Vol.VI / Issue XI March-2017 ISSN:2278-4187

Anuşandhan

Science Technology & Management Journal

Celebrating
Five Years of Meaningful
Research Publication

A better tomorrow for every one through Research & Innovation

Mangalyaan - India

Tejas Jet - India

Solar Road-France

Hi-Tech Robet-Japan

First 3D Printer-USA

Driverless Car-Germany

AISECT UNIVERSITY
Where aspirations become achievements.

AISECT University: Village- Mandua, Post-Bhojpur, Distt - Raisen (M.P.)
India Pin-464993 Ph-0755-6766100, 07480-295707
e-Mail aisectjournal@rediffmail.com, info@aisectuniversity.ac.in
Web site : www.aisectuniversity.ac.in

RABINDRANATH TAGORE UNIVERSITY

UGC Approved Journals

Anusandhan (AUJ-AN)

- Technology & Management

Indexing and Impact Factor :

INDEX COPERNICUS : 48609 (2018)

Read / Download More Articles

Anusandhan - AISECT University Journal Vol.VI/Issue XI March 2017 ISBN: 2278-4187

Power Controlled Grid Linked Inverter Using Phase Shifting Technique

SudhaBhutada[1], Dr. S.R. Nigam[2]

[1]Dept. of Electrical Engineering, S.V. Polytechnic College, Bhopal (M.P.) India.

[2]Dept. of Electrical Engineering, AISECT University, Bhopal (M.P.) India.

ABSTRACT

In the grid connected photovoltaic system Inverter the essential criteria is the power control both active and reactive required before it is injected into the grid. In this paper a control strategy microcontroller based grid linked PWM inverter has been designed. The strategy is made on the basis of shifting of inverter output voltage with respect to grid. The controlled strategy is done using Simulink blocks, function block, counter, and by generating PWM pulses for synchronization with the grid. The proposed model for single phase PWM inverter grid linked has been simulated using Mat lab/ Simulink. The model can be applied for 50/60 Hz frequency. The Inverter model proposed is an easy solution for low power grid linked inverter applications.

Index Terms—Grid connected photovoltaic inverter, Power control, Phase shifting.

I INTRODUCTION

Today the whole world is facing challenge of two major issues, one is energy and the other one is environment [1] To meet the above challenges importance of renewable energy sources has increased. The PV system as the renewable energy source now a days a very important source of energy, because it is pollution less and requires less maintenance and can be easily be applied for residential and commercial purposes [2][3].This has led to increasing use of grid connected PV system for utilization of power.

Most Grid connected inverters based on PV system get useful power from their PV module fitted based on maximum power point tracking analogy along with DC to DC or Boost converters [4][5][6].

The PV Inverters linking with the grid should be properly synchronized. Then only there will be a control on power transfer from Inverter to the grid[7]in present circumstances.

For this the grid connected inverters are to be so designed that they can control active, reactive power and hence control power factor. Then only the system can feed sinusoidal voltage and current into the grid.

Moreover for Grid linked Inverters the various important factors that are to be considered in their designing and execution is, removal of DC part while feeding to the grid, reduction of total harmonic distortion and a proper control so that there is a complete synchronization between the inverter and the grid.

The idea suggested by various researchers is that there should be complete control on current and active power that is injected into the Grid when power factor is unity [7].

The strategy used in this paper is microcontroller based grid linked PWM inverter control system. The approach adopted in this system for linking inverter with the grid is based on a controlled phase shifting, so that the output voltage of inverter with respect to grid voltage is synchronized.

For the above approach the control strategy based on shifting of counter pulse forward or backward is adopted for matching the phase and frequency of the inverter and the grid.

PV Array s designed in Mat lab/Simulink for the controlled approach and can be easily used for single phase grid supply and for frequency variations of 50/60 Hz respectively.

This paper also explains a controlled approach to be used in mat lab/Simulink for generating controlled pulses for the H-Bridge Inverter in order to get a synchronized output generated.

This approach will be able to control voltage and current of PV inverter with respect to the grid. Hence it will control the active and reactive power.

The proposed control approach requires very few components and can be easily applied in hardware circuitry for grid synchronization.

In the paper simulated and experimental results are explained and verified for the controlled approach for grid linked PV inverter.

