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PERFORMANCE ANALYSIS OF A DG BASED INVERTER CONNECTED WITH MICROGRID

K. Radha Rani and N. Chaithanya
Department of Electrical and Electronics Engineering, R.V. R. and J. C. College of Engineering, Chowdavaram, Guntur, India
E-Mail: korrapatiradharani@gmail.com

ABSTRACT

In this paper, control of 300 watt grid tied PV inverter is addressed. The ac output of grid tied inverter is connected to the load and to a virtual micro grid through the point of common coupling. The main objectives of this paper are synchronization of solar inverter to micro grid, evaluation of the performance of inverter, determination of apparent power at the point of common coupling which is connected between three lines. One line is connected to the main or artificial micro grid and battery storage system, second line is connected to the solar inverter and third line is the local load. A complete control structure for the single phase PV system is presented. Plenary results are obtained to validate the performance of solar grid tied training system. The grid tied inverter ability is discussed to deliver a sinusoidal current to the grid while meeting the appropriate standards i.e. the total harmonic distortion and power factor requirements are examined.

Keywords: PV cell, single phase inverter, phase locked loop, PI Controller, DG.

INTRODUCTION

Majority of electrical systems are centralized, but centralized system suffers from many problems for example congestion and losses in transmission lines, stability issues. So to avoid all these problems the only viable solution is distributed power generation by using renewable energy sources like PV, Wind, Fuel cells, small hydro, bio mass, biogas. Among all the sources PV is very promising, effective, and reliable in satellite systems, transmission & distribution of power systems [1]. Current source inverters are widely adopted for non-conventional energy systems. Nevertheless, it is a feasible resolution for injecting PV energy to the grid due to the following reasons [3], [4]:

a) Source side current is ripple free which is more suitable for PV applications.

b) The system is further consistent when an inductance having longer lifetime replaces the input electrolytic capacitor.

Proportional resonant (PR) controller is used to get precise control of the current source inverter. As cited in [2], Proportional Resonant controllers have enhanced steady state performance rather Proportional Integral controllers in tracing the sinusoidal references and larger transient dynamic forces.

The main objective of this paper is analysis of a grid-connected CSI (current source inverter) topology for Photo Voltaic applications. To validate the efficacy and robustness of the suggested system, computer assisted simulation is used. To track maximum power point, Perturb and Observe algorithm is used in the suggested system. Second-order generalized integrator (SOGI) - phase-locked loop (PLL) method is used for synchronization of the injected current with the grid. Proportional resonant (PR) controller is used to attain zero steady state error and its performance is compared with the conventional proportional integral (PI) controller for the grid tied DC- AC inverter in the Photo Voltaic system.

To provide a unity power factor operation phase locked loop (PLL) method is used which includes harmonization of the inverter with the grid voltage waveform. The actual methodology of the phase locked loop (PLL) method is that it permits a signal to track another. It continues harmonization of an output signal with an input signal in frequency & phase [5], [6]. Current controlled voltage source inverter has several advantages such as fast dynamic response, inherent peak current protection, good DC link utilization, instantaneous current control [7]. When DG units are connected to grid the main focus is on synchronization of grid to DG units. Zero crossing detection is the easiest method to get the frequency data readings. Zero crossing of voltage is sensed and ideally duration between two consecutive zero crossing equals to reciprocal of double of voltage frequency. However harmonics are present in the practical voltage and can finally result in detection of zero crossing at the rate different than fundamental frequency and also it is not possible to get instantaneous phase information. Grid synchronization using a PLL (Phase Locked Loop) is a fast, reliable, and widely used technique.

GRID TIED SOLAR INVERTER

The inverter's primary purpose is to produce ac output current in phase with the ac grid voltage. Here the inverters are constructed in such a manner if the ac voltage sensed by the inverter from the grid is outside a specific range, the inverter will shut down. Single phase inverter with full bridge topology is considered for this case and this inverter contain four switching devices two of them in each leg. The DC and AC side parameters of the grid-tied solar inverter, as well as the parameters of the solar cell, are shown in Tables 1 and 2.

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Table-1. Displays the parameters of a grid-connected solar inverter.

S.No	Parameter (DC input side)	Rating
1	Maximum start voltage	100v
2	Maximum input voltage	135v
3	Minimum input voltage	45v
4	Minimum input voltage for rated output	64v
5	MPP voltage	45v
6	Maximum input current	5A
7	Maximum input power	320W
8	Maximum recommended PV power	375 w
S.No	Parameter (AC output side)	Rating
1	Grid voltage	210v
2	Rated grid voltage	230v
3	Maximum output current	1.5A
4	Maximum output power	300w
5	Rated power	300w
6	Rated frequency	50Hz
7	Feeding phase	Single phase

Table-2. Parameters of solar cell.

