ADVANCED CONTROL SCHEME FOR LCL TYPE GRID CONNECTED INVERTER TOPOLOGY

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Abstract

In a power system, the electrical parameters like current and grid voltage are to be controlled to obtain the synchronism and stability. It is absolutely necessary to measure the variation of phase and frequency with grid voltage accurately and quickly at every instant of time. The power electronic equipment is increasing gradually, such as grid-connected inverters, reactive compensators and other equipment. The lot of problems in the system due to the above converters which further increases the complexity to lock phase for phase-locked loop (PLL). The best method is to achieve stability is the small signal impedance analysis. The research on the stability of grid-connected LCL-type inverters is often based on the impedance model, which greatly simplifies the analysis complexity. The impedance stability criterion can be directly employed to evaluate the grid-connected system stability.

In order to overcome the problem of harmonics, the concept of small signal analysis is applied along with the help of phase locked loop control. In order to achieve more reliability, an LCL type grid tied inverter is being used. The simulation of this project is developed by MATLAB/SIMULINK. This method is a much reliable method and can be realized more effectively further.

Keywords— Small Signal Impedance analysis, Phase-locked loop (PLL), LCL-type Grid Tied Inverters, MATLAB/SIMULINK

I. INTRODUCTION

Grid Tied Inverters are deliver renewable energy to the grid they are typically controlled as current sources injecting current to the grid. With the increasing prevalence of renewable energy resources, power quality and stability issues induced by grid-tied inverters. Harmonic pollution could happen due to the interaction between inverter and grid impedance. Large grid impedance could destabilize the inverter system. In order to deliver power to the grid, frequency and phase angle of the inverter output current should synchronize with grid voltage, which is usually served by phase-locked loop. Some recent literatures discovered that PLL has a negative impact on the system stability.

In the past, instability issues of power electronics related systems are mainly believed to be caused by the negative incremental resistors of dc–dc, dc–ac converters in dc systems, and ac–dc converters in ac systems. The negative incremental resistors are results of the output voltage regulation of these converters. Together with the high efficiency features of these converters, they become constant power loads, which consumes a fixed amount of power regardless what the supply voltage is. The input current increases when the supply voltage decreases, and vice versa. The negative resistor in combination with other components in the system can under certain conditions constitute a negative resistor oscillator, and is the origin of the system potential instability. This kind instability can be analysed by applying nyquist stability criterion to the impedance ratio between source and load in the dc system[1].

This project analyses the small-signal impedance of three-phase grid-tied inverters with feedback control and phase- locked loop (PLL). The result unveils an interesting and important feature of three-phase grid-tied inverters – namely, that its channel impedance behaves as a negative incremental resistor. Moreover, this project shows that this behaviour is a consequence of grid synchronization, where the bandwidth of the PLL determines the frequency range of the resistor behaviour, and the power rating of the inverter determines the magnitude of the resistor[2]. Advanced PLL, current, and power control strategies do not change this feature. An example shows that under weak grid conditions, a change of the PLL bandwidth could lead the inverter system to unstable conditions as a result of this behaviour. In order to improve the phenomenon that a traditional phase- locked loop based on a double second-order generalized integrator cannot track signal amplitude and phase accurately when the input signal contains DC components and high-order harmonics, the structure of a second-order generalized integrator-quadrature signals generator is modified. This project establishes the impedance model considering the DSOGI-PLL structure of the inductor- capacitor-inductor-type (LCL-type) inverter grid-connected system adopting current control measured from the grid terminal in alternating current side, introducing voltage feedback control to enhance the stability of the system [3]. Meanwhile, analyzing the influence of parameters on impedance according to the impedance model established preferable design parameters.