II DESCRIPTION OF INVERTER CONTROL MODEL

The single phase grid linked inverter model is as shown in fig.1 [4]. The model consists of PV Array, Boost converter, PWM Inverter, Filter, PWM Controller and the Grid. The constant 24V DC supply is used as input to DC to DC Converter (Boost Converter). The Boost Converter based on dual boost concept is designed [8] and utilized to convert firstly the 24 V dc input into 86 V and then it converts the voltage into 312V. This Boost Converter output was then fed to H-Bridge Inverter whose output was then linked with LCL filter circuit [9] which converts the input voltage into 230 V rms. The inverter voltage obtained was then checked for phase and frequency matching before it is fed to the grid. This requires a phase locked loop to be designed. For this a PWM controller was designed using the concept of phase shifting with the help of counter moving either forward or backward. It also generates pulses required for triggering of mosfet's of the H-bridge so that the output of inverter is locked with respect to the grid. Hence phase and frequency are verified easily of inverter and the grid.

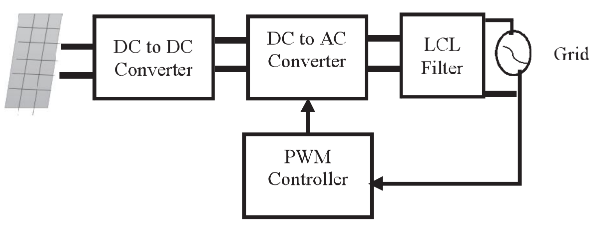

Fig. 1. Grid linked Inverter Model

The grid inverter current is obtainable from PV module. The inverter and grid are coupled through either L, LC or LCL filters according to the requirements of smooth output of the inverter.

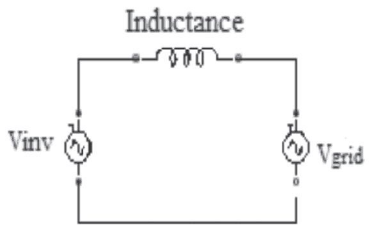

Fig. 2. Behavioural performance of inverter and grid

Fig.2 represents the behavioural performance of inverter and grid. For the above circuit phasor diagram is as shown in fig. 3.

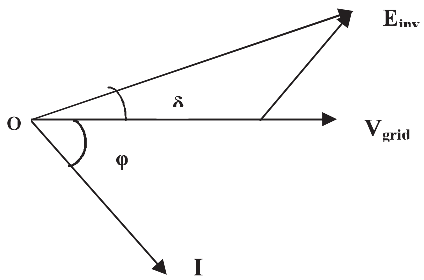

Fig.3. Phasor diagram

In the phasor diagram where,

V = Grid RMS voltage
E = Inverter output voltage (RMS)
I= Inverter output current (RMS)
$jX_L I$=Voltage drop across the inductance
φ = Angle between grid voltage and inverter output current
δ = Load angle between grid voltage and inverter output current.

From the phasor diagram shown in fig.3 we have a relation between V, E and X_L as follows,

$$V = E + jX_L I \quad \text{(i)}$$

$$ESin(\delta) = X_L I Cos(\varphi) \quad \text{(ii)}$$

From above expressions the active power given by inverter to the grid is given by equation as:

$$P = VI\ Cos\ (\varphi) = \frac{VESin(\delta)}{X_L} \quad \text{(iii)}$$

Hence, reactive power Q is given by the equation as,

$$Q = \frac{VECos(\delta)}{X_L} - \frac{V^2}{X_L} \quad \text{(iv)}$$

From the equations of P and Q it is found that both P and Q are related to load angle δ.

Thus for controlling active and reactive power we need to control angle δ which is the phase difference in between the grid voltage and inverter output voltage. Also at that moment reactive power is also easily controllable as it also depends on angle δ.

Equation (iii) and (iv) also suggest that the output current depends on the amplitude of inverter voltage and on angle δ. Required conditions for a grid inverter are as follows:

(i) The output voltage magnitude and phase should be same as grid voltage.
(ii) The inverter output frequency should also be same as that of grid.

Also for maximum power transfer from inverter to the grid the angle δ should be closed to 90°. But for stability condition it should be slightly less than 90°[7][10].

III PROPOSED DESIGN

The proposed system model is as shown in fig.4.

