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Design and Firing Control of Grid Connected Inverter

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Abstract:

In grid interactive mode, inverter supplies the local loads and if the generated energy higher than the demand the excess energy is export to the grid. So battery groups are unneeded. On the other hand, control of the grid interactive inverter is more complex than the stand alone one. In this work, we have proposed a voltage controlled grid interactive inverters to control the export of power to the grid. We have used a conventional PI control strategies in grid interactive inverter applications. Acceptable performance will tried to achieve by using a PI controller designed to work around a determined operating point; thus giving a cost effective power solution to the society.

Keywords: Firing Control, Connecting Grids, DC-AC Inverter, PLL, Pulse controller

INTRODUCTION:

In order for grid tie inverters to comply with utility electrical standards, the output power needs to be clean, undistorted and in phase with the AC grid. Typical modern GTI's have a fixed unity power factor, which means its output voltage and current are perfectly lined up, and its phase angle is within 1 degree of the AC power grid. The inverter has an on board computer which will sense the current AC grid waveform, and output a voltage to correspond with the grid.

There are currently around 22 companies around the globe that manufacture grid tied inverters. However the US and European markets are dominated by two brands SMA (Sunny Boy) and. There are two types of waveform generation control schemes used for grid-connected inverters - Voltage control and Current control. Voltage and current controlled inverters look quite different on a sub 20ms time scale. On a longer time scale (ie seconds) however, inverters used for injection of energy from a PV array directly into the grid are controlled as power sources ie. they inject “constant” power into the grid at close to unity power factor. The control systems constantly monitor incoming power from the PV array and adjust the magnitude and phase of the ac voltage (voltage controlled) or current (current controlled) to export the power extracted from the PV array.

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Voltage Control

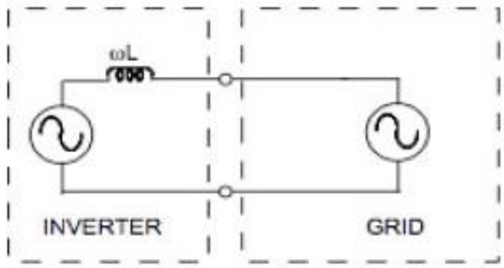


Figure 1a: Voltage control inverter ideal equivalent circuit.

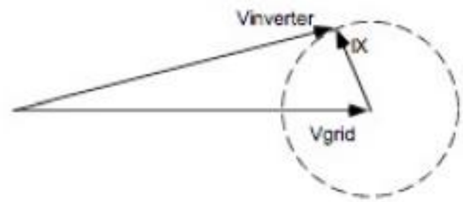


Figure 1b: Voltage control inverter vector diagram

A voltage control inverter produces a sinusoidal voltage output. It is capable of stand-alone operation supplying a local load. If non linear loads are connected within the rating of the inverter, the inverter's output voltage remains sinusoidal and the inverter supplies non sinusoidal current as demanded by the load. Because it is a voltage controlled source it cannot be directly connected to the grid. If the voltage or phase of the inverter is not identical to the grid, a theoretically infinite current would flow. This type of inverter is therefore connected to the grid via an inductance. The inverter voltage may be controlled in magnitude and phase with respect to the grid voltage - see Figures 1a and 1b. The inverter can be thought of as very similar to a conventional synchronous generator with a very low inertia. A phasor diagram for the system is shown in Figure 1b. The inverter voltage may be controlled by controlling the modulation index and this controls the VARs. The phase angle of the inverter may be controlled with respect to the grid and this controls the power.

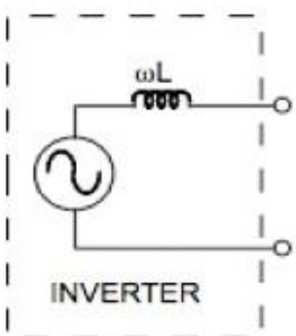


Figure 3a: Voltage controlled inverter 50Hz ideal equivalent circuit.