S.No	Parameter	Rating
1	Power rating	250 watts
2	Maximum power voltage	45 V
3	Maximum power current	7.14A
4	Open circuit voltage	43.2V
5	Short circuit current	7.5A
6	Module dimension	980*1745mm
7	Panel type	Poly crystalline type

Figure-1 shows the overall control circuit used for single phase grid connected DG system.

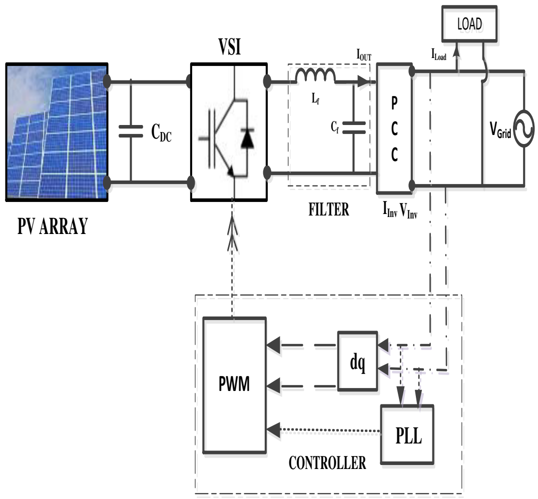

Figure-1. over all control circuit used for single phase DG based grid connected system.

Performance equations for the Figure-1 are as follows

$$V_{inv}(S) - V_{load}(S) = L_i S i_1(S) \tag{1}$$

$$i_1(S) = \frac{V_{inv}(S) - V_{load}(S)}{SL_f} \tag{2}$$

$$V_{Laod}(S) = \frac{i_c(s)}{C_f S} \tag{3}$$

$$i_c(s) = i_1(s) - i_{load}(s) \tag{4}$$

$$i_{load} = \frac{V_{load}}{Z_L} \tag{5}$$

PHASE LOCKED LOOP

The PLL is used to achieve unity power factor by synchronizing the inverter output current with the grid voltage and providing a clean sinusoidal current reference. The PLL structure's PI controller parameters are measured in such a way that the PLL's settling time and damping factor can be set directly. In order to control grid voltage, the PLL structure is also used [8].

By applying minor changes, 3 phase PLL can be used for single phase system also. For a three phase system, three voltage components Va, Vb, Vc are converted to two component system (d-q frame) by applying the mathematical equation (6).

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{6}$$

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The above equation (6) can be written in complex notation as

$$V_{dq} = V_d + j * V_q \tag{7}$$

V_d and V_q are two sinusoidal quantities in which Vq lags the V_d by 90^0.

Since there is only one voltage component available for single phase unlike three for three phase system. So instead of using the abc-dq transformation matrix, single phase voltage $V_S=V_m*\sin(\omega t+\phi)$ component itself is assume to be direct axis component i.e $V_d = V_s = V_m*\sin(\omega t+\phi)$ then 90^0 phase delayed component of single phase voltage is calculated and is assumed to be quadrature axis component $V_q=V_m*\sin(\omega t+\phi-90^0) = V_m*\cos(\omega t+\phi)$.

If we draw Vdq phasor on d-q axis then we will see a vector with magnitude equals to Vm rotating at speed equals to synchronous speed(ω) (or) instantaneous phase equal to (ωt+ϕ).

Now suppose if this vector is observed from the frame rotating at the synchronous speed, it appears to be a stationary vector with a magnitude equal to Vm and a constant phase ϕ. Suppose if the dq reference frame rotates at angular speed ω_o, then the mathematical equation is shown in equation (7) as

$$\begin{bmatrix} V_{de} \\ V_{qe} \end{bmatrix} = \begin{bmatrix} \sin\omega_o t & -\cos\omega_o t \\ \cos\omega_o t & \sin\omega_o t \end{bmatrix} \begin{bmatrix} V_d \\ V_q \end{bmatrix} \tag{8}$$

Both the vector will appear stationary with respect to each other only when speed of this frame equals to synchronous speed(i.e $\omega=\omega_o$) and even if phase is also matched the q-axis component becomes zero. Block diagram of PLL is shown in Figure-2. Performance of PLL is evaluated in terms of its ability to get synchronized to poor quality voltage, time lapsed to synchronize, response to rapidly changing frequency and up to what poor quality voltage it can stay synchronized.