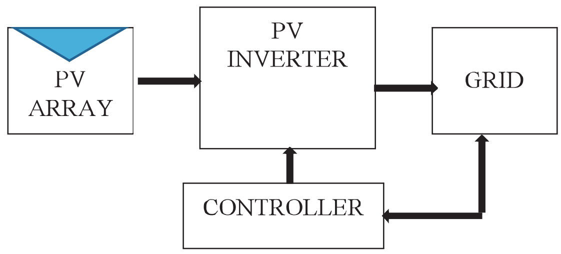

Fig.4. Proposed System Model

In the proposed model microcontroller based PWM controller is designed for grid linked inverter.

The important components of control structure are PWM generating unit, control block consisting of zero crossing detector, counter and a logical array required for phase shifting of pulses for synchronization, Boost converter and H bridge inverter are the main elements of the controlled system required for synchronization of the grid linked inverter. The controlled structure locks the phase and frequency of inverter voltage to the grid voltage as required for the synchronization. Moreover under this condition only active power is transferred to the grid and grid current is also in phase with the inverter current.

The required System control model with blocks is shown in fig. 5 prepared in the environment of Matlab/Simulink.
The logic used for phase and frequency matching of grid linked inverter is based on phase and frequency matching using controlled phase shift either leading or lagging of the inverter output voltage with respect to the grid voltage. For this a system microcontroller based grid linked PWM inverter control system is designed. This model will lock phase and frequency. Hence a new phase locked loop for synchronization between the inverter and the grid is designed.

 ISBN: 2278-4187

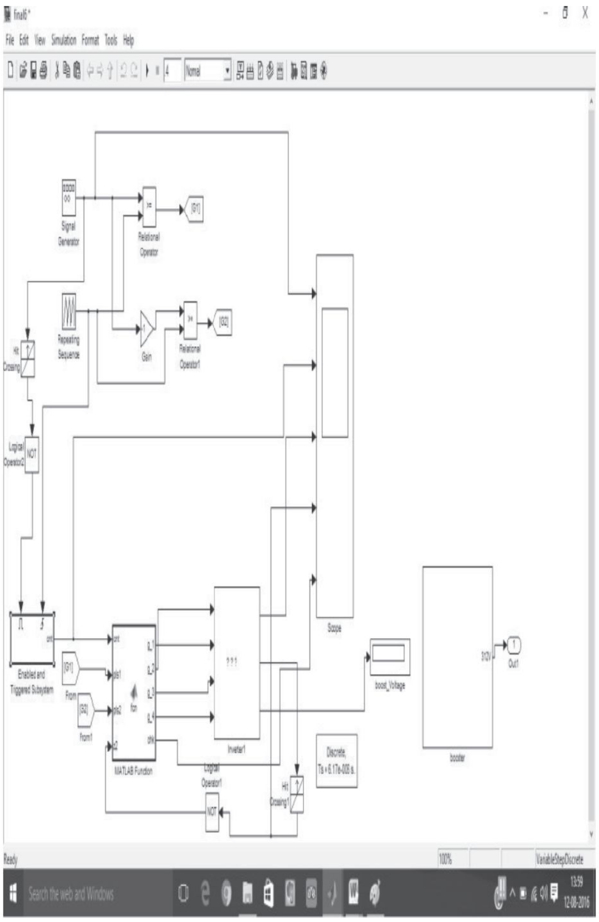

Fig. 5.Matlab / Simulink model of Grid linked PWM control system

Fig.5 shows the PWM controlled model prepared using Matlab/Simulink. The logic used for the above model is as follows:

Firstly the ramp generator and grid supply voltage is compared by a comparator for generating the triggered pulses required for H Bridge switches i.e. Mosfet's. At the same time the grid voltage is passed through zero crossing detectors to detect the rising edge of the pulse. The pulse is negated and enabled and shifted by one unit delay. At the same time the ramp pulse is also triggered, delayed on rising edge of pulse. Hence a subsystem counter is developed for the two pulses to be enabled and triggered accordingly. In Fig.6 enabled and triggered counter model is shown as a subsystem of PWM control model.

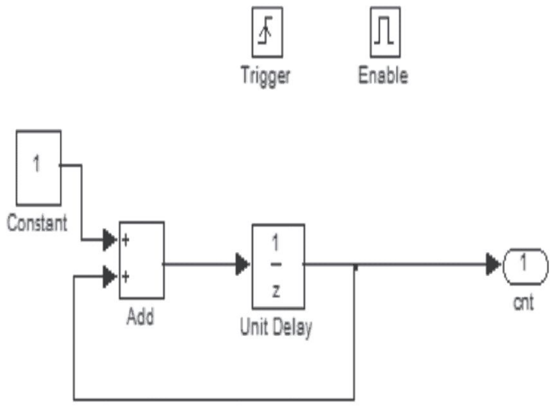

Fig. 6. Enabled and triggered counter subsystem model

In the Model the logic used is as given in fig. 7.