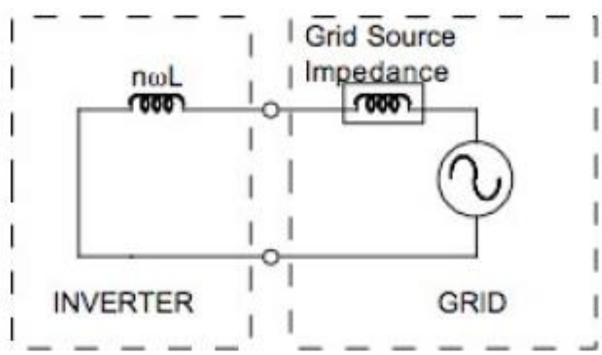


Figure 3b: Voltage controlled inverter harmonic ideal equivalent circuit.

Voltage controlled inverters produce a sinusoidal voltage waveform and are connected to the grid via inductive impedance - see Figure 2a. Looking from the grid into the inverter at other frequencies the inverter (provided it has very good waveform quality) will look like an inductive impedance only - as shown in Figure 2b. If at the point of connection the grid impedance is inductive, the inverter will effectively attenuate the grid harmonic voltage at the point of connection. So the inverter will tend to improve the waveform quality at the point of connection. The other effect that becomes evident is that the inverter will absorb some harmonic current. The amplitude of the harmonic current that flows will depend on the impedances in the system and the amplitude of the harmonic voltage on the grid. If the loads local to the inverter are non linear and hence draw harmonic

currents, the voltage controlled inverter will supply those harmonic currents or at least a portion of them. This reduces the harmonics seen by the grid. Care has to be taken in connecting a voltage controlled inverter to a severely distorted grid. In an extreme case the inverter could use all its output rating on harmonics absorbed from the grid. This is not necessarily a bad thing as it improves the grid voltage but the inverter may not then be capable of exporting power or VARS. The grid interactive inverter provides the interface between the renewable energy sources and the utility. A typical grid interactive inverter injects a sinusoidal current to the grid, and must meet the international standards like IEC61727, IEEE1547 and EN61000-3-2, and radio frequency interference due to high frequency switching should be under control . The grid interactive inverter can be designed as voltage controlled. When the inverter is designed as a voltage controlled it operates as voltage source, and the grid-connection system is equivalent to the parallel connection of two voltage sources. In this mode the inverter is controlled to generate a sine waveform voltage in the same frequency and phase with grid. The output current, injected into grid, depends on the grid voltage quality and the small phase errors can overload the inverter.
The equivalent model of the grid-connected inverter system operated in voltage-controlled mode is shown in Fig. 1. The voltage injected into grid can match the grid voltage on frequency and phase, so the power can be injected into grid with unity power factor. Phase locked loop (PLL) control is employed to match the frequency and phase of grid voltage. The reference voltage is generated by the sine generator based on the voltage phase and the given amplitude of output voltage.
The designed pulse generator generates the switching pattern for single phase full bridge VSI and used to control the inverter output voltage according to reference voltage. Some type of inverters use a high frequency transformer embedded in DC-DC converter or DC-AC inverter, others are interconnected to the grid line via a line frequency transformer, and some inverters do not include transformer. Line frequency transformer can prevent DC current injection problem, provide galvanic isolation between the DC source and the grid line and makes the grounding easier. Although they have disadvantages like size, weight and price, the line frequency transformer is a natural solution of DC current injection and preferred in this study.
As seen from Fig. the system consists of a renewable energy source, a DC-AC voltage source inverter, a line frequency transformer and a LC filter. The renewable energy source can be photovoltaic modules, fuel cells or a small wind turbine. A controlled pulse generator is used for the voltage control. Inverter output voltage is boosted to the line voltage with a line frequency transformer. The line frequency transformer also prevents DC ripple injection in current waveform and provides galvanic isolation between the inverter and the grid line. In addition the transformer simplifies the grounding of the DC energy source. A LC filter is employed to reduce the high frequency harmonic components in current waveform due to PWM switching and to reduce the output current THD.