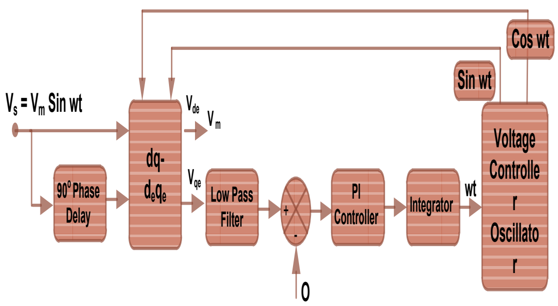

Figure-2. Block diagram of PLL.

LC FILTER SELECTION

To reduce inverter power output harmonics to a great extent, appropriate design of LC filter is used. And hence it delivers a very smooth power to the load. Size of LC filter determines the magnitude of ripples in output voltage and current of inverter. It is possible to choose PI controller constants [9] based on the size of the filter. Here a 300 watt inverter is used with an output voltage of 210 volts, 50 Hz.

LC Filter:

Dimension of the inductor and switching frequency level plays key role on ripple current of the inductor.

$$L_f = \frac{V_{dc}}{4 f \Delta i} \tag{9}$$

If the filter inductance is 0.001 H, the highest amount of inductor ripple current is restricted to 20% of the maximum peak to peak o.p current (i.e 20% of 5 amps).

Vdc is the DC bus voltage (70 volts), f is the switching frequency (18 khz). The output filter capacitor size is determined by the allowable ripple ΔV_0 [9].

$$C_f = \frac{\Delta i}{8 f \Delta V_0} \tag{10}$$

If the highest amount of ripple voltage is restricted to 2% of the peak to peak o.p voltage (2% of 210 volts),Then the filter capacitance is approximately 1.6 µF.

SYNCHRONIZATION OF GRID

The grid is synchronized with the inverter using the phase locked loop technique. To determine synchronization time and inverter efficiency first of all consider solar cell output voltage as DC bus voltage, inverter is connected in between DC bus and AC bus, that means DC bus voltage is nothing but input voltage of the inverter, the AC bus voltage is nothing but output voltage of inverter, to check about synchronization of grid with inverter first by pass the inductance of transmission line and then adjust the voltage of auto transformer at 210V. Whenever the inverter is supplied with the DC voltage, some current starts flowing from grid to inverter, as soon inverter gets synchronized current starts flowing from inverter to grid.

$$Efficiency \quad of \quad inverter = \frac{P_{inverter}}{V_{dc} I_{dc}} \times 100 \tag{11}$$

Power quality of inverter is done by measuring the THD, whenever the current supplied by the PV array is less then THD of current supplied by inverter is very high because here the output power will vary according to the current supplied by the inverter. whenever the current supplied by inverter is near to its rated value then the THD of output current will get reduced drastically and also the inverter operate at its maximum efficiency. All the measured parameters are tabulated in Table-3.

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Table-3. Parameters measured during the synchronization of grid.

S.No	Parameter	Quantity
1	Time taken for synchronization	20sec
2	PV panel voltage	59.5 volts
3	PV panel current	5.04 amps
4	Power supplied by PV panels	299.88 watts
5	Active power reading from power analyser1	0.251 kw
6	Efficiency of inverter	83.7%
7	Inverter output voltage	215 volts
8	Inverter output current	1.184 amp
9	Inverter output power	0.252kw
10	Inverter output voltage THD	2.714%
11	Inverter output current THD	8%

For low currents inverter output current THD is more, when the array current is 5 amps then THD in current supplied by the inverter becomes less.

Table-4 is the observation table for linear and nonlinear loads, in linear load case the results shows that the fundamental voltage is nearly equal to the actual load value, in nonlinear load case the fundamental load voltage become very less when compared to actual load voltage and power factor also become less due to the reactive power drawn by the load is more.

Table-4. Observation table for linear and nonlinear loads.

Load type	Over all Distortion factor	Over all Power factor	Fundamental voltage	Fundamental current	Active power	Reactive power
Linear load	0.99	0.98	207.9	1.485	311.85	44.415
Nonlinear load	0.95	0.9	199.5	1.425	299.25	98.28

Figure-3 shows the voltage and current waveforms when nonlinear load is connected, distortions in current waveform is high due to the nonlinear load.