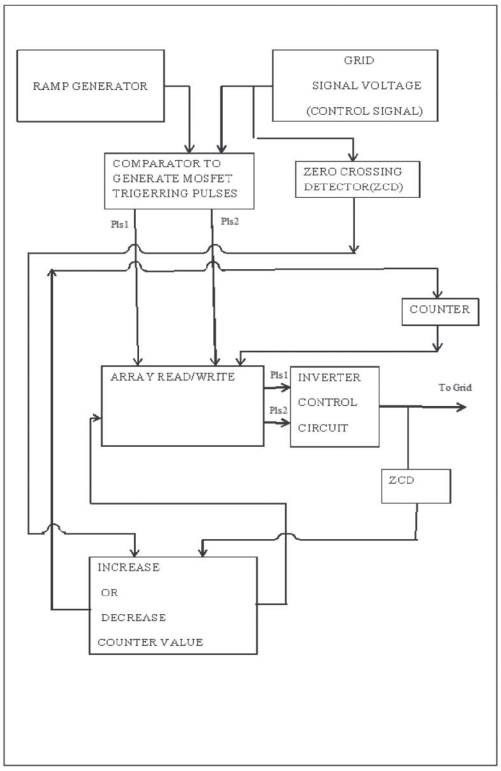

Fig. 7. System Controlled Model Logic

The subsystem forms a counter and it starts storing counter values in accordance with the ramp generator time value. Hence an array is developed which can read or write the counter values.

A logical programme flow chart is shown for the two generated pulses in an array in fig. 8 for the functional block of the system model, in which firstly the values are initialised, than counter values are shifted forward or backward as per inverter output. The counter is shifted as analysed by the functional block in which logic is prepared for shifting of pulses.

Then the pulses are passed through zero crossing detector and linked with the grid for phase matching. The whole process continues by passing the two pulses Pls1 and Pls2 generated again through a crossing detector on rising edge of pulses so that a required wave with zero phase shifts is obtained. The pulses generated are used for triggering Mosfet's. Therefore the output of inverter obtained is in phase with the grid as required.

If the grid waveform leads the inverter waveform than counter values is added and if it lags the counter value is subtracted for synchronization of the waveform.

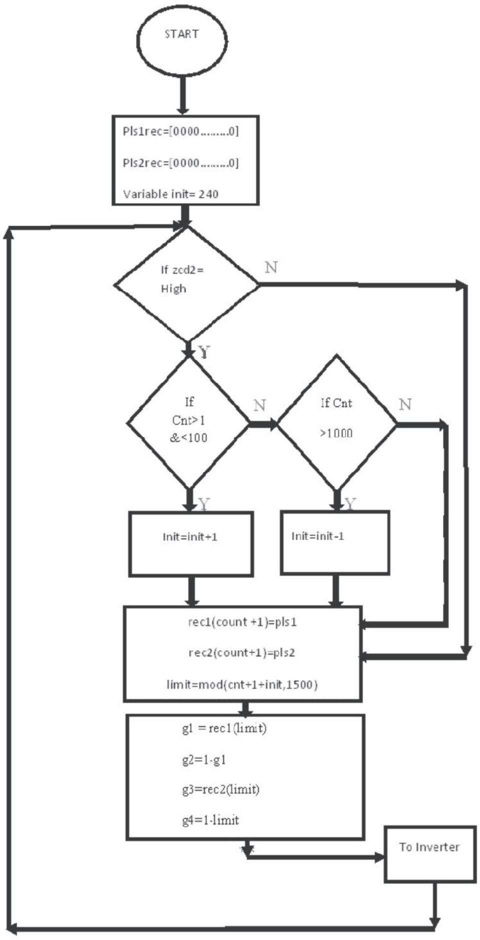

Fig. 8. Logical flow chart for the functional block of the system model

Also in fig.9 the subsystem inverter model is shown in which the boost converter model and H bridge inverter model is designed as per references [8] and [9] respectively.