Grid to Inverter power Flow:

Current injections at a bus are analogous to power injections. Current injections may be either positive (into the bus) or negative (out of the bus). Unlike current flowing through a branch (and thus is a branch quantity), a current injection is a nodal quantity. The admittance matrix, a fundamental network analysis tool that we shall use heavily, relates current injections at a bus to the bus voltages. Thus, the admittance matrix relates nodal quantities.

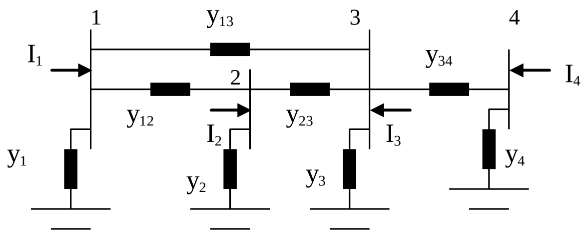


Fig. 1 shows a network represented in a hybrid fashion using one-line diagram representation for the nodes (buses 1-4) and circuit representation for the branches connecting the nodes and the branches to ground. The branches connecting the nodes represent lines. The branches to ground represent any shunt elements at the buses, including the charging capacitance at either end of the line. All branches are denoted with their admittance values y_{ij} for a branch connecting bus i to bus j and y_i for a shunt element at bus i. The current injections at each bus i are denoted by I_i.

$$\underline{Y} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{bmatrix}$$

The power flow equations:

Define the net complex power injection into a bus as $S_k=S_{gk}-S_{dk}$. In this section, we desire to derive an expression for this quantity in terms of network voltages and admittances. We begin by reminding that all quantities are assumed to be in per unit, so we may utilize single-phase power relations. Drawing on the familiar relation for complex power, we may express S_k as:

$S_k=V_kI_k^*$

$$I_k = \sum_{j=1}^{N} Y_{kj}V_j$$

where, Y_{kj} terms are admittance matrix. Substituting eq. (11) into eq. (10) yields:

$$S_k = V_k \left(\sum_{j=1}^{N} Y_{kj}V_j \right)^* = V_k \sum_{j=1}^{N} Y_{kj}^* V_j^*$$

V_k is a phasor, having magnitude and angle, so that $V_k=|V_k|\angle\theta_k$. Also, Y_{kj}, being a function of admittances, is therefore generally complex, and we define G_{kj} and B_{kj} as the real and imaginary parts of the admittance matrix element Y_{kj}, respectively, so that $Y_{kj}=G_{kj}+jB_{kj}$. Then we may rewrite eq. (12) as

$$S_k = V_k \sum_{j=1}^{N} Y_{kj}^{*} V_j^{*} = |V_k|\angle\theta_k \sum_{j=1}^{N} (G_{kj}+jB_{kj})^{*} \left(|V_j|\angle\theta_j\right)^{*}$$

$$= |V_k|\angle\theta_k \sum_{j=1}^{N} (G_{kj}-jB_{kj}) \left(|V_j|\angle-\theta_j\right)$$

$$= \sum_{j=1}^{N} |V_k|\angle\theta_k \left(|V_j|\angle-\theta_j\right)(G_{kj}-jB_{kj})$$

$$= \sum_{j=1}^{N} \left(|V_k||V_j|\angle(\theta_k-\theta_j)\right)(G_{kj}-jB_{kj})$$

From the Euler relation, that a phasor may be expressed as complex function of sinusoids, i.e., $V=|V|\angle\theta=|V|\{\cos\theta+j\sin\theta\}$. With this, we may rewrite eq. (13) as

$$S_k = \sum_{j=1}^{N} \left(|V_k||V_j|\angle(\theta_k-\theta_j)\right)(G_{kj}-jB_{kj})$$

$$= \sum_{j=1}^{N} |V_k||V_j| \left(\cos(\theta_k-\theta_j)+j\sin(\theta_k-\theta_j)\right)(G_{kj}-jB_{kj})$$