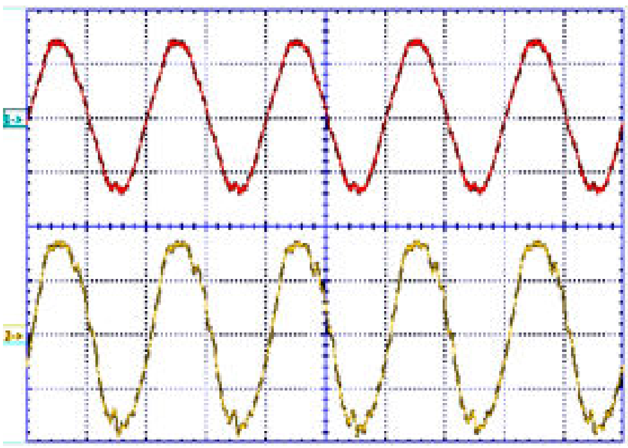

Figure-3. When Fan load is connected variations of voltage and current: 50 V, 0.5 A, and 4 ms per division are the vertical and horizontal scales, respectively.

EXPERIMENTAL AND SIMULATION RESULTS

Figure-4 shows the synchronization of output voltage of the inverter with the grid voltage due to the phase locked loop the output voltage of the inverter get synchronized with the grid voltage.

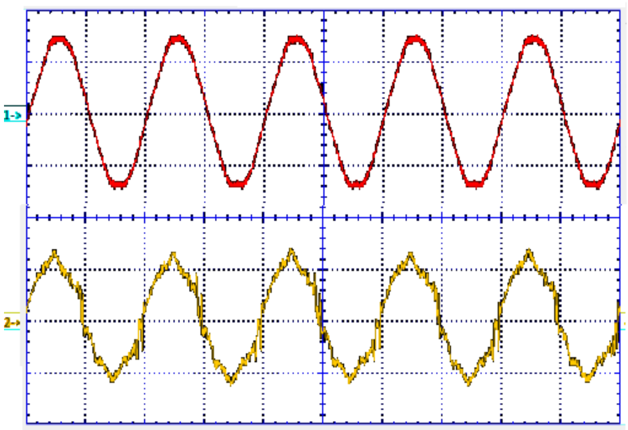

Figure-4. Inverter and grid voltage waveforms: the vertical and horizontal scales are 70 V and 4 ms per division

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Table-5 is the observation table for inverter output and PCC, even though the load is linear inverter output current THD is high, for nonlinear loads inverter output current THD becomes very high but inverter output voltage THD is acceptable value for both linear and nonlinear loads. The power factor also very less at AC side of the inverter and at the point of common coupling, from the results of the table 5 it is observed that whenever the current supplied by the PV array is rated or near to the rated value then only the Total harmonic distortion and power factor values are allowable otherwise for any type of loads the solar grid tied training system maintains very poor power factor and the current total harmonic distortions also not within the acceptable range.

Table-5. Observation table for inverter output and PCC when PV panel supplying very less current.

Load type	output voltage at inverter	output current	PCC Voltage	PCC current	Inverter output voltage THD	Inverter output current THD	Power factor at inverter	PCC Voltage THD	PCC current THD	Power factor at PCC
Linear load (100 watt bulb)	209.5V	0.25A	208.8v	0.354A	2.8%	30%	0.632	2%	24%	0.78
Nonlinear load (fan load)	209V	0.25A	209v	0.45A	3.2%	34%	0.61	3.2%	20.9%	0.70

Figure-5 shows the Synchronization of voltage and current waveform when linear load is connected.

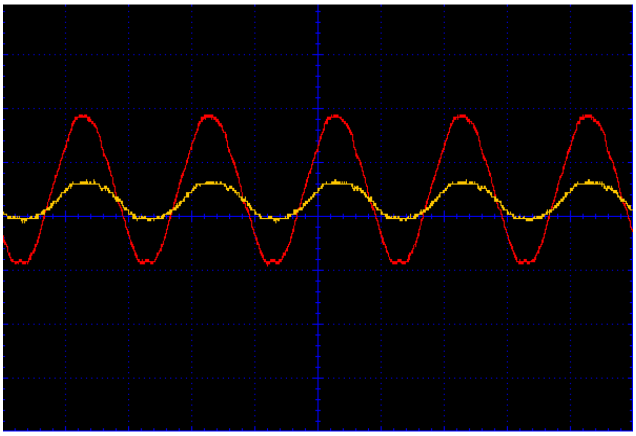

Figure-5. Synchronization of voltage and current waveform when linear load is connected: the Vertical and horizontal scales are 2 A, 70 V and 4ms per division.

When a nonlinear load is attached, the voltage and current waveforms synchronise as shown in Figure-6.