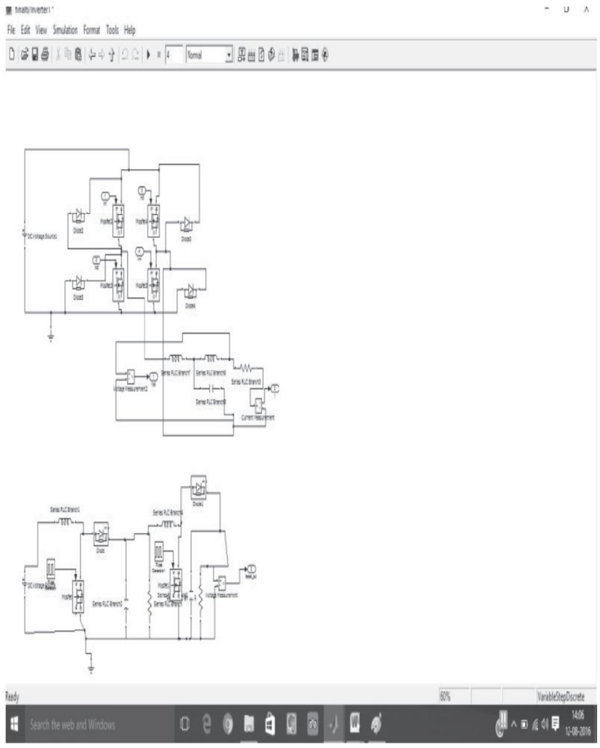

Fig. 9 Inverter model

The boost converter boosts the input voltage. The converter converts PV Array energy into electrical energy and thus it full fills the requirement of linking inverter with the Grid effectively without using transformer[12].The H Bridge inverter converts dc voltage into alternating voltage so as to link it with the grid or utility purposes. The H bridge inverter output is a square wave. Therefore at the output of Inverter low pass filter, for reducing harmonics and converting the square wave to sinusoidal one, is required [11]. In the fig. 10 LCL filter model is shown in which Vi, Vo are the inverter and grid voltages and L_1, L_2, r_1, r_2 are inductances and resistances of inverter and grid respectively and C is the capacitance.

By applying Kirchhoff's Voltage Law (KVL) in the two loops of LCL filter model following equations are obtained.

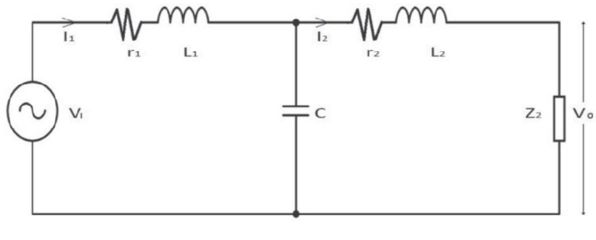

Fig. 10. LCL Filter Model

$V_i(s) = Z_{L_1}(s)I_1(s) + V_C(s)$

$V_C(s) = Z_{L_2}(s)I_2(s) + V_2(s)$

Where, $Z_{L_1}(s) = r_1 + \square L_1 s$, $Z_{L_2}(s) = r_2 + \square L_2 s$ and

$V_C(s) = I_C(s)\frac{1}{Cs}$

By KCL we have, $I_C(s) = I_1(s) - I_2(s)$

Therefore, from above equations we have,

$A = (L_1s + r_1)\, Cs + 1$

$B = (L_1s + r_1)(r_2 + L_2s)\, C_s + (L_1s + r_1) + (r_2 + L_2s)$

$C = C_s$

$D = \{(r_2 + L_2s) + \frac{1}{Cs}\}C_s$

Where $s = j\omega$

At resonant frequency, (taking resonant frequency, $\omega_r = \omega$),

We have, $\omega L = \omega C$

$\omega^2 = \sqrt{\frac{1}{LC}}$, $Z_0 = \sqrt{\frac{1}{LC}}$ and $Q_1 = \frac{\omega L}{r_1}$, $Q_2 = \frac{\omega L}{r_2}$

Where, Q_1 and Q_2 are the quality factors of inductors.

If $L_1 = L_2 = L$ than A B C D parameters becomes,

$A = j\frac{1}{Q_1}$

$B = jZ_0[1 + j\frac{1}{Q1Q2}]$

$C = j\frac{1}{Z0}$

$D = j\frac{1}{Q_2}$

If Q_1 and Q_2 high then A = D= 0 and BC = 1 which is a property of ideal convertor.