If we now perform the algebraic multiplication of the two terms inside the parentheses of eq. (14), and then collect real and imaginary parts, and recall that $S_k=P_k+jQ_k$, we can express eq. (14) as two equations, one for the real part, P_k, and one for the imaginary part, Q_k, according to:

$$P_k = \sum_{j=1}^{N} |V_k||V_j| \left(B_{kj}\sin(\theta_k-\theta_j)\right)$$

$$Q_k = \sum_{j=1}^{N} |V_k||V_j| \left(-B_{kj}\cos(\theta_k-\theta_j)\right)$$

RESULT AND DISCUSSION

A Grid Tied Inverter or a (GTI) allows a direct connection between the DC solar array and your homes AC power grid. This means that PV system can operate without batteries. From there the DC power generated by the solar modules is inverted to higher voltage AC and it's either used directly by your AC appliances or its sold back to your utility company which lowers your monthly electric bill. Having a grid tied solar setup also lowers the cost of going 'green', and is more efficient than using a conventional system which uses a battery power bank.

Grid tied inverter work just like a conventional DC-AC inverter. They will take the input DC power, step it up, filter it into a pure sine wave, and feed it back in to the AC grid. The step up is done via high frequency DC-DC converter (PWM controlled inverter), and the filtration is done via inductors and capacitors. The electricity flows back the other way because the output voltage is slightly higher than the AC grid voltage.

The system in figure 3 represents a model of grid connected inverter. Both the power supply is connected to each other via common load. The simulation is run for 1 second. Also the grid is disconnected from the system sing an isolator at time 30 second.

We can notice from the figure3 that the output voltage of inverter, grid and load are all synchronized with each other. The voltage levels of both the sources (i.e., grid and inverter) are generating and receiving the power at same voltage levels and frequency. At time 30 seconds, we have observed a much better pure sine wave as the grid voltage end. This is because we have disconnected the grid system from the inverter source by an isolator, and harmonics developed by the inverter is no more fed to the grid after 30 seconds. The inverter voltage and load voltage are at the same levels irrespective of grid connection.