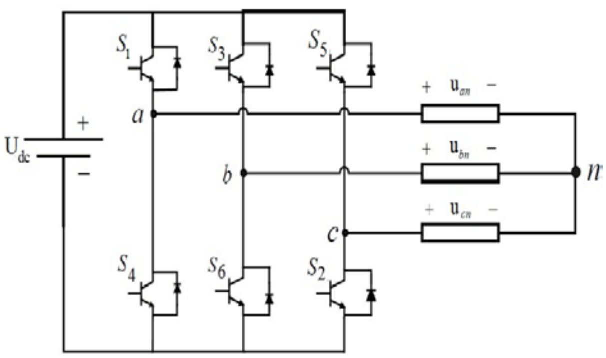

Fig.1. Grid Connected Inverter Topology Structure

II. GRID TIED INVERTER AND COMPONENTS

A) GRID TIED INVERTER:

An inverter is an electrical device that converts direct current (DC) to alternating current (AC); the AC signal can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits. Fig.1 shows the power circuit diagram for a three phase bridge voltage source inverter. Six switches (in three legs) are used to generate an AC waveform at the output from the DC source. Any semiconductor switch like IGBT, MOSFET or BJT can be used. Diodes in parallel with switches are called feedback diodes. They feed energy back to the DC source in case of inductive loads when the main switch is turned off. The special kind of inverter used to connect a renewable resource to an AC network is called a grid-tied inverter.

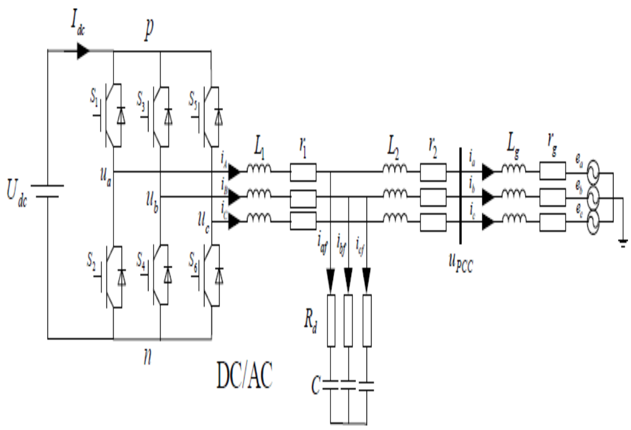

Fig.2. Power Circuit Diagram of IGBT based Three phase Inverter

The consumption of electrical energy in the world is continuously ascent. Large primarily moderate conventional power sources attached to transmission system are aggregated or replaced with greater number of inferior renewable energy sources straightly attached to local distribution grid. Power electronic converters serve as an efficient interface between primary energy sources and the utility grid.

A grid-tie inverter (GTI) is a special type of inverter that converts DC power to AC power for connection to an existing electrical grid. GTIs are often used to convert DC power produced by renewable energy sources, such as solar arrays or wind turbines, into the AC power used to power homes and businesses.

As very broad amount of energy is essential in recent Technological word, whole energy sources works their best to complete the requirement of energy. By applying continual energy Sources like Solar, Wind, we can assist to overcome energy crisis. If we think about solar the homelike production of electricity is possible and it may be amounted greater than our need. The extra amount of energy can fed to Electricity Company. For such operation the device used to feed this generated power is known as grid tie inverter.

The electricity produced by any endless energy source will be gathered in the battery. By using inverter or Grid Tie Inverter (GTI) Battery supply i.e. dc will be converting into ac. In Hardware model, we use the MOSFET as a switching or semiconductor device for inverter. To operate this device we use the SPWM technique to provide gate pulse to MOSFET.

The main part of grid is the synchronizing the voltage and frequency. The circuit also used in grid design for protection purpose. In order to implant electrical power adequately & provided that to grid, the Grid Tied Inverter must properly suit Voltage and Phase of the grid Sine AC waveform.

B) Block Diagram of GTI:

The GTI is used to connect sources to an 18V RMS AC network. Commercial GTI" s were not used because they are typically designed for higher voltage systems (e.g. 120V RMS AC), do not have the capability to control real/reactive power (four quadrant) output and are unable to directly interface with the PLCs in our system. We need a GTI capable of bidirectional control of active and reactive power flowing to and from the network, providing the ability to regulate power quality and dynamic and transient characteristics of power angle.