Hence I_2 becomes $\cong \frac{V_1}{Z_0}$

Now taking $\omega_0 = 1$ radian per second, cut off frequency f_c = 50 Hz and $Z_0 = 20\ \Omega$ the values of L and C of filter circuit can be found.

$$\text{As } C = \frac{1}{2\pi fc\ Z0} = \frac{1}{2*\pi*50*20} = 0.159\text{mF}$$

$$\text{And } L = \frac{Z0}{2\pi fc} = \frac{20}{2*\pi*50} = 63.60\text{mH}$$

Experimentally the values of L chosen is 55mH and C as .159mF for the LCL filter designed for single phase grid linked Inverter.

Bode plot of LCL Filter

Putting the values of L and C in the transfer function

$$G(s) = \frac{159*10^{-3} + 1000}{480975*10^{-9}s^3 + 17490*10^{-6}\, s^2 + 110s}$$

For above transfer function bode plot is plotted in Mat lab and the output obtained is as shown in fig. 11 and Fig. 12 respectively.

The fig. 12 shows the Bode plot after inserting damping resistance in the capacitor path.

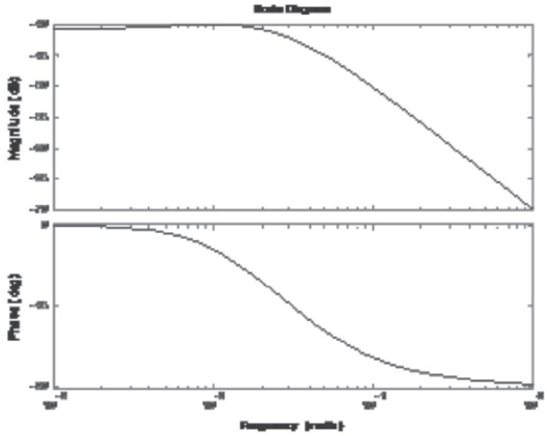

Fig. 11.Bode plot of LCL Filter

In the LCL filter by inserting damping resistance in the capacitor path eliminates spikes and the response is better smooth. From bode diagram the close bandwidth is ≅1000Hz around phase shift of -90°.

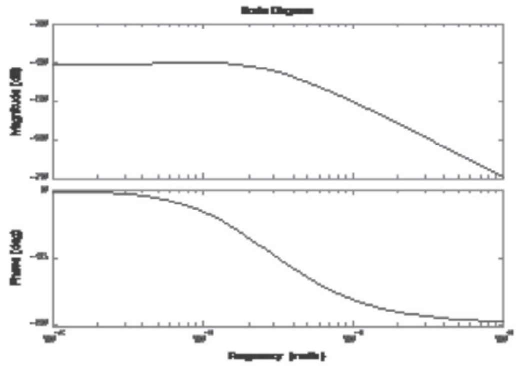

Fig. 12. Bode Plot of LCL Filter after damping resistor inserted

IV SIMULATED RESULTS

In the fig. 13 generated results of Simulink model of Grid linked system of PWM Inverter as shown in fig. 5 is obtained using Matlab/Simulink software. The Simulation was run for 1 second with solver discrete type having settling time of 6.17e-06s. The simulated results obtained after simulation are shown as per fig.13. In the fig.13 the first waveform is of reference signal which is a signal generator of 230 volts 50 hertz frequency.

The second waveform is of ramp counter which is a repeating sequence block in Simulink, whose time values taken as [0 .5e-5 1e-5 1.5e-5] and output values as [-230 0 230 0].

The third waveform is of output voltage of inverter after locking with the grid. It is a waveform which is phase locked with a frequency of 50 Hertz and can be supplied to the grid. The output obtained is of 230 volts 50 Hertz.

The fourth waveform is of zero crossing detector which helps to increase or decrease counter value for phase and frequency locking.