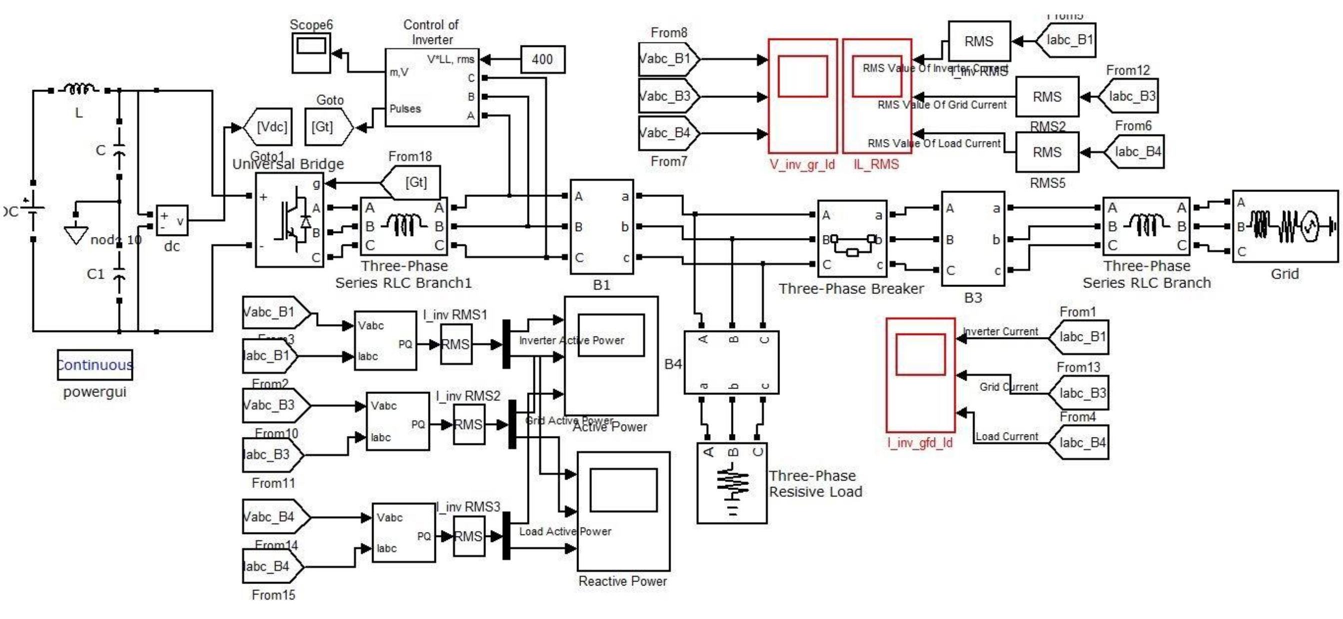


Figure3: Simulink model for the proposed Grid connected system

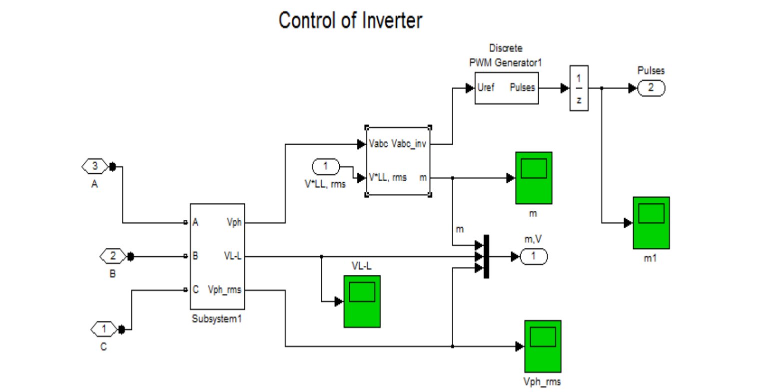


FIGURE4:block diagram for inverter control

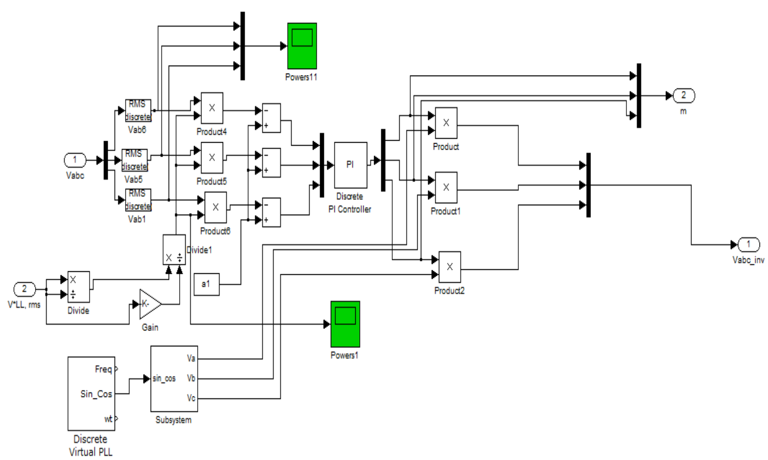
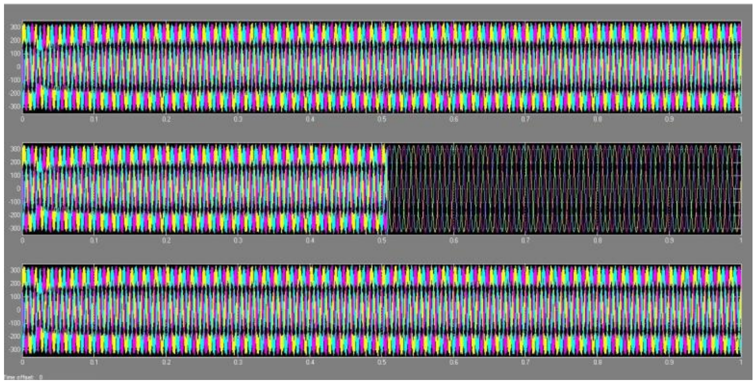
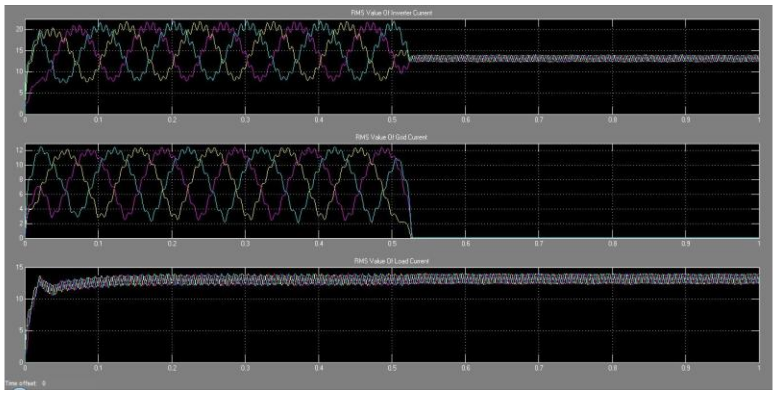


