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Harmonic Stability Assessment for Multi Paralleled PV Inverters-Connected to Grid

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Abstract

This work gives the idea of investigation on Harmonic commerce between current controllers used in multi paralleled PV inverters connected to grid. The harmonic instability problem is point out and solved by impedance based stability criterion under the consideration of dynamic behaviour of the grid. The causes for stabilized/destabilize the PV inverter by varying grid impedance and it is point out and solved by the impedance-based stability criterion. Beyond, case studies are given, which give the idea of the non-passive nature of multi paralleled PV inverters connected to grid under the consideration of dynamic behaviour of the system by inserting connections of other grid connected PV inverters. After, the Time domain simulation results of multi paralleled PV inverters connected to grid are provided in the MATLAB-Simulink area in brood nature. The harmonic commerce problems are occurred in current power system and it can be assessed by the impedance-based stability analysis through shoot those problems.

Keywords: Impedance-based Stability Criterion Analysis, Harmonic Stability, Distribution Generation, Inverter Output Impedance, Grid Impedance, Passivity.

I. INTRODUCTION

In current and future days, renewable energy sources are developed to overcome the future load demand and they are now expected future electric supplies and commercialized. Renewable sources may be solar, wind or geothermal. These sources can have operated as isolated system or grid connected system. When these sources are interfaced with grid and we can use the voltage source or current source inverters based on their own advantages. when PV voltage source inverter are connected in parallel to the grid then there is possibility of harmonic instability problem arise, which is mainly caused by the commerce of inner current control loops with respect to LCL-filter parameters and grid impedance [1],[2] may exhibit resonance amplification in a wide frequency range as compared to fundamental frequency, this problem effects the PV inverters are suddenly shut-down occurs unexpectedly[3] and Each PV inverter is designed individually stable as per grid connection standards , the quality of the power at the point of common coupling (PCC) may not be good.[4].Recent research work shows the impedance commerce between the multiple inverters may cause two problems, these are (1) Resonance amplification (2) The consequent harmonic instability. The above two problems are analyzed and solved by impedance base stability criterion (IBSC) analysis (or) passivity based analysis, the impedance based stability criterion (IBSC) was used to design the input filters for DC-DC converters [5], [6], in earlier days. Nowadays the IBSC analysis is applied to multi paralleled inverters connected to grid to study the harmonic commerce problems of the current controllers used in the AC distribution power system, the system stability is analyzed by nyquist plot analysis using minor loop gain and from the Nyquist plot analysis the system is stable when there are no encirclements of (-1, j0) point otherwise the system unstable. The concept of passivity originated in control engineering, has recently been gaining attention [7] and it provides phase angle based design guideline for the all connected subsystems and each subsystem must have phase angle range between $[-90^{\circ}, 90^{\circ}]$,then the system is in stable otherwise unstable.

II. PV ARRAY MODELING AND MPPT

II.a. PV Array Modeling

A PV Array comprises the number of solar modules wired in cascaded and shunted to get the required voltage and power rating. The single diode model of the PV Cell is shown below for simple modeling neglect the series and shunt resistance.

$$I = I_{pv} - I_{D1} \quad (1)$$

$$I_{D1} = I_{o1}\left[\exp\left(\frac{q(V)}{A_1KT}\right) - 1\right] \tag{2}$$

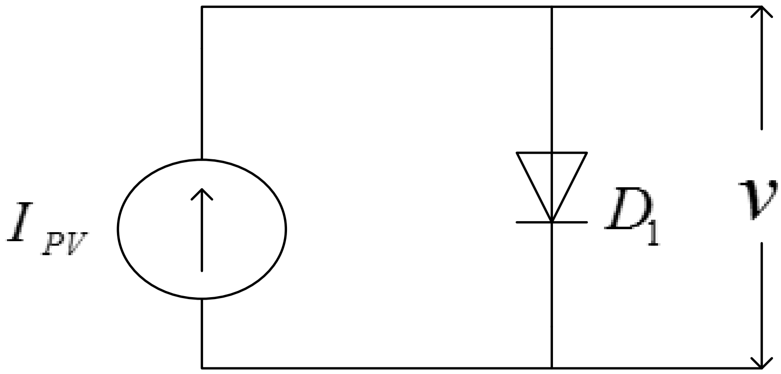

Figure 1: PV Cell Equivalent Circuit.

$$I_{pv} = \left[I_{scr} + K_i\left(T_k - T_{refk}\right)\right] \times \lambda/1000 \tag{3}$$

Here λ is the solar irradiation, I_{scr} is cell shorted current, T_k and T_{refk} are, the actual and standard temperature. Kis temperature coefficient of short-circuit current (A/ K), A_1 is the diode ideality factors. q is the charge of the electron and I_{o1} is the reverse saturation currents of D. Equation (1) is modified for PV module as given in eq.5& 6.

$$I = N_p I_{pv} - N_p I_D \tag{4}$$

$$I = N_p \times I_{pv} - N_p \times I_o\left[\exp\left\{\frac{q \times (V)}{N_s A_1 kT}\right\} - 1\right] \tag{5}$$

Here N_s is the number cell connected in cascade. Np is the number of parallel cell branches connected in module. The Parameters in Table.1. is used to Simulate The PV Module in MATLAB Simulink and PV Array is Designed for 7 KW,350V.