The main part of the GTI in Fig.3 is the full-bridge inverter that consists of six semiconductor switches. The inverter has a driver section that provides the switching pulses to the power switches. A controller section (typically an electronic circuit) is used to generate the right commands/pulses to control the inverter in an appropriate way.

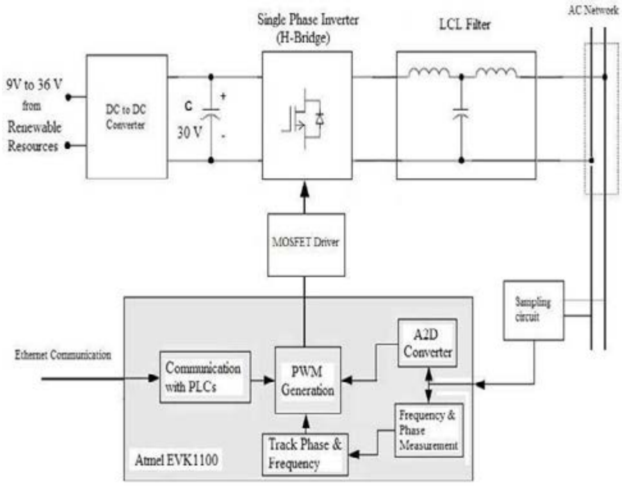

Fig.3. Block Diagram of Grid Tied Inverter

Here, a microcontroller is used to control the GTI system as well as perform other tasks such as sampling the grid voltage and communicating with higher-level controllers in the network. The DC-DC converter converts non-constant voltage from renewable resources into a constant 24V DC voltage and supplies it to the inverter. The transformer amplifies the magnitude of the voltage coming out from the full-bridge inverter. The low pass filter is used to remove the high frequency signals produced by the switching pulses from the output waveform to produce a clean AC signal. Because the output of the GTI is connected to the grid, the waveform output should be synchronized with the grid in terms of amplitude, frequency, and phase. For this purpose, the grid voltage is sampled and used in the software to generate the appropriate output waveforms.

III. DESIGN OF GRID TIED INVERTER

The grid is a complex dynamic system originally. The two main schemes to realize the phase-locking, one based on PLL that the paper focuses on and another without PLL for the purpose of frequency tracking and phase locking of the gird. PLL is used to implement synchronization between the control loop and the grid system, however, a large amount of penetration of distributed generation systems in the grid will inevitably give rise to the grid system stability problem. Therefore, it is fairly necessary to research the phase-locked loop in order to ensure the system does not lose stability because of the phase synchronous problem.

A) PHASE LOCKED LOOP CONTROL (PLL):

In view of the PLL as an indispensable part of grid-connected system, scholars have always insisted on researching it to improve the performance of PLL. It is a common phase-locked way due to simple control mode and fast response speed. However, if the conditions of voltage unbalance and high-order harmonics resulting from grid fault appear, PLL will have a larger error in phase locking. In light of decoupled PLL utilizing the decoupling network to eliminate the double harmonics caused by the negative sequence component, a good result of phase lock is obtained. However, the method has a large amount of computation and slow dynamic response. Besides, the low pass filter will generate delay to some extent that may affect the real-time performance of the control whereas the second-order generalized integrator-PLL (DSOGI-PLL) can effectively deal with the inaccurate phase-locking problem of decoupled- PLL under an unbalanced grid voltage fault[10]. However, the phase-locked information cannot be accurately obtained under the condition of DC voltage and high harmonics included in the grid voltage. However, the project only considers the phase synchronization capacity of the PLL under DC bias without considering other conditions, such as three-phase unbalance of grid voltage. An adaptive filter based on SOGI to extract the positive and negative sequence of three-phase grid voltage, aiming at the tracking error generated by traditional PLL under harmonic distortion and grid asymmetry[4]. In allusion to the phenomenon that the traditional DSOGI-PLL cannot lock phase precisely when the DC components and high order harmonics are contained in the grid voltage, the improved second-order generalized integrator-quadrature signals generator (SOGI- QSG) structure is proposed.