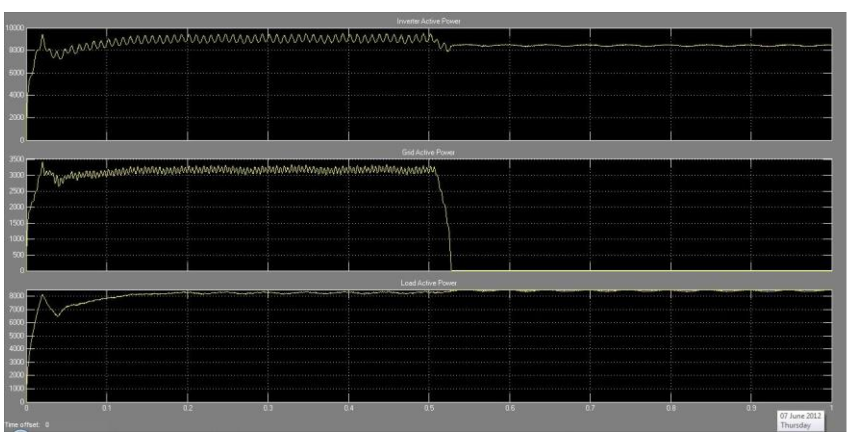
Figure5: internal veiw of inverter controller

Spikes and harmonics can also be seen in all the three voltages, i.e., grid, inverter and load. For such a purpose of harmonics reduction, a properly designed filter must be added / installed at the inverter output end.





Above figure(outputs based on MATLAB) is used to investigate the rms value of the inverter current, grid current and load current. Ideally at a voltage level, the current must be balanced. If a balanced current is assumed, then the magnitude and frequency of all the three phase current must be same; thus producing a constant rms value of current in each of the phase. It can be noted in the figure that grid current has reduced to zero after time 30 second. This happened because of isolation of the grid from the system. It can be observed that the load current rms value is almost constant in all the three phases. Some minor fluctuations in rms value of load current can also be seen in the figure. These fluctuations are much more noticeable, when inverter and grid currents are observed. These effects can be reduced if proper power filter is added at the inverter output.



Above figure show the plot of active power flow from the inverter, power received by the grid and power received by the load.

CONCLUSION:

If analyzed more deeply, at time less than 0.5 seconds, the approximate instantaneous active power can be correlated as

$$Inverter\,ActivePower = Grid\,ActivePower + Load\,ActivePower$$

Also at time more than 0.5 seconds, when grid is disconnected from the system; the power can be correlated as

$$Inverter\,Active\,Power = Load\,ActivePower$$

A noticeable amount of power fluctuations can be seen in the figure. These fluctuations are not tolerable for practical purposes. Thus proper designing of harmonics filter is very essential for future work.

Thus, a non renewable power source can be used much more efficiently and economically using such kind of battery less schemes. This scheme has been designed and proposed so that the extra power generated by the non-renewable energy sources, must not be wasted in dump load (as it is a usual practice). The extra power can now be fed back to the grid, thus virtually reducing the consumption of carbon fuels.

Using this approach have the following advantages of their own

- Reduction of carbon fuel consumption.
- Reduction of renewable power sources
- Reduction in tariff plans at consumer end
- Remowal of dump load from the system
- Eliminating the use of backup power of battery
- Cost reduction

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