Table 1. Parameters of the PV Module

Parameter	Variable	Value
Current at Maximum Power	I_m	8.30A
Voltage at Maximum Power	V_m	30.2V
Open Circuit Voltage	V_{OC}	37.3V
Short Circuit Current	I_{SC}	8.71A
Internal Series Resistance	R_S	0.217ohm
Reference Solar Radiation	S_{ref}	1000W/m2
Reference Temperature	T_{ref}	300k

II.b. Maximum Power Point Tracking(MPPT)

As Temperature and Irradiations values are change due climatic conditions. So to extract the maximum power from PV array. Perturb & Observe algorithm is implemented in this work. which is simple method by means which variable duty cycle is generated given to the boost converter.

III. CALCULATION OF INVERTER OUTPUT ADMITTANCE

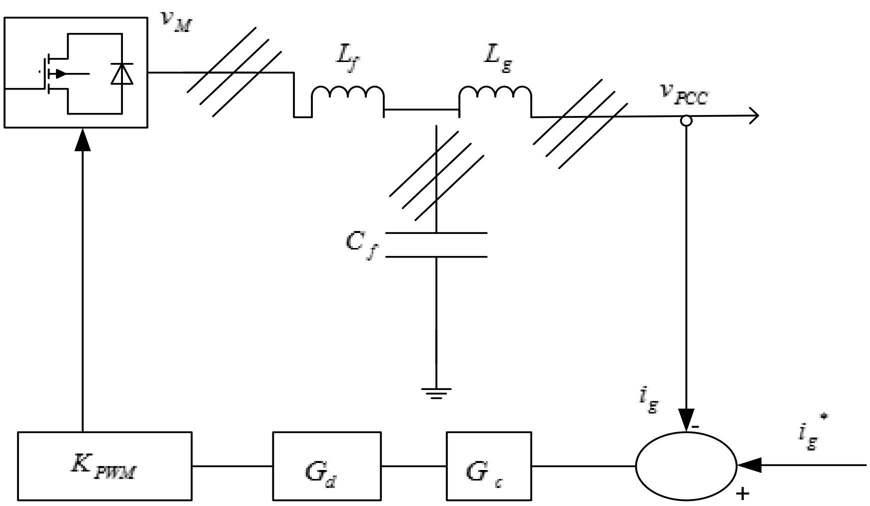

Figure 2: Single-Phase Representation of LCL-filtered Inverter with grid Current Control.

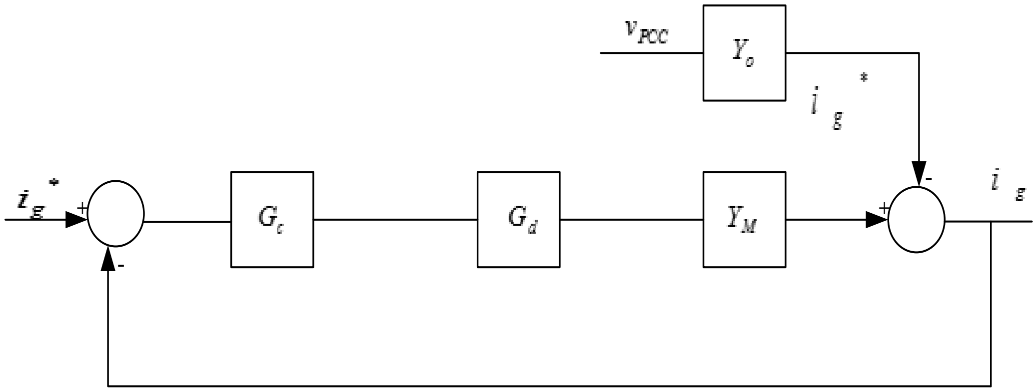

Fig .3. Averaged Switching Model of the grid inverter.

In order to model the inverter output impedance the averaged switching model is shown in Fig.2 and the feedback path having the components are current controller (G_c),delay gain (G_d) and modulator gain (K_{PWM}) are defined as:

$$G_C(s) = K\,, G_d(s) = e^{-1.5T_S s}\,, K_{PWM} = 1 \tag{6}$$

The inverter output to filter input relation is given by

$$Y_o(s) = \left.\frac{-i_g}{v_{PCC}}\right|_{v_M=0} = \frac{s^2 C_f L_f + 1}{s(s^2 C_f L_f L_g + L_f + L_g)} \tag{7}$$

The filter output to grid (or) load relation is given by

$$Y_M(s) = \left.\frac{i_g}{v_M}\right|_{v_{PCC}=0} = \frac{1}{s(s^2 C_f L_f L_g + L_f + L_g)} \tag{8}$$

Finally, the inverter output admittance can be defined as:

$$Y_C(s) = \left.\frac{i_g}{v_{PCC}}\right|_{i_g^*=0} = \frac{Y_O}{1 + G_c G_d Y_M} = \frac{s^2 C_f L_f + 1}{s^3 C_f L_f L_g + s(L_f + L_g) + K e^{-1.5T_S s}} \tag{9}$$

Here K- proportional gain of the current controller.

T_s - sampling time of the inverter in seconds.

i_g - Grid current.

v_M & v_{PCC} - Modulator and PCC voltages.

L_f & L_g -Converter and grid side inductance of the filter.

IV. PV INVERTER CONNECTED TO GRID WITH CONTROL DIAGRAM FOR MATLAB-SIMULINK IMPLