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Research Article

Simulation and Analysis of a New Grid Connected Solar Inverter

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Abstract: This paper proposes and analyzes the performance of a new grid connected inverter topology with Solar PV (SPV) as a dc source. The simulation is done in SIMULINK/ MATLAB Software. The RMS inverter output voltage is kept slightly higher than the RMS grid voltage and the power transfer to the grid is controlled by controlling the phase lag angle of grid with respect to inverter. It is shown that when the phase lag angle of the grid is changed, the THD in output current, RMS current, active power and reactive power changes while RMS voltage and output voltage THD remains approximately the same. This paper shows that if the phase angle increases, the grid current THD reduces and RMS grid current increases. The simulation results with the variation of phase angle are tabulated and the variations of THD, P and Q with phase angle are shown graphically. These results are compared with those obtained from mathematical analysis and found to be in agreement.

Keywords: Grid connected SPV, H-Bridge inverter, Level Module (LM), Power Quality, Total Harmonic Distortion (THD).

INTRODUCTION

Recently, renewable energy resources are becoming popular due to the depletion of conventional fuel sources and their negative impacts on the environment. Solar energy is one of these alternative renewable energy resources. It is converted to the electrical energy by photovoltaic (PV) arrays [1]. PV arrays do not generate any toxic or harmful substances that pollute the environment and have long life. Another considerable feature of them is the requirement of low maintenance. Due to the development in photovoltaic technologies, the efficiency of the PV arrays has been improved. Therefore, studies on PV systems have increased gradually. Multilevel inverters have received increasing interest for power conversion in high-power applications due to their lower harmonics, higher efficiency and lower voltage stress compared to two-level inverters. Multilevel inverters generate a staircase waveform [2].

By increasing the number of levels in the output voltage, the harmonic content and therefore THD are reduced[3]. Therefore, they produce high quality output voltage by increasing the level number. The level number can be easily increased. As a result, voltage stress is reduced and the output voltage wave shape move closure to the sinusoidal shape [4-6]. In this paper, a single phase a 15 level inverter system is proposed. The principle of the proposed method will be explained for a 15-level inverter. However, the structure can be easily adapted to any number of levels.

PROPOSED INVERTER

The proposed multi-level inverter system consists of Level Module, H-Bridge inverter, Solar PV Module as dc voltage source and RL load. The proposed circuit with solar panel as source for two level modules is shown in Fig. 1. The level of output voltage shape depends on the level module used in the circuit.

No. of output Levels

$$n = 2^{(m+1)} - 1$$

where m is the no. of Level Module used.

The no. of switches used in the circuit

$$n_s = 2m+4$$

The input dc voltage fed to k^{th} module varies with particular module no. as:

$$V_k = 2^{(k-1)} \cdot V_b$$

Where k =1, 2, 3 … m.