The research on the stability of grid-connected LCL-type inverters is often based on the impedance model, which greatly simplifies the analysis complexity. Simultaneously, impedance stability criterion can be directly employed to evaluate the grid-connected system stability. The control strategy of optimization delay aims to solve the problem that the control path calculation delay is not conductive to the system stability under the current control mode of LCL-type grid-connected inverter. The strategy is effective to improve the system stability. A simplified proportion multi-resonant (PMR) current controller tuning strategy considered for grid- connected stability which effectively improves the current harmonic distortion, aiming to solve the problem of low frequency harmonics caused by the grid voltage distortion or the non-linear characteristics of current loop in the grid-connected voltage source inverter (VSI). Based on the impedance, the influence of PLL, current loop and power loop on the inverter, and the influence of bandwidth in PLL on the system stability also is analyzed. A novel impedance control strategy to reshape the output impedance of the PV grid-connected inverter in order to suppress the harmonic resonance phenomenon in the PV grid- connected system. Active impedance control strategy based on voltage feed forward is proposed, so that the grid-connected inverter has better control robustness under different dynamic gird conditions. Meanwhile, the influence of PLL on the stability of single-phase LCL-type grid-connected inverter is also a high priority and the method of PLL parameter design based on the requirement of phase angle margin is crucial. For improving the stability of LCL-type grid-connected inverter, the output impedance model of LCL-type grid-connected inverter considering DSOGI-PLL structure is established. Meanwhile, the system phase margin at the impedance intersection is raised by introducing compensated grid-connected voltage into the current loop, thereby enhancing the system stability. Aiming at the phenomenon that the traditional PLL cannot realize precise synchronization in the gird fault, the improved SOGI-QSG structure is important, which can realize precise phase-locking in the grid fault, such as the unbalanced grid, DC components and harmonic included in the grid voltage. Meanwhile, the voltage feedback control strategy is crucial to raise the system stability based on impedance analysis. Firstly, an improved DSOGI-PLL is important to solve the problem that the original DSOGI-PLL cannot accurately lock the phase when the DC component included. Then, the output impedance mathematical model of LCL-type grid-connected inverter considering PLL is established and the stability of grid-connected inverter is analyzed based on the cascade stability criterion of impedance [10]. At last, the design parameters of improved SOGI-QSG structure and control strategy are displayed, which is verified by simulation. Simulation results show that the accuracy of improved PLL output frequency and the voltage and current characteristics of grid-connection are improved effectively.

B) IMPEDANCE MODEL OF GTI:

The inverter adopts grid side current closed loop control mode. It is a LCL type Grid connected Inverter system. Where Zinv(s) is the equivalent output impedance of the inverter AC terminal Zg(s) is the equivalent impedance of the grid; I(s) is the equivalent current source of the inverter; E(s) is the ideal grid voltage source.

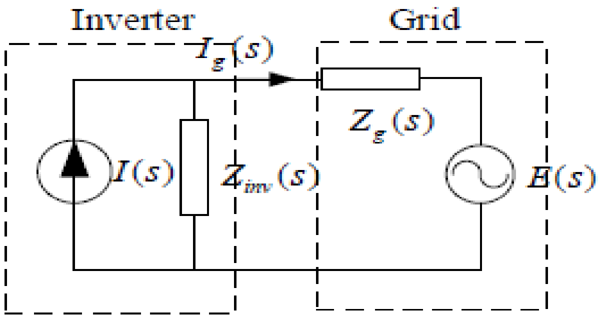

Fig.4. Equivalent Grid Inverted Circuit

Equation (1) is the expression of grid current Ig(s).

$$I_g(s) = \left[I(s) - E(s)Z_{inv}^{-1}(s)\right]\left[Z_g(s)Z_{inv}^{-1}(s) + E\right]^{-1} \quad \ldots\ldots(1)$$

where E denotes identity matrix.