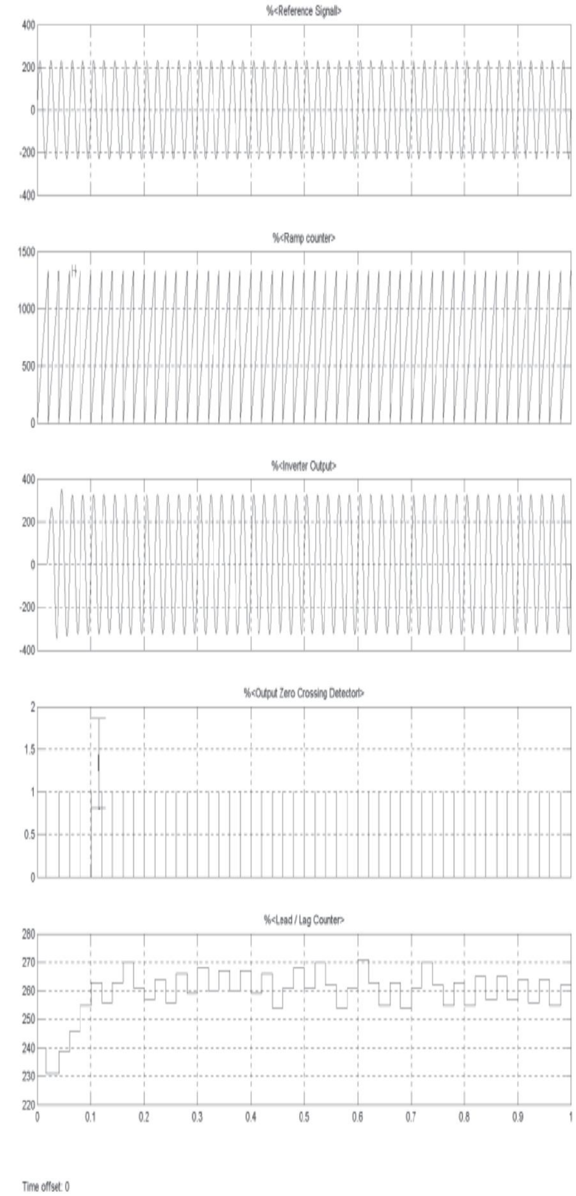

Fig. 13. Output of Grid Linked Inverter Model for 50 Hz Frequency

The fifth waveform is of counter as per the zero crossing edge it detects and increases or decreases the counter for locking so that the inverter and grid output are in synchronization. Thus counter helps to control angle δ. Hence active and reactive powers are controlled.

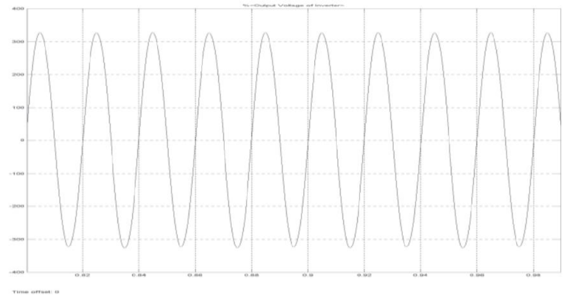

Fig. 14. Output Voltage of Inverter

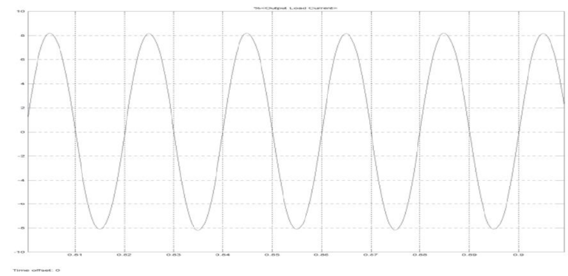

Fig. 15 Output Current of Inverter

The inverter output voltage obtained from the model as 234 volts RMS and output load current as 5.85Amp with THD of 1.96% as shown in fig. 14 and fig. 15 respectively.

The model was also tested for 60 Hz frequency and results obtained are satisfactory. The fig.16 shows the generated results of model for 60 Hz frequency.

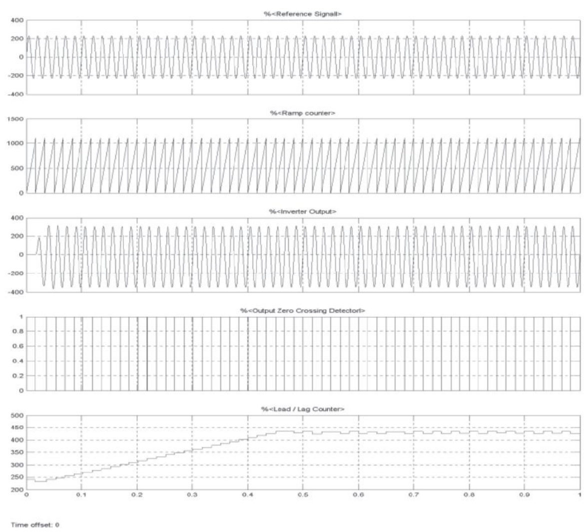

Fig.16. Output of Grid Linked Inverter Model for 60 Hz Frequency

V CONCLUSION

The paper presents a novel controlled strategy for low voltage and low power transformer less single phase Inverter to be linked with the Grid effectively. In this paper the new and efficient approach to control angle δ is presented and can be used for 50 or 60 Hz frequency with total harmonic distortion in the output of inverter restricted to 1.96%. The Inverter controlled model analysis and experimental simulation have been presented in the paper. The Inverter output is easily controllable by varying delta angle using counter to shift forward or backward as required for controlling the output voltage and current in respect to the grid for locking conditions. The output results obtained are good as expected. The limitations of the model are boost converter output to be a fixed one. The PV Array output is not fixed as it depends on the weather conditions. So it is required to control the Boost Converter output for better performance of the inverter model proposed. Another limitation of the model is the filter which circuit requires large inductance and capacitance but the greatest advantage of the circuit is that it eliminates transformer and hence it overcomes all other disadvantage is of less importance.

The model proposed is a new approach and can be verified easily by implementing it in the hardware circuitry requiring minimum components at much less cost.

REFERENCES

[1] Bimal K. Bose, "Global warming: energy, environmental pollution, and the impact of power electronics", IEEE Industrial Electronics Magazine, March 2010, pp. 6-17.)

[2] N. Kaushika & N. Gautam, "Energy Yield Simulations of Inter connected PV Arrays," IEEE Transactions on Energy Conversion,Vol.18, No. 1, May 2003, Page(s): 127~134.

[3] N. Femia, G. Lisi, G. Petrone, G. Spagnuolo & M. Vitteli, "Distributed Maximum Power Point Tracking of Photovoltaic Arrays: Novel Approach and System Analysis",IEEE Transactions on IndustrialElectronics, Vol. 55, No. 7, July 2008, Page(s): 2610~2621.

[4] Hugo Nunes, Nelson Pimenta, Luís Fernandes, Paulo Chaves, J.M. Dores Costa, "Modular buck-boost transformer less grid-tied inverter for low voltage solar panels", International Conference on Renewable Energies and Power Quality, ISSN 2172-038 x, No. 12, April 2014.

[5] ChuanYao,X, Ruan, X.Wang , "Isolated Buck-Boost DC/DC Converter for PV Grid-Connected System", 978-1-4244-6392-3/10 IEEE 2010

[6] Zhigang Liang, Alex Q. Huang, Rong Guo, "High Efficiency Switched Capacitor Buck-Boost Converter for PV Application", 978-1-4577-1216-6/12/$26.00 ©2012 IEEE 08 DECEMBER, 2012.

[7] Linda Hassaine, Emilio Olías, Jesús Quintero and Andrés Barrado ,"Power control for grid connected applications based on the phase shifting of the inverter output voltage with respect to the grid voltage", Electrical Power and Energy Systems 57 (2014) pp. 250–260

[8] S.Bhutada,S.R.Nigam," Design & Simulation of Boost Converter for Solar Application" Ciit International Journal of Programmable Device Circuits and Systems,Vol 7,No 01,January 2015.

[9] S.Bhutada,S.R. Nigam, "Single Phase PV inverter Applying a Dual Boost Technology", International Journal of Scientific Engineering and Technology VolumeNo. 4 Issue No. 6, pp:356-360, ISSN2277-1581,)1 June 2015.

[10] Dalia H Al Maamoury, Muhamad Bin Mansor, Ali Assim Al Obaidi,"Active Power Control For A Single-Phase Grid- Connected PV System",International Journal of Scientific & Technology Research Volume 2, Issue 3, March 2013,ISSN 2277-8616 198.

[11] Hyosung Kim and Seung-Ki Sul."A Novel Filter Design for Output LC Filters of PWM Inverters", Journal of Power Electronics, Vol. 11, No. 1, January 2011.

[12] Nkundayesu Gloire, Dong Lei,Liao,Xiaozhong,XiaoFurong,"Single Phase Grid-Connected PV Inverter applying a Boost coupled inductor," ITEC Asia-Pacific 2014 1569950583