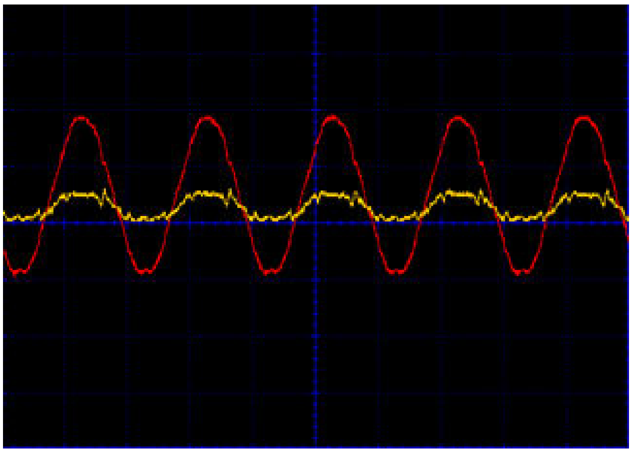

Figure-6. Synchronization of Voltage and current waveform when nonlinear load is connected: 2 A, 70 V and 4ms per division are the vertical and horizontal scales respectively.

Figure-7 shows the simulated result of the inverter output current in amperes for nonlinear load case.

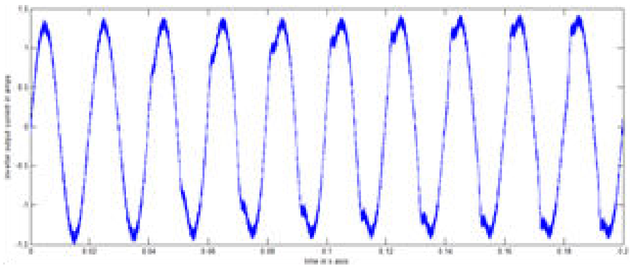

Figure-7. Inverter output current in amps for nonlinear load.

Figure-8 shows the simulated result of inverter output voltage in volts for nonlinear load case.

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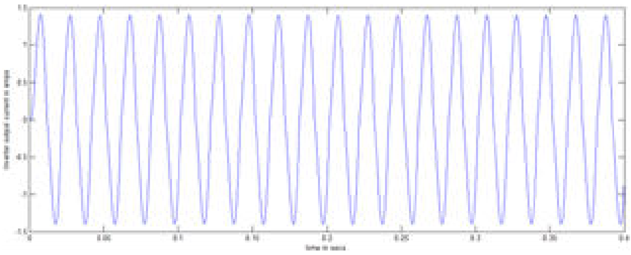

Figure-8. Inverter output voltage in volts for non linear Load.

The simulated effect of inverter output current in amperes for the linear load case is shown in Figure-9.

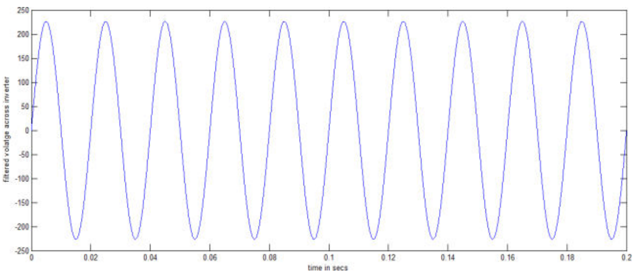

Figure-9. Inverter output current in amps for linear load.

Figure-10. Shows the simulated result of inverter output voltage in volts for linear load case.

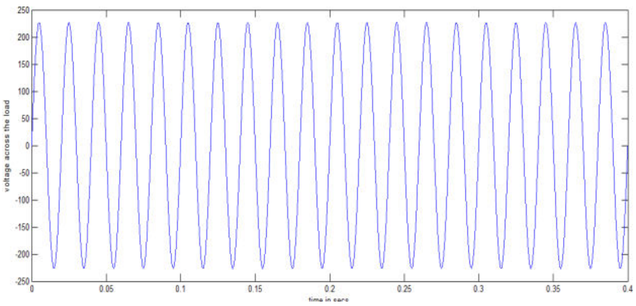

Figure-10. Inverter output voltage in volts for linear load.

CONCLUSIONS

This paper examined the performance evaluation of a 300 watt single phase solar grid tied training system. Time taken for synchronization of grid is very less and efficiency of the inverter is also allowable value. The current supplied by the PV array is rated or near to the rated value distortion factor, power factor, fundamental voltage and fundamental current of the inverter for both linear and nonlinear loads are permissible. Whenever the current supplied by the PV array is very less than the rated value or below 1 ampere, the PV grid tied training system performance is not appreciable due to the low power factor and high total harmonic distortions in the output current of the inverter. By using Simulink an artificial environment is created to validate the inverter output voltage and current waveforms.

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