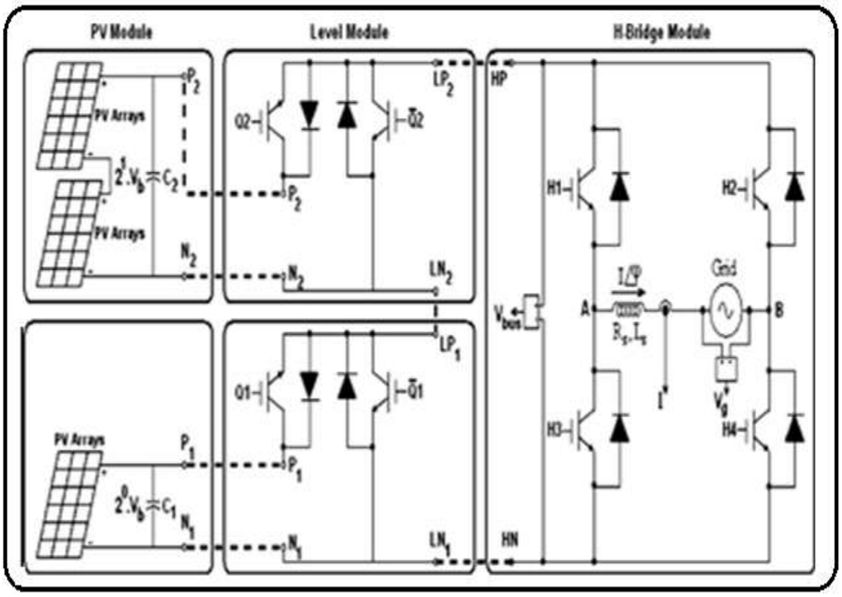

Fig-1: Proposed Multilevel circuit of two Level Module

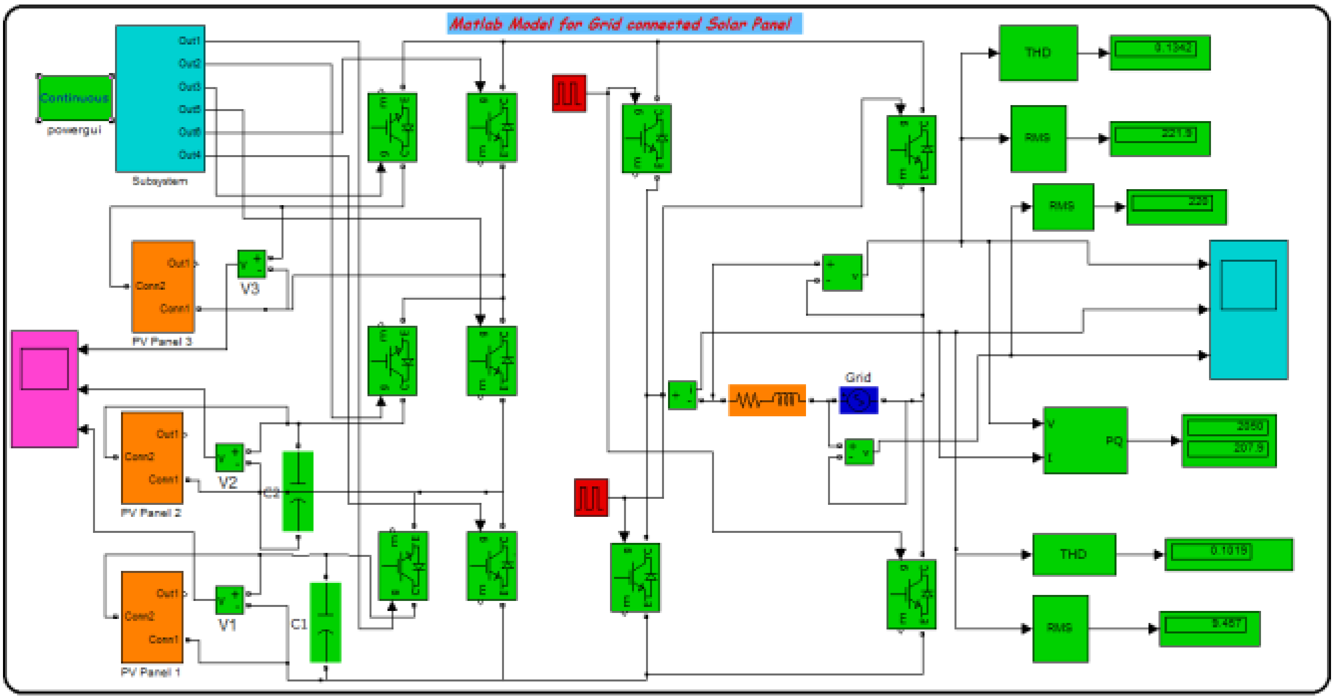

Fig-2: Matlab Model for the proposed circuit

The Simulink model of the proposed circuit is shown in Fig. 2. In the proposed circuit, 3 Level modules (LM), 1 H-Bridge inverter, and 3 Solar PV Array of output voltage V_1 (=V_b), V_2 (=2V_b) and V_3 (=4V_b) are used. Output wave has 15 levels and the total no. of switches used are 10. Total dc voltage used in the circuit is 7V_b.

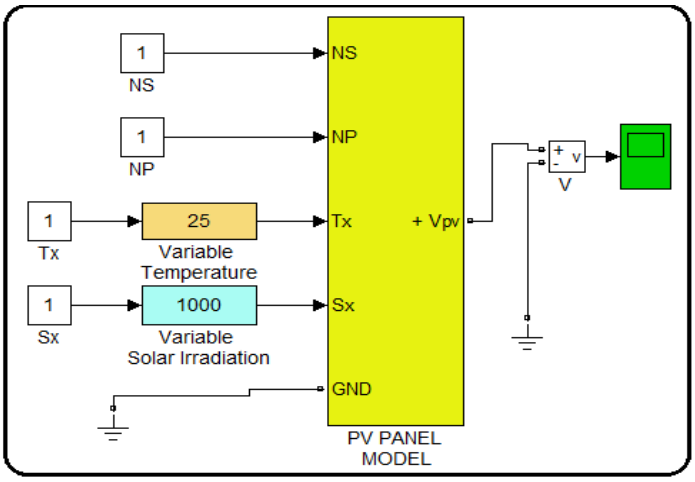

Fig-3: PV Array Model used in the proposed circuit

The Simulink Model of PV Array used in the above circuit is shown in Fig. 3 [4]. The pulse generation is done for LM switches [5]. The simulation is done for V_b=48Volt. V_b is measured when the PV model is open circuited. When the PV Array is loaded, some fluctuations in PV Voltage are measured.

Simulation and Results

The proposed circuit is simulated for grid in SIMULINK/MATLAB software [7]. Since proposed inverter is connected in parallel to grid through a small transmission line having small inductance along with small resistance. The simulation is carried out for 50µF capacitances across PV panel.

Panel Output Voltages are: $V_1(=V_b)$ =48V, V_2=96V, V_3=192V, RMS grid voltage Vg = 220V, L=25mH, R=0.5Ω.

The phase angle between the inverter voltage and grid voltage controls the active power flow to the grid. Power is transferred from SPV inverter to the grid, when the phase angle of the grid is lagging. As the lagging phase angle of the grid increases, RMS grid current, active power P and reactive power Q increases while THD in grid current deceases. The THD in load voltage remains approximately the same. TABLE I shows the variations of RMS inverter output voltage V_r, RMS output current I_r, active power P, reactive power Q, THD in inverter output voltage and THD in output current with the variation of phase angle of the grid.

Table-1: Performance of Grid Connected SPV Inverter With Variation Of Phase Angle

Phase Angle (°)	V_r (V)	I_r (A)	P (W)	Q (VAR)	THD in V (%)	THD in I (%)
-5	222.7	2.2	444.6	9.3	13.43	47.41
-10	222.3	4.67	995	25.39	13.42	21.17
-15	222.2	7.04	1525	94.27	13.45	13.8
-20	221.9	9.45	2050	207.9	13.42	10.19
-25	221.8	11.88	2564	370	13.43	8.10
-30	221.8	14.3	3066	579.5	13.42	6.78
-35	221.8	16.68	3547	831.8	13.41	5.80
-40	221.8	19.0	4002	1128	13.41	5.0
-45	221.9	21.2	4428	1468	13.38	4.47
-50	222.1	23.51	4827	1858	13.32	3.9
-55	223.1	25.9	5229	2348	13.06	3.26
-60	225.5	26.68	5672	2984	13.35	2.5

Fig 4 and 5 shows the inverter output voltage, grid current and grid voltage for 15°, 30° lagging phase angle. Negative sign in the table shows that the phase angle of grid voltage is lagging with the inverter output voltage.

The variation of THD in output voltage and output current with the phase angle is shown in Fig. 6. The graph shows that the load voltage THD is nearly constant while the load current THD is continuously decreasing with the phase angle of the grid.

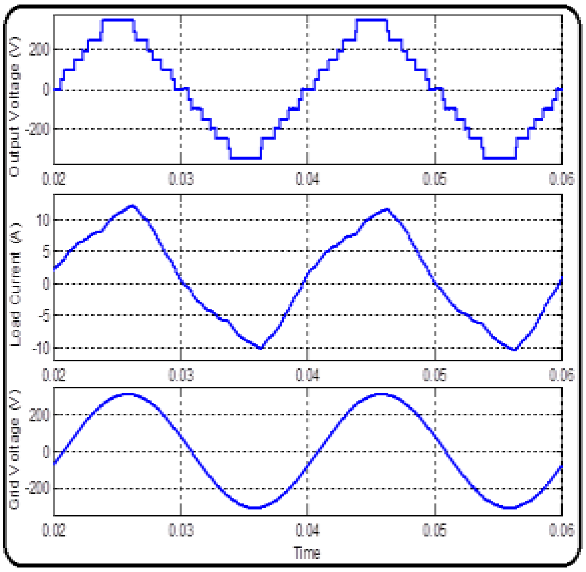

Fig-4: Inverter output voltage, grid current and grid voltage for 15° lagging phase angle

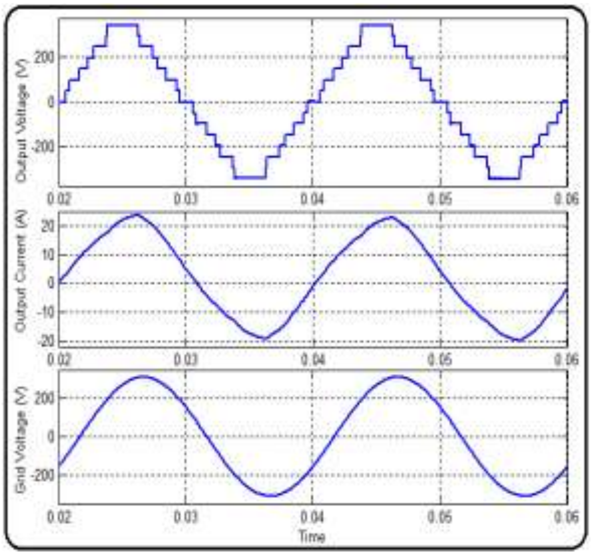

Fig-5: Inverter output voltage, grid current and grid voltage for 30° lagging phase angle

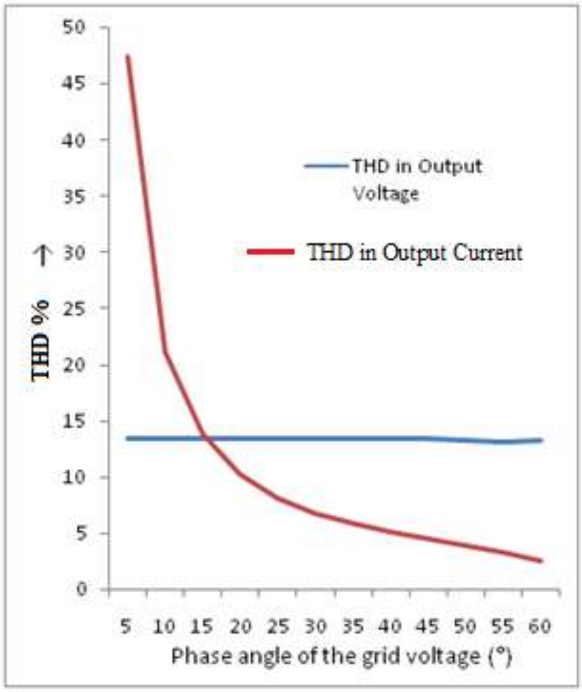

Fig-6: Variation of output voltage THD and output current THD with phase angle

ANALYTICAL RESULTS

The power transfer between two sinusoidal voltage sources [7], when the phase of one source is taken as reference and neglecting resistance between the sources, is given by:

Active power $P = \frac{V_1 V_2}{X} \sin \delta$

where δ is the phase angle of voltage source, X is the reactance between the two sources.

Reactive power $Q = \frac{V_1}{X}(V_1 - V_2 \cos \delta)$

In this paper, solar inverter feed the power into the grid. V_1 is SPV inverter rms output voltage, V_r. V_2 is the grid rms voltage, V_g. The phase angle of the inverter is taken as reference. And the phase angle of grid is reduced from zero i.e. increased with negative sign. Now in the above formulae, δ is assumed to be grid phase angle (negative sign included).

Table-2: Power Results From Formulae For Different Phase Angle

Phase Angle (°)	Vg (Volt)	Vr (Volt)	P (W)	Q (VAR)
-5	220	222.7	543	100
-10	220	222.3	1080	160
-15	220	222.2	1609	274
-20	220	221.9	2124	428
-25	220	221.8	2623	632
-30	220	221.8	3104	882
-35	220	221.8	3560	1173
-40	220	221.8	3990	1503
-45	220	221.9	4391	1873
-50	220	222.1	4762	2280
-55	220	223.1	5115	2751
-60	220	225.5	5466	3314

COMPARISON

The power transfer from the inverter to the grid obtained from the simulation is compared with the power calculated from the formulae. It is found that the Active Power P results obtained from simulation and formula are very close to each other. At starting, P from formula is more as compared to P from simulation. And for phase lag angle of grid of 40° or more, the power from simulation becomes large. The variation of P with grid voltage phase angle for both the cases is shown in Fig. 7.

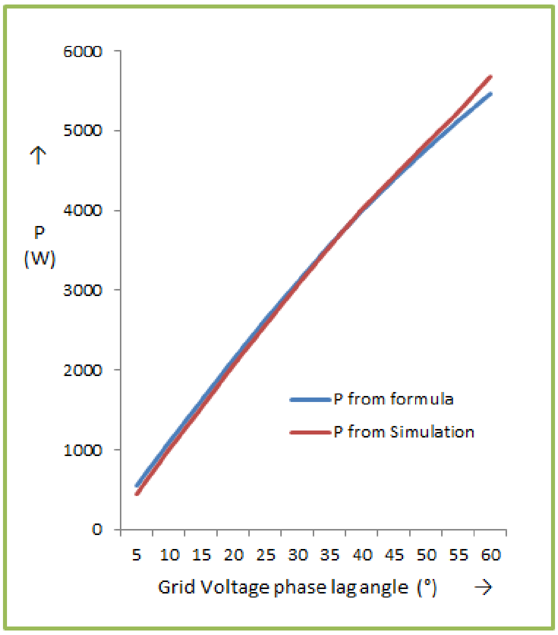

Fig-7: Variation of Active power results with phase angle obtained from simulation and formula

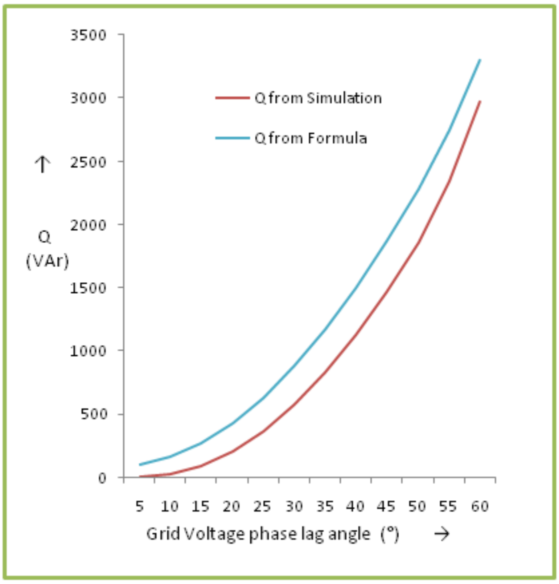

Fig-8:Variation of Reactive power results with phase angle obtained from simulation and formula

The Reactive Power Q from formula is large as compared to Q from simulation. The difference is attributed to the presence of small resistance between inverter and the grid that has been neglected. It is found that as the phase lag angle increases, the reactive power flow also increases. The variation of reactive power Q with grid voltage phase angle obtained from simulation and formula is shown in Fig. 8.

CONCLUSION

In this paper, a grid connected multilevel inverter circuit is proposed. The power from the inverter to the grid is controlled by controlling the phase angle between the grid and the inverter. It is found that active power and reactive power increases with the phase angle. However, THD in grid current decreases while the THD in output voltage remains approximately the same.

Finally the power from evaluated simulation is compared with that obtained from formulae and found to be in conformity with theory. The results are tabulated and also elaborated graphically

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