In order to ensure the system stability under the conditions of impedance variation, the following two terms must be satisfied

(1) When the grid impedance is equal to zero, the system is stable

(2) When the grid impedance exists, $Zg(s)Z^{-1}(s)$ needs to satisfy the impedance stability criterion.

According to the Equation (1), the whole grid-connected system will be stable if the above terms can be satisfied at the same time. Then, the inverter output impedance and grid impedance are modeled respectively.

C) Mathematical modeling of Grid Tied Inverter:

A LCL-type grid-connected inverter can availably suppress the high-order harmonics of the grid current, while the grid inductance can also play a role in suppressing the impulse current.

In the Fig.5. Udc and Idc represent DC link voltage and current respectively; L1, r1 represent the machine-side filter inductance and inductance parasitic resistance respectively; L2, r2 represent the grid-side filter inductance and inductance parasitic resistance respectively; Rd represents the damping resistance; C is the filter capacitance; Lg, rg represent the equivalent inductance and resistance of electric wires respectively; and ei (I = a,b,c) represents the ideal three-phase grid voltage.

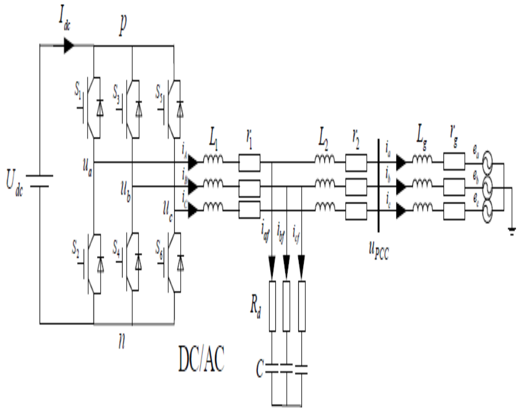

Fig.5.Grid inverted topology

Equation (2) is the state-space equation of grid-connected inverter in three-phase stationary coordinates.

$$\begin{cases} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = L_1 \frac{d}{dt}\begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + r_1 \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + L_2 \frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + r_2 \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} u_{ga} \\ u_{gb} \\ u_{gc} \end{bmatrix} \\ C\frac{d}{dt}\begin{bmatrix} u_{afc} \\ u_{bfc} \\ u_{cfc} \end{bmatrix} = \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} - \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \\ R_d C \frac{d}{dt}\begin{bmatrix} u_{afc} \\ u_{bfc} \\ u_{cfc} \end{bmatrix} + \begin{bmatrix} u_{afc} \\ u_{bfc} \\ u_{cfc} \end{bmatrix} = L_2 \frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + r_2 \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} u_{ga} \\ u_{gb} \\ u_{gc} \end{bmatrix} \end{cases}$$

…………(2)

where ui, ugi (I = a,b,c) represent the three-phase voltage at the machine side and the grid side respectively; ii (I = A,B,C), ii (I = a,b,c) represent the three-phase current at the machine side and grid side respectively; and uifc (I = a,b,c) represents the capacitor terminal voltage.

The derivation of grid small signal model is similar to the grid-connected inverter. Grid state-space equation in three-phase stationary coordinatesis given by

$$\begin{bmatrix} u_{ga} \\ u_{gb} \\ u_{gc} \end{bmatrix} = L_g \frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + r_g \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

…………………(3)

D) Mathematical modelling of PLL:

The quadrature signal generator based on the traditional second- order generalized integrator (SOGI) not only can realize 90° phase angle offset of input signal, but also filter out high-order harmonics.

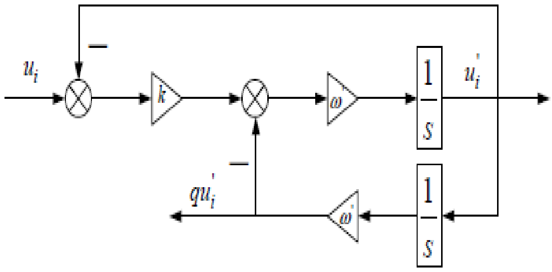

Fig.6.Traditional second-order generalized integrator quadrature signals generator (SOGI-QSG) structure

E) STEADY STATE STABILITY

Steady state stability is the capability of power system to restore to its initial condition after a small disturbance or to reach a condition very close to the initial one when the disturbance is still present and steady state stability refers to the maximum flow of power possible through a particular point without causing the loss of stability when the power is increased very gradually. Since the electrical system is always subjected to small disturbances, the steady state stability requirement is essential for the system to operate properly[6].

The assessment of the steady state stability is required for checking of stability of an electrical power system in a specified state. When all the components of an electrical system act together, they are being treated as one large system connected at that point, for the purpose of steady state stability. Steady state stability problems arise when there is a problem with constant voltage and constant frequency.

IV. SIMULATION MODEL AND RESULTS

A) Simulation Model:

The simulation of the given model consists of a PLL block and the Matlab function block and they are constructed and combined with the help of basic blocks and in order to achieve ans auto correction we take the help of an programming interfa.

The technique is used to operate systems automatically by connecting an interlink between them. It is actually perfectly termed as synchronization as this technique establishes a relation between the grid and the grid tied inverter with the help of a C program i.e establishing a concept of sync with the help of both Matlab and C programming Interface.

This method also gives a flexibility in testing a range of values in a short period of time and reduces the complexity of manual correction again and again. The values are being set and adjusted with the help of an manually corrected C program.

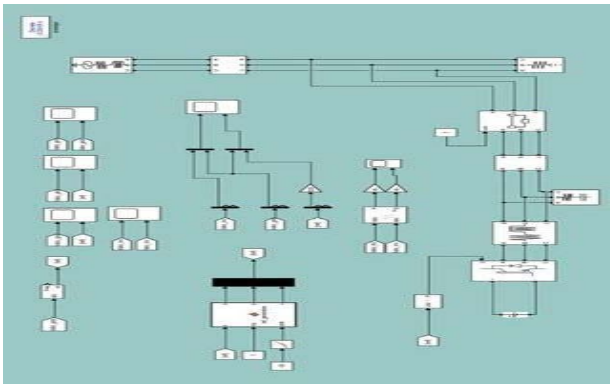

Fig.7. Simulation diagram of Grid Tied Inverter

B) S**imulation results**:

The simulation results are taken from the scope, where it was given to two axes, both voltage and current. The results after the simulation of the model taken from scope are as follows:

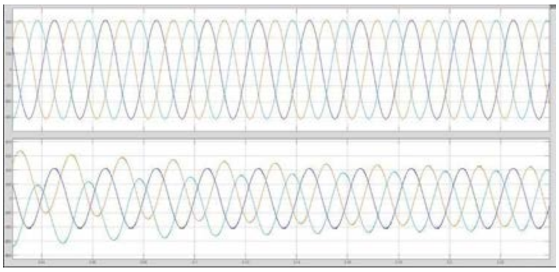

Fig.8.Voltage and Current Waveforms of Grid

The voltage and the current are not properly balanced in the grid. So here in order to compensate it we take the help of the grid tied inverter and then we try to synchronize them as per the stability requirement.

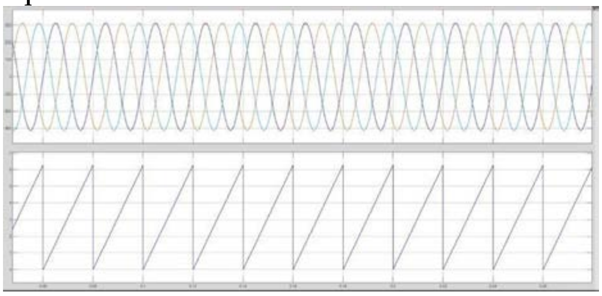

Fig.9.Voltage and pulse width modulated waveforms of grid

Here the voltage of the grid is being shown with reference to the frequency signal. Here the concept of pulse width modulation comes into picture. It is being treated as a reference signal over here.

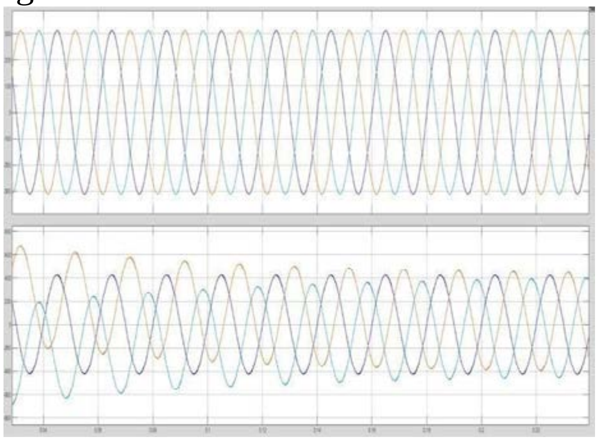

Fig.10.Voltage and reference signal waveforms of grid

Here the voltage and the normal reference signal waveforms are given in order to show the amount of deflection existing in the grid without being synchronized.

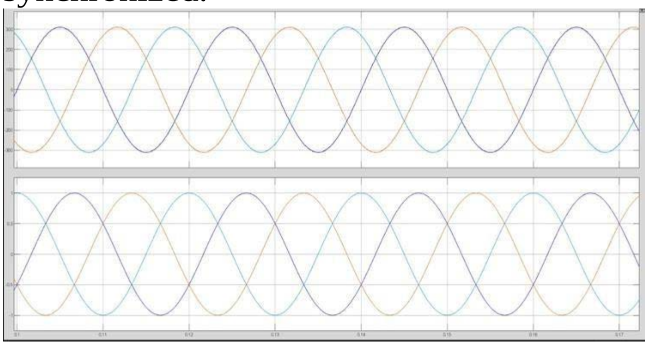

Fig.11.Voltage and current waveforms of grid tied inverter

The voltage and current Waveforms of grid tied inverter are completely in phase with their respective other phases. This is to be merged with the grid in order to achieve the required synchronism and equilibrium of the entire system.

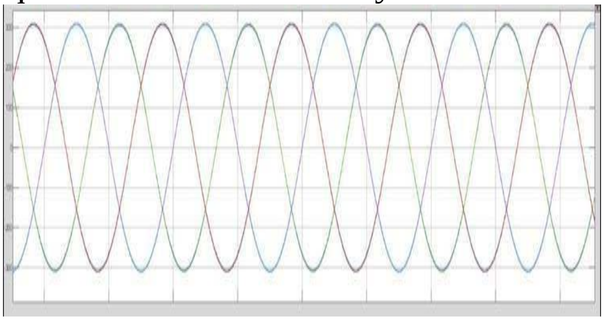

Fig.12.Voltage synchronization Waveforms of grid and grid tiedinverter

The required synchronism between the grid and the grid tied inverter is obtained .The voltage fluctuation is nevertheless or same in both the connected systems.

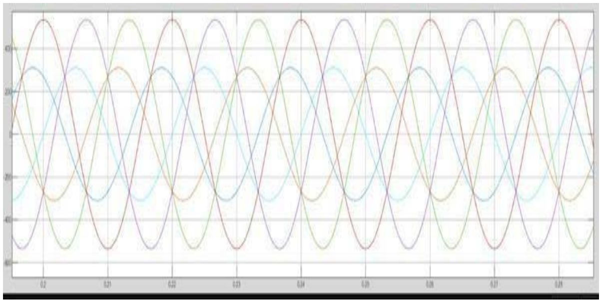

Fig.13.Comparison waveform between the Grid voltage and reference waveforms after synchronization

A certain range of gain is used in order to achieve the synchronism and also to avoid the possibility of occurrence of harmonics in the system which possibly occur both in the grid and the grid tied inverter.

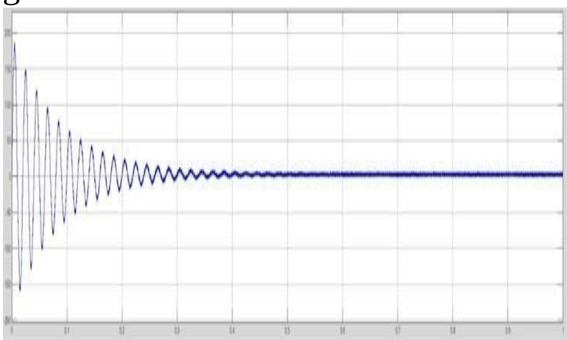

Fig.14.Waveform of Power and the reduction of third orderHarmonics

The Third order harmonics are reduced by obtaining synchronism between the grid and the grid tied inverter. A 3 ph instantaneous power block and a gain value of 1/1000 is used to obtain the power within the operable limits.

V. CONCLUSIONS

The proposed technique of the power inverters forming the grid have been presented according to the power inverter role. The impedance concept has been introduced and its suitability to control power sharing in paralleled power converters has been pointed out. The hierarchical control structure on grid has been presented as well and the functionality of each layer has been discussed, being highlighted the importance of high- level control layers for optimizing efficiency and performances, meanwhile generation costs are reduced. The grid services have been reviewed as well and their requirements on the control scheme layers have been pointed out.

REFERENCES

[1] Mukhopadhyay, S.; Soonee, S.K.; Singh, B.; Sehgal, Y. Opportunities and Problems of Smart Grids with Large Penetration of Renewable Energy-Indian Perspective. In Proceedings of the IEEE Power and Energy Society General Meeting, Vancouver, BC, Canada, 21–25 July 2013.

[2] Bose, B. Power Electronics, Smart Grid, and Renewable Energy Systems. Proc. IEEE **2017**, 105, 2011–2018.

[3] Zeng, M.; Huang, L.; Yan, F.; Jiang, D. Research of the Problems of Renewable Energy Orderly Combined to the Grid in Smart Grid. In Proceedings of the Asia-Pacific Power and Energy Engineering Conference, Chengdu, China, 28–31 March 2010.

[4] Khan, S.; Bletterie, B.; Anta, A.; Gawlik,W. On Small Signal Frequency Stability under Virtual Inertia and the Role of PLLs. Energies **2018**, 11, 2372.

[5] Liu, B.; Zhuo, F.; Zhu, Y.; Yi, H.;Wang, F. A Three-Phase PLL Algorithm Based on Signal Reforming Under Distorted Grid Conditions. IEEE Trans. Power Electron. **2015**, 30, 5272–5283.

[6] Zheng, X.; Xiao, L.;Wang, H.;

Liu, S. Grid Frequency Tracking Control Strategy without PLL for Three-Phase Inverter. In Proceedings of the Energy Conversion Congress and Exposition, Pittsburgh, PA, USA,14–18 September 2014.

[7] Sawant, R.; Rao, Y. A Discrete-Time Controller for Phase Shift Controlled Load-Resonant Inverter Without PLL. In Proceedings of the IEEE International Conference on Power Electronics, Drives and Energy Systems, Mumbai, India, 16–19 December 2014.

[8] Rasheduzzaman, M.; Khorbotly, S.; Kimball, J. A Modified SRF-PLL for Phase and Frequency Measurement of Single-Phase Systems. In Proceedings of the Energy Conversion Congress and Exposition, Milwaukee, WI, USA, 18–22 September 2016.

[9] Hui, N.;Wang, D.; Li, Y. An Efficient Hybrid Filter-Based Phase-Locked Loop under Adverse Grid Conditions. Energies **2018**, 11, 703. Energies **2018**, 11, 3077 21 of 21.

[10] Yuxia Jiang, Yonggang Li, Yanjun Tian * and Luo Wang, Phase-Locked Loop Research of Grid-Connected Inverter Based on Impedance Analysis. Article *Energies* **2018**, *11*(11), 3077;