, equipment heating, equipment failure, dielectric breakdown in insulation, interference with telecommunication etc [5,6]. Harmonics are regarded as the integer multiples of fundamental frequency and some examples are 3rd (3x50=150 Hz), 5th (5x50=250Hz), 7th (7x50=350Hz) etc. [7]. Harmonics are created and produced by non-linear loads connected to the system. Some of the non-linear loads are domestic loads such as computers, printers, discharge lighting and some of the non-linear loads utilize power semiconductor devices used for converting power such as DC to AC, AC to AC, DC to DC and AC to DC converters [8,9]. Since non-linear loads draw currents in non-sinusoidal pulses, it produces current harmonics [5,10]. The voltage harmonics are induced by current harmonics [11]. However current harmonics only have impact on non-linear loads which are producing them but the voltage harmonics affects the entire grid connected system [12,13]. Therefore implementation of filter is necessary while connecting non-linear loads. Among many types of filter used for mitigating harmonics, here passive LC filter is used [14]. Passive filter is the combination of passive components like inductance, capacitance and by tuning the inductance and capacitance values the harmonics are mitigated [15].

Methodology

Grid connected photovoltaic system

PV is integrated with the grid via inverter called grid tie inverter. The inverter is used to convert the DC produced by PV panel in to AC. The basic photovoltaic structure is given below in fig. 1. Standalone PV system uses battery to store the DC but grid connected PV system rarely uses battery.

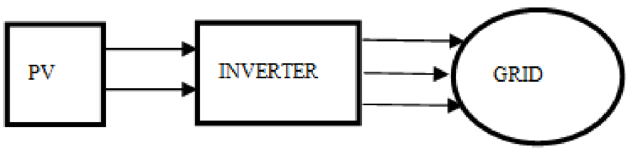

Fig. 1. Photovoltaic System Structure

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The inverter may use IGBT/MOSFET switches and the gating pulse for the inverter is provided by PWM generator. The synchronization will be better if Phase Locked Loop (PLL) is used in generating pulses for inverter.

Proposed PV grid connected system

The proposed system is consisting two solar sources, PWM inverters, load and three-phase grid supply. PV source 1 is a 415 W panel and PV source 2 is 54 W panel. PV source 1 DC output is converted into AC by a 3-Level IGBT Bridge inverter. Inverter control is provided with the use of PLL. PV source 2 DC output is converted into AC by using PWM inverter. Source 1 and source 2 outputs are stepped up to 125 KV and synchronized with 125 KV grid as shown in fig. 2.

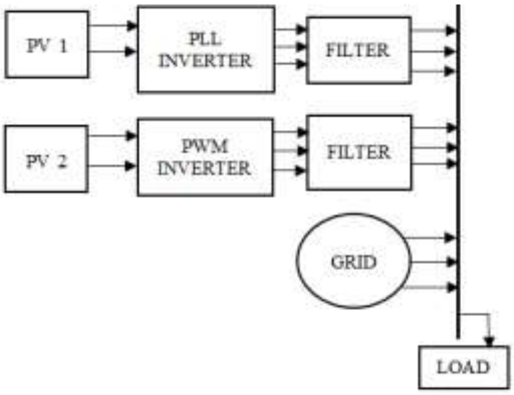

Fig. 2. Block diagram of proposed system

Inverter with PLL

Two control strategies are proposed for controlling three-phase voltage-source inverters (VSI): (i) current control (ii) voltage control. In the current controlled VSI, pulse width modulation (PWM) technique controls the active and reactive components of current injected to the grid. Voltage phase shifts and distortion in the grid voltage are less sensed by current voltage controller. Current controlled VSI has fast response. Inverter output current which is to be injected into utility grid have many control mechanism to regulate. The three major types of current controller are (i) hysteresis control (ii) predictive control (iii) linear proportional-integral (PI) control [16].

The PI controller is the most common control algorithm used for current error compensation. A PI controller calculates an error value as the difference between a measured inverter output current and a desired injected current to the grid, then the controller attempts to minimize the error between them (Fig. 3).

The voltage and current from grid is measured where voltage is given to PLL to get phase angle required for transformation from three-phase abc to dq. The voltage and current values undergo Park's transformation and Vd Vq & Id Iq is given to current controller. The reference current values Id * Iq* is also given to current controller. The reference voltage value Vd * Vq * for inverter is produced. It is given for sinusoidal reference wave generation along with ωt. The reference wave is then given to PWM generator where it produces gating pulses for inverter.

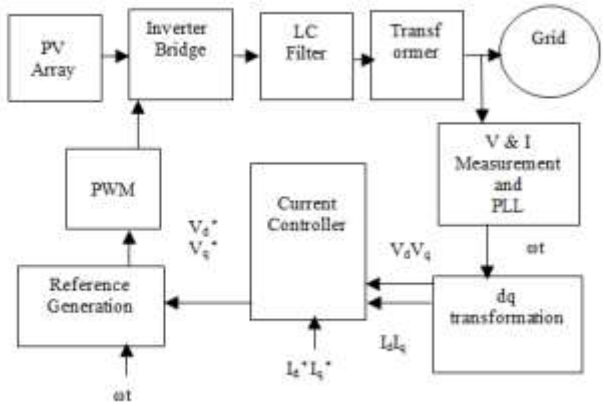

Fig. 3. Block diagram of PLL control for inverter

LC filter

Harmonics generated by the pulsating modulation waveform at the output terminal of Full Bridge PWM inverter which is to be synchronized with grid is mitigated by using three-phase low pass LC filter (Fig. 4).

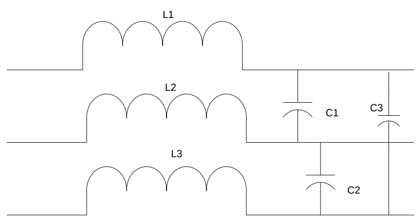

Fig. 4. Three-phase LC filter

In another case where the non-linear loads are connected in power system network cause harmonic resonance. Ill effects of harmonics are increased if resonance occurs where the harmonic frequency produced by a non-linear load and power system frequency closely coincides. IEEE standard 519-1992 defines the current distortion limits and voltage distortion limits which should be met at the point of common coupling (PCC). The distortion limits should be within 5%. Fig. 4 is the three phase LC combination.

Tuning of LC circuit provides low impedance to particular harmonic frequency thereby diverting the harmonic currents. It bypasses the harmonic current generated by the equipment from entering the power system. The values are tuned such that inductance value is kept fixed and capacitance value is varied or vice versa and it is calculated from eq (1).

$$f = \frac{1}{2\pi\sqrt{LC}} \quad (1)$$

Results and discussion

Linear load grid connected system

When linear load (Fig. 5.) is linked to the PV integrated grid connected system [17], there will be no harmonics produced and the system runs smoothly. Parallel RL load of 250 KW is connected with the grid. The block diagram shown in fig. 5 is simulated using Matlab simulation and shown in Fig. 6. The voltage and the current waveforms of the circuit shown in fig. 6 at load and PCC are given in fig. 7 and 8. The corresponding peak values are shown in the table 1.

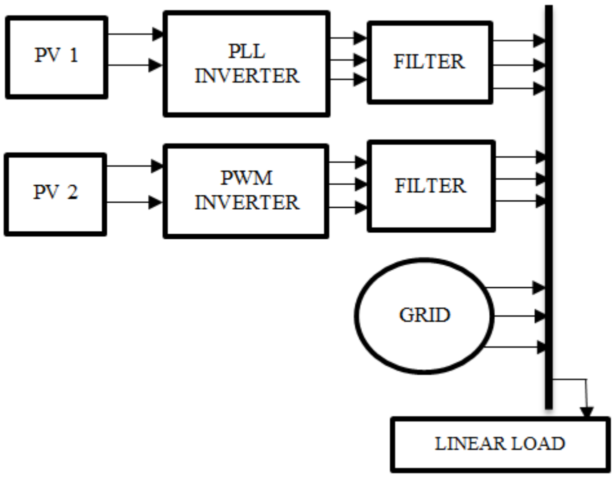

Fig. 5. Block diagram of linear load connected grid system

Non-linear load grid connected system

A non-linear load (Fig. 9) is coupled to the PV grid connected system. Non-linear load connected here is a thyristor based PWM inverter whose input is DC link of 100 μF. A resistive load of 100Ω is connected across the DC input. The block diagram shown in fig. 9 is simulated using Matlab simulation and shown in fig. 10.

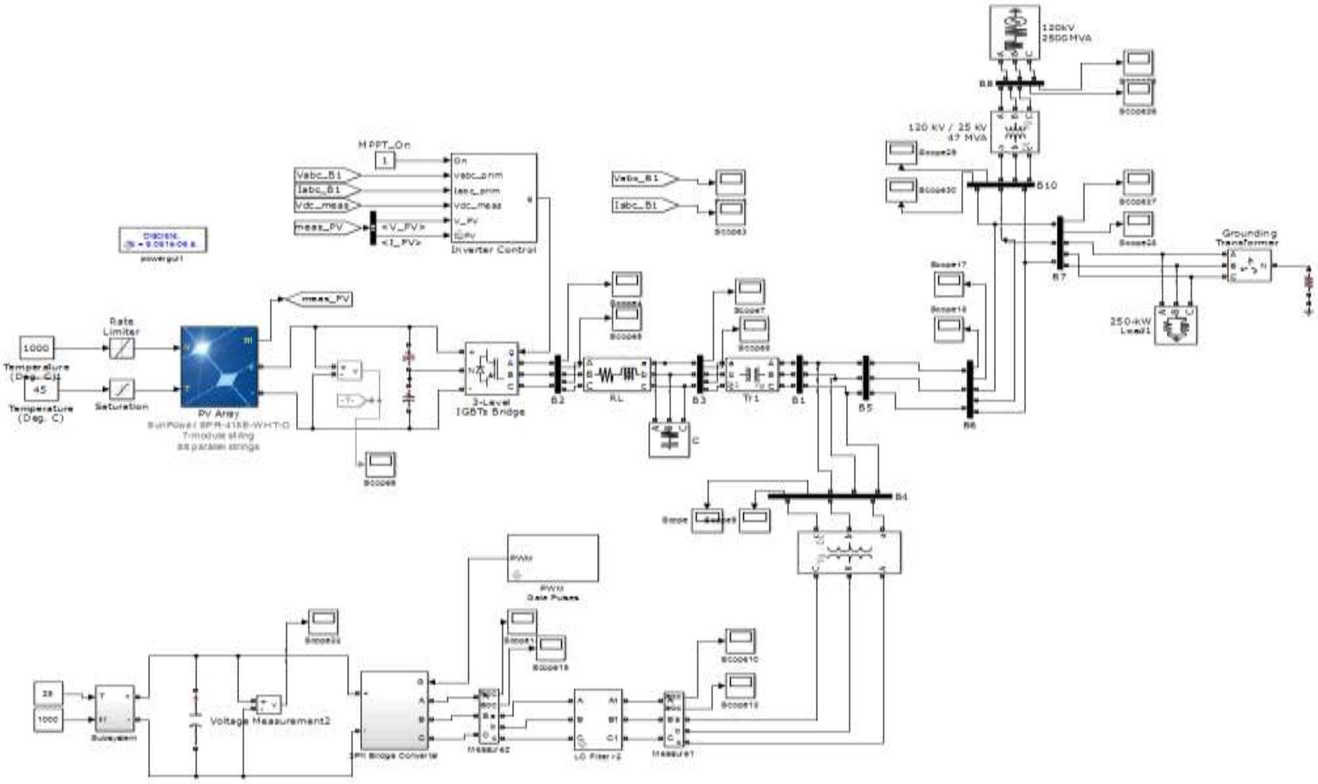

Fig. 6. Simulation of linear load connected grid system

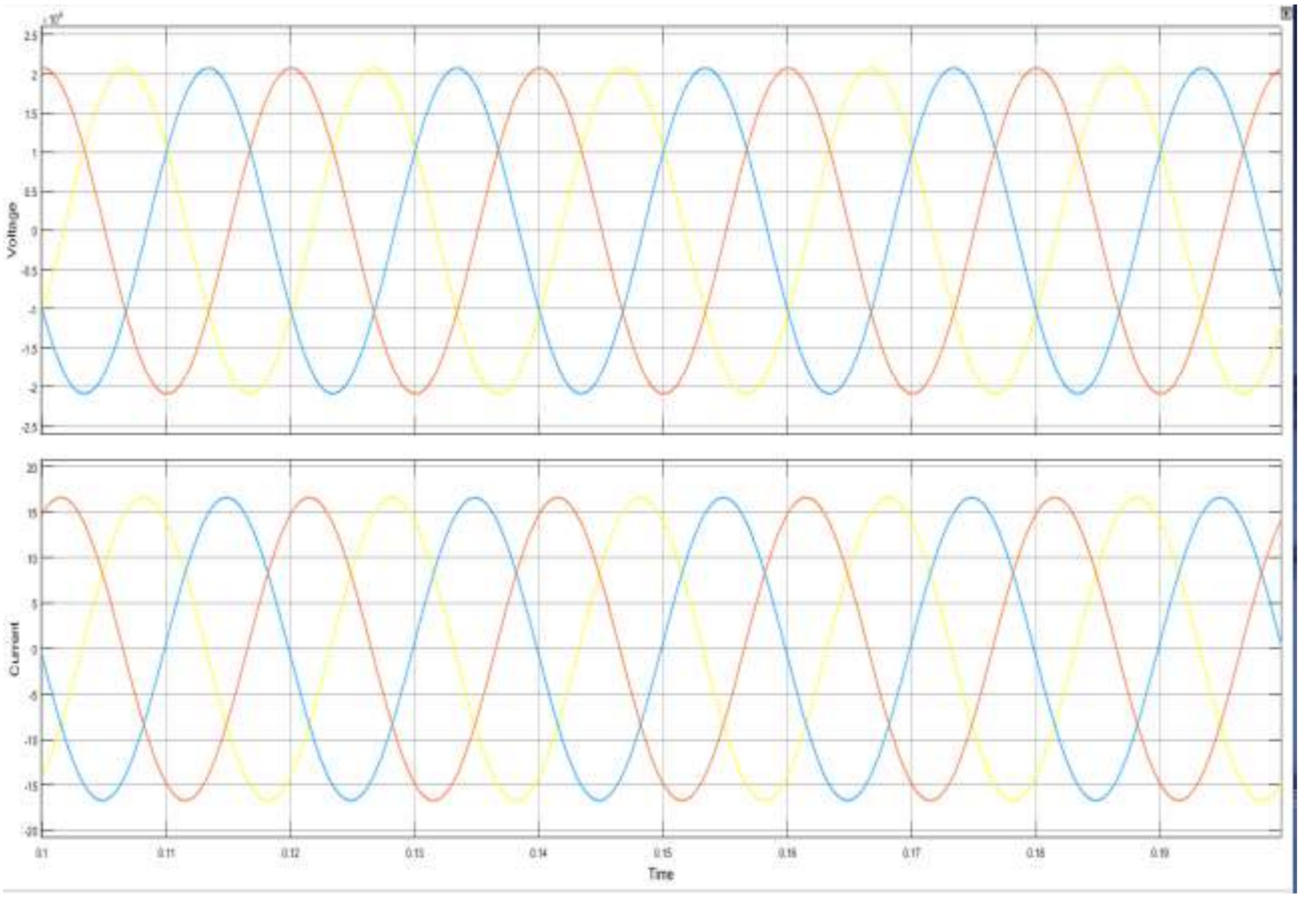

Fig. 7. Voltage and current waveform at load

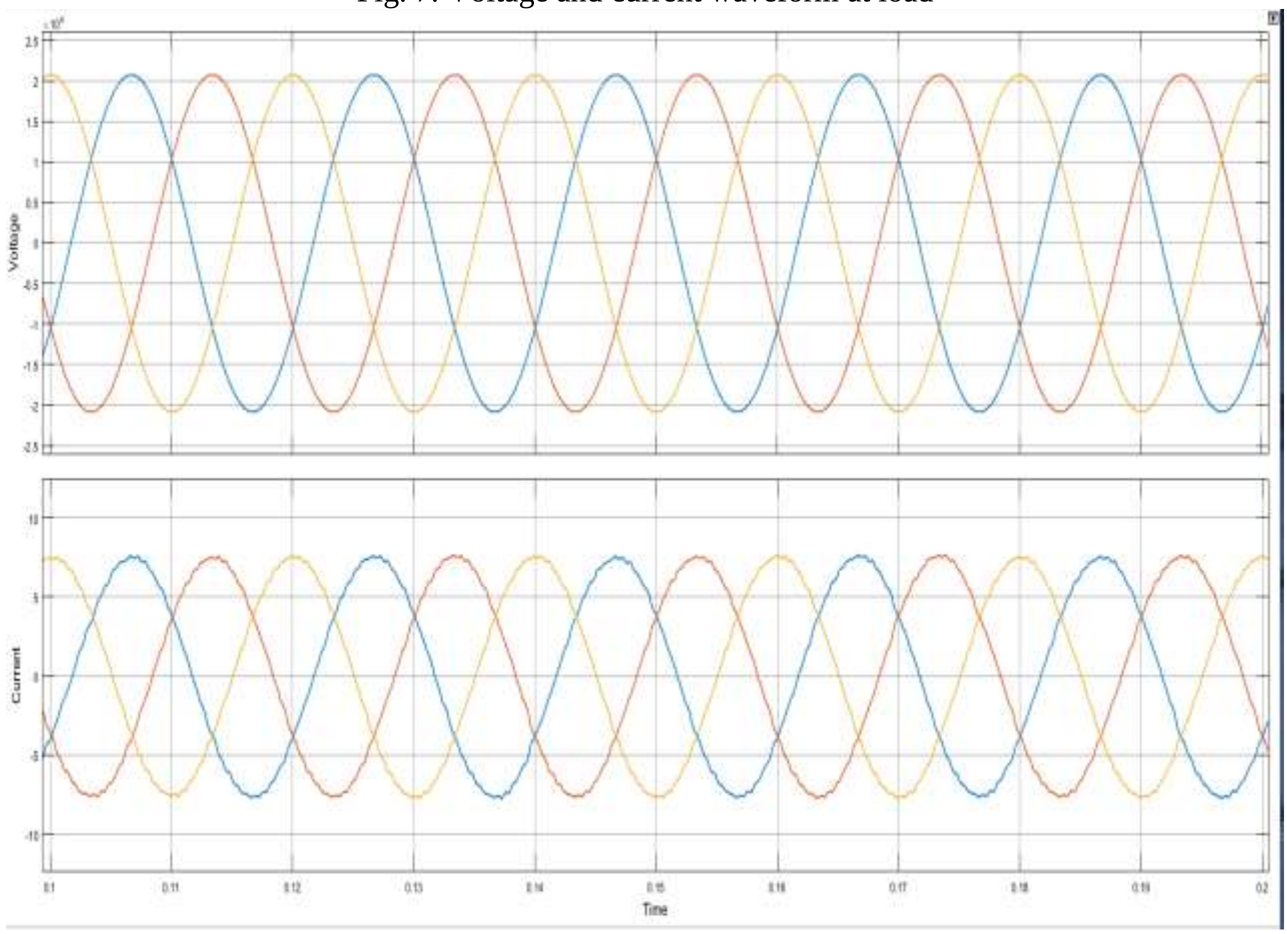

Fig. 8. Voltage and current waveforms at PCC

Table 1. Volatge and current values of linear load connected with grid

Parameters	PV1	PV2	Grid	Load
Voltage, KV	25	25	25	25
Current, A	7.6	0.04	10.4	16.64

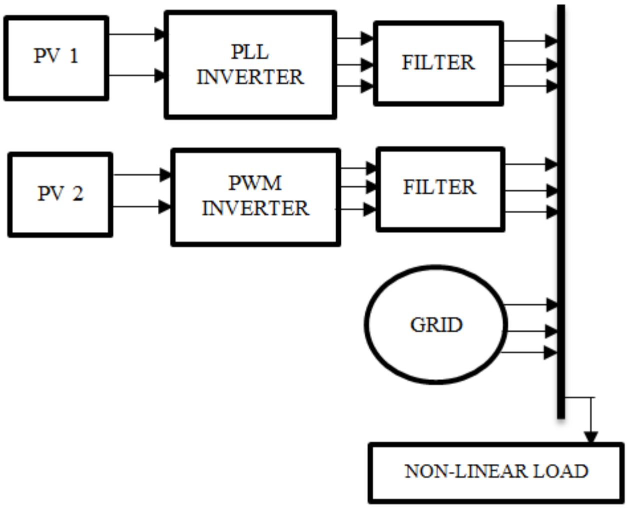

Fig. 9. Block diagram of non-linear connected grid system

The voltage and the current waveforms of the circuit shown in Fig. 10 at load and PCC are given in fig. 11 and 12. The corresponding peak values are shown in the table 2. The current values from PV source 1, PV source 2 and grid when added matches to the load current and has a loss of 1 A.

Due to the connection of non-linear load, harmonics are injected into the entire system and filter has to be implemented in order to reduce harmonics (Table 3).

Table 2. Volatge and current values of non-linear load connected with grid

Parameters	PV1	PV2	Grid	PCC	Load
Voltage, KV	25	25	25	25	25
Current, A	8.9	0.04	469.5	9	477.4

Non-linear load grid connected system with filter

A non-linear load (Fig. 9) is coupled to the PV grid connected system. To this a filter is added [18]. The block diagram shown in fig. 13 is simulated using Matlab simulation and shown in fig. 14.

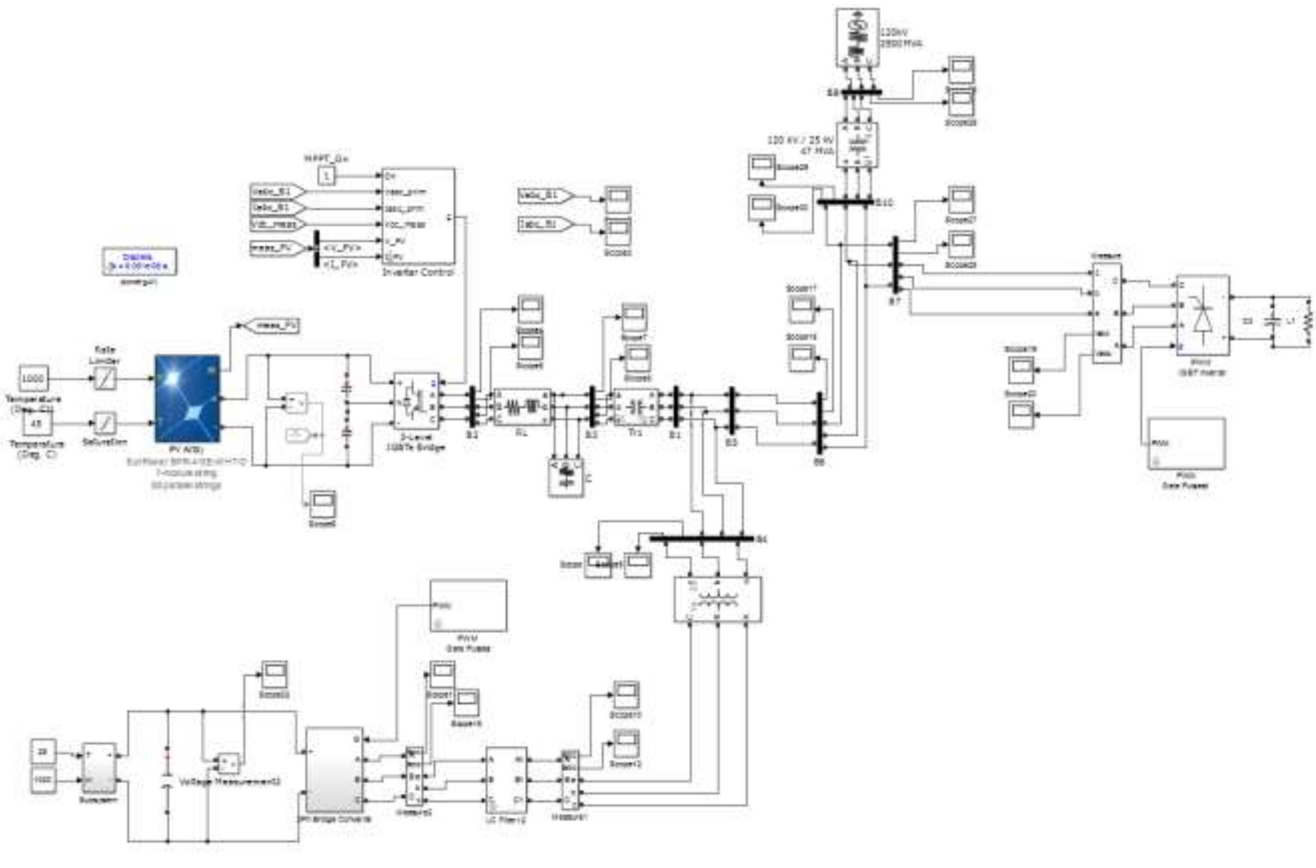

Fig.10. Simulation of non-linear connected grid system

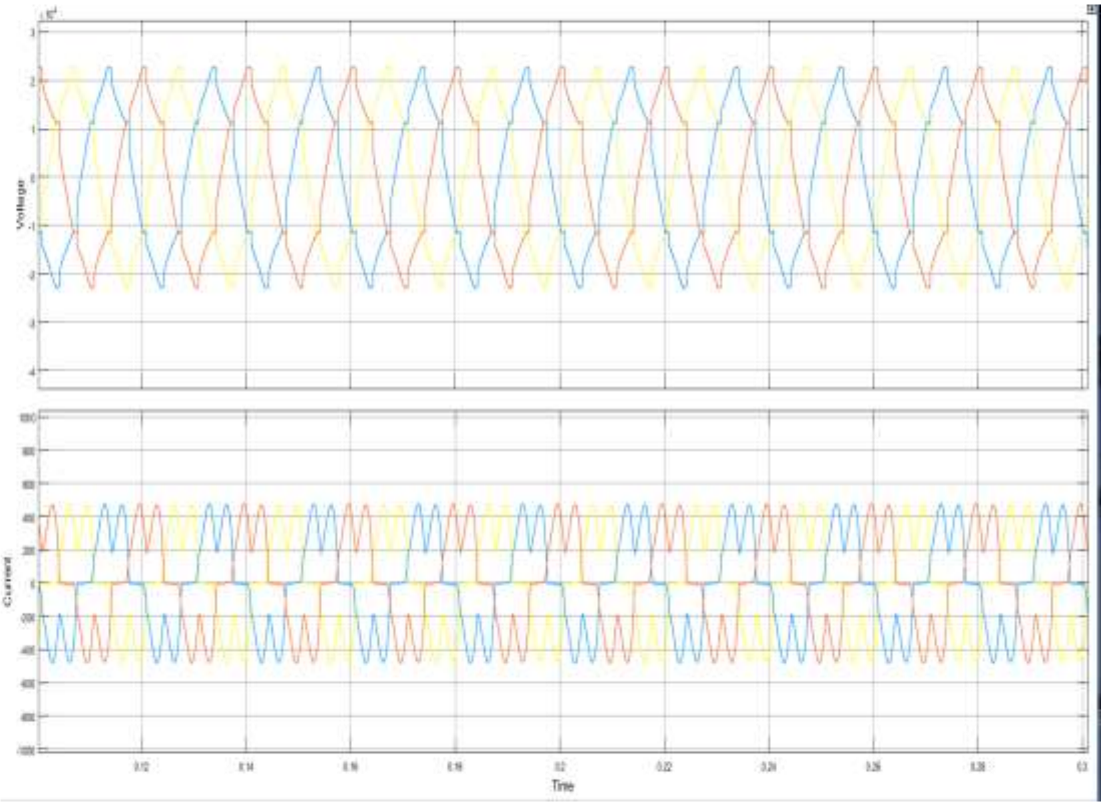

Fig. 11. Voltage and current waveform at load

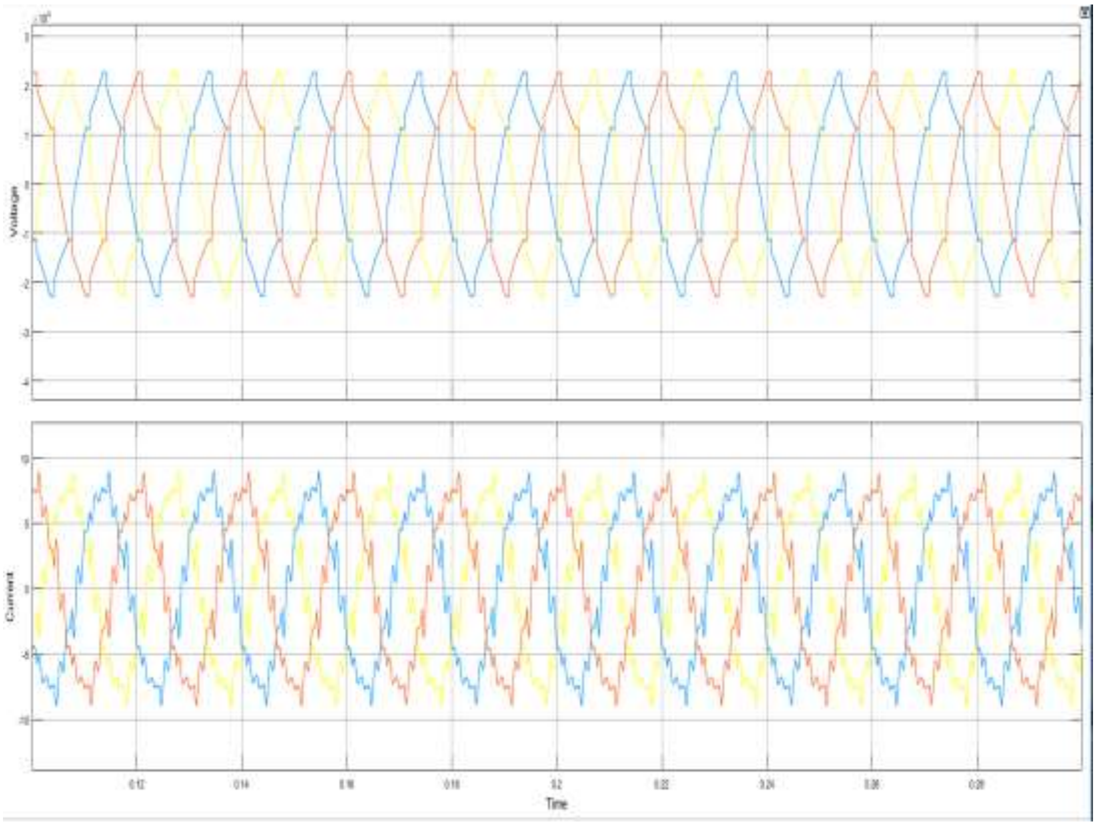

Fig. 12. Voltage and current waveforms at PCC

Table 3. Voltage and current THD values of non-linear load connected with grid

Parameters	PV1	PV2	Grid	PCC	Load
Voltage, %	10.36	10.36	10.36	10.36	10.36
Current, %	14.62	13.45	38.45	14.56	37.51

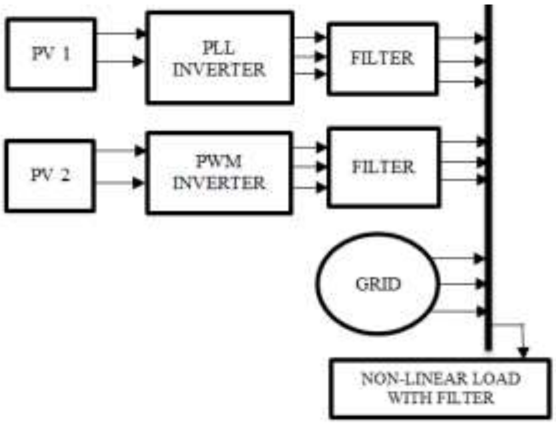

Fig. 13. Block diagram of non-linear load with filter grid system

The voltage and the current waveforms of the circuit shown in fig. 14 at load and PCC are given in fig. 15 and 16. The corresponding peak values are shown in the table 4. The current values from PV source 1, PV source 2 and grid when added matches to the load current and has a loss of 1.94 A. The THD values are reduced by comparing the table 3 and table 5. The L and C value used for filter to reduce harmonics produced from non-linear load is mentioned in table 6.

Table 4. Volatge and current values of non-linear load with filter connected with grid

Parameters	PV1	PV2	Grid	PCC	Load
Voltage, KV	25	25	25	25	25
Current, A	7.9	0.04	239	7.75	245

Table 5. Voltage and current thd values of non-linear load with filter connected with grid

Parameters	PV1	PV2	Grid	PCC	Load
Voltage, %	0.66	0.66	0.66	0.66	0.66
Current, %	1.69	1.61	3.96	1.69	3.87

Table 6. L and C values for LC filter

Parameters	L, H	C, µF
Values	0.206	1

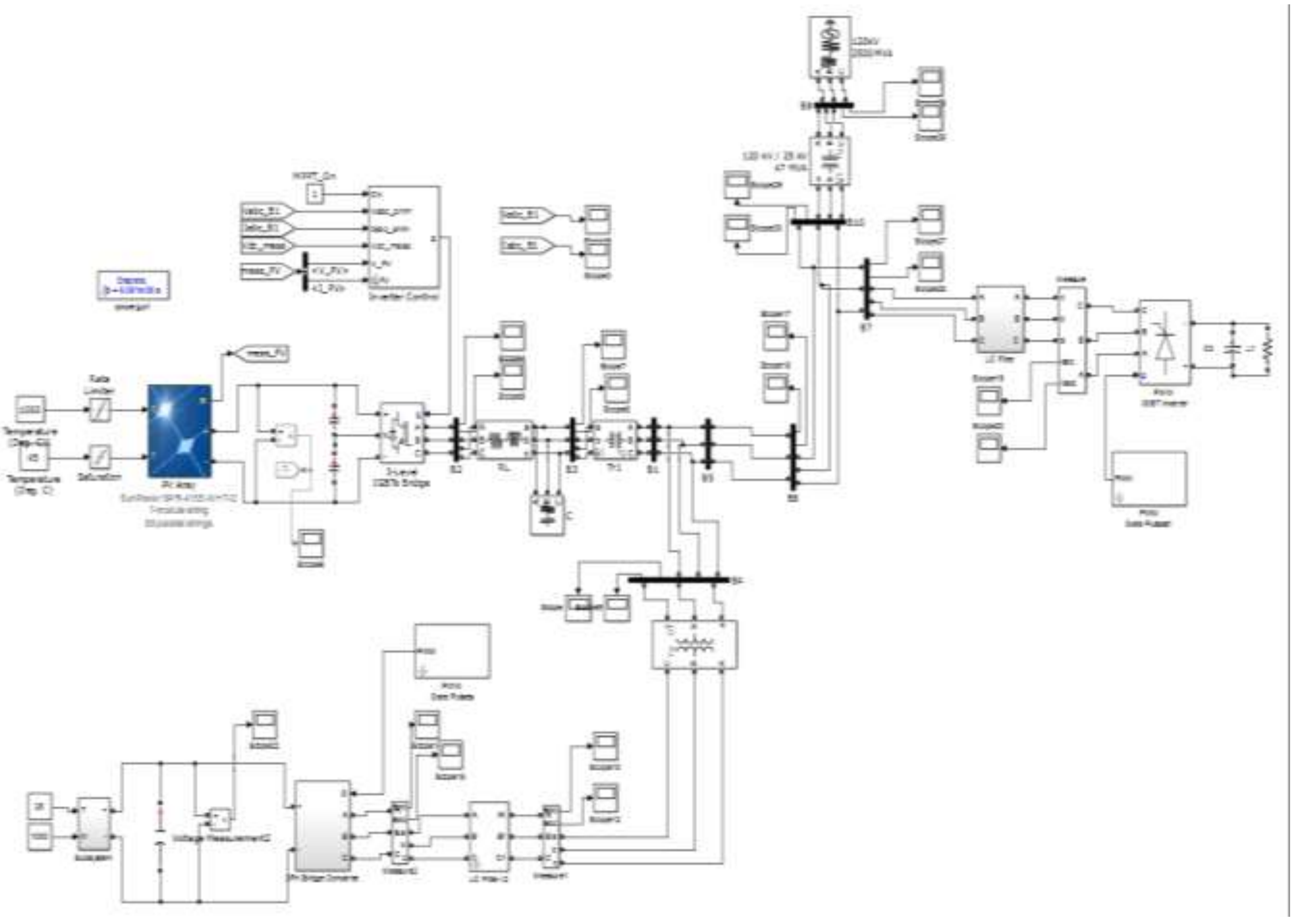

Fig.14. Simulation of non-linear load with filter grid connected system

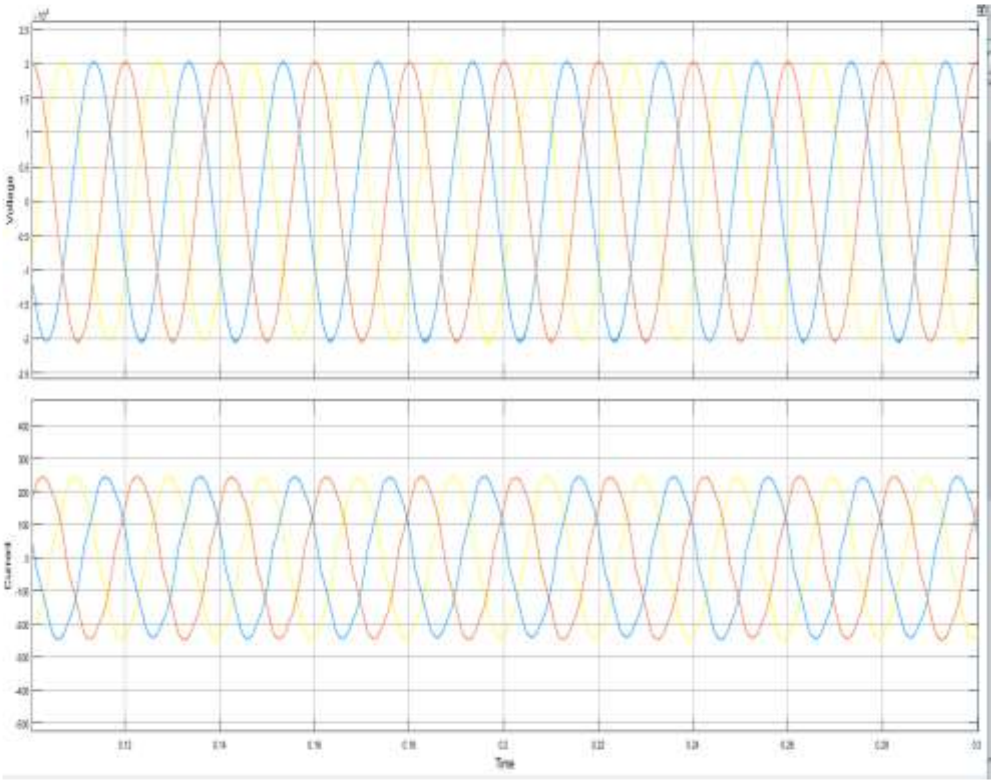

Fig.15. Voltage and current waveforms at load

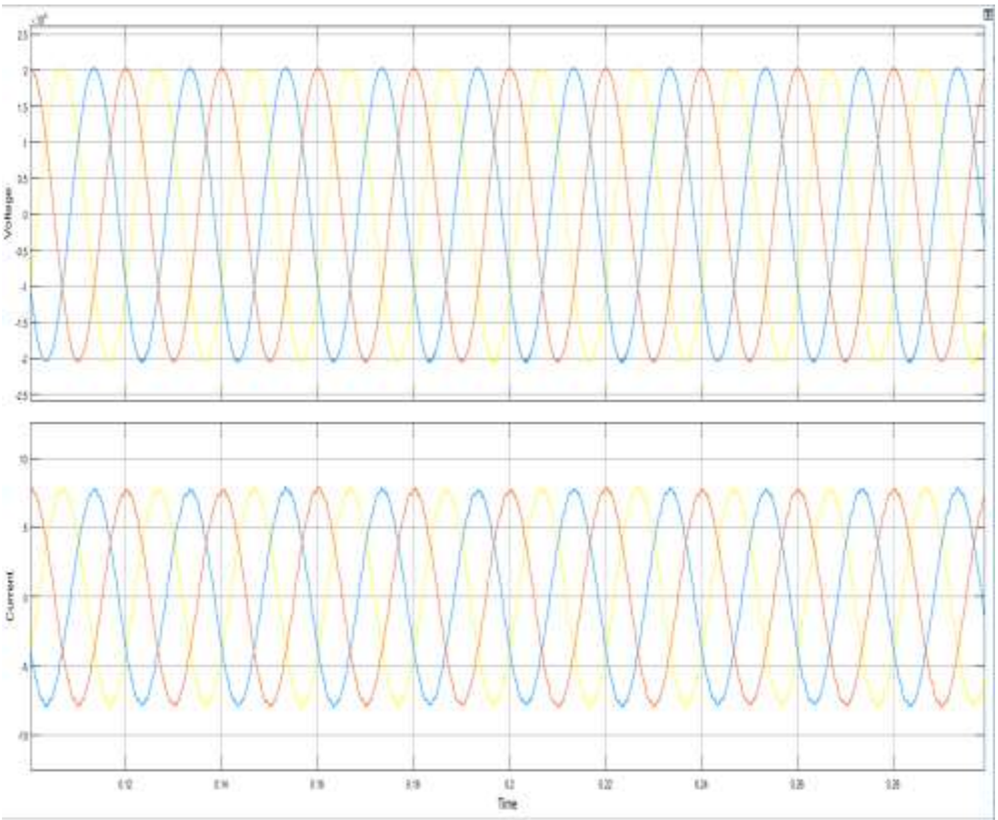

Fig.16. Voltage and current waveforms at PCC

Conclusions

From the results of the present systems, in the PV sources integrated grid connected system, the difference between connecting linear and non-linear load is analyzed. Linear load doesn't cause harmonics and when connecting non-linear load due to the drawing of non-sinusoidal current harmonics are produced and affects the entire system. To prevent the power loss produced by harmonics and to protect the entire system LC filter is implemented and harmonics are greatly reduced.

Conflicts of interest

Authors declare no conflict of interest.

References

[1] Bellia H, Youcef R, Fatima M. A detailed modeling of photovoltaic module using MATLAB. NRIAG Journal of Astronomy and Geophysics. 2014;3:53-61.

[2] Prodanovic M, Green TC. Control and filter design of three-phase inverters for high power quality grid connection. IEEE Transactions on Power Electronics. 2003;18:373-80.

[3] Sangita RN, Mini R. Design and simulation of three phase inverter for grid connected photovoltic systems. Proceedings of Third Biennial National Conference. Feb 24-25; 2012. p. 80-83.

[4] Kumar D, Zare F. Harmonic analysis of grid connected power electronic systems in low voltage distribution networks. IEEE Journal of Emerging and Selected Topics in Power Electronics. 2016;4:70-9.

[5] Murali G, Manivannan A. Analysis of power quality problems in solar power distribution system. International Journal of Engineering Research and Applications. 2013;3:799-805.

[6] Muhammad H, Rashid MH. Power Electronics Circuits, Devices, and Applications. 3rd ed. New Delhi: Pearson Education India: 2009.

[7] Kavitha A, Senthil Kumar N, Vanaja N. Design and control of grid synchronization of renewable energy sources. International Conference on Circuit, Power and Computing Technologies. 18-19 March 2016. Nagercoil, India.

[8] Suresh Kumar B, Avinash G. Mitigation of lower order harmonics in a grid connected three phase PV inverter. International Research Journal of Engineering and Technology. 2015;2:1036-46.

[9] Eng. Osamah Saleh Al-duaij EOS. Harmonics Effects in Power System. International Journal of Engineering Research and Applications. 2015;5:1-19.

[10] Panda A, Pathak MK, Srivastava SP. A single phase photovoltaic inverter control for grid connected system. Sadhana. 2016;41:15-30.

[11] Prasad H, Sudhakar TD. Application of passive filters for harmonics mitigation in a dual input converter. Proceedings of International Conference on Computation of Power, Energy, Information and Communication. 16-17 April 2014; Chennai, India. IEEE Xplore; 2014.

[12] Prasad H, Sudhakar TD. Harmonic analysis of a real time laptop charging circuit with non-linear loads. International Journal of Applied Engineering Research. 2014;9:8602-8.

[13] Sudhakar TD, Prasad H. Harmonic analysis and simulation of shunt active filter for three phase induction motor power backup system using Matlab/Simulink. Middle East Journal of Scientific Research. 2015;23:1461-69.

[14] Prasad H, Chilambarasan M, Sudhakar TD. Mitigation of current harmonics in a solar hybrid system by installation of passive harmonic filters. Proceedings of International Conference on Computation of Power, Energy, Information and Communication. 16-17 April 2014; Chennai, India. IEEE Xplore; 2014.

[15] Prasad H, Sudhakar TD. Design of active filters to reduce harmonics for power quality improvement. Proceedings of International Conference on Computation of Power, Energy, Information and Communication. 16-17 April 2014; Chennai, India. IEEE Xplore; 2014.

[16] Sudhakar TD, Edel Quinn Julin M, Mohanadasse M. MATLAB simulation based load flow analysis of a photovoltaic solar energy powered ship. International Journal of Industrail Engineering. 2018;2(1):76-81.

[17] Sudhakar TD, Vinodini S. PV system based grid-connected system. International Journal of Modern Science and Technology. 2016;1(1):29-33.

[18] Sudhakar TD, Prasad H, Vinodini S. A Study of harmonic mitigation using active power filters in a PV system integrated with GRID through a multilevel inverter. International Journal of Modern Science and Technology. 2016;1(4):144-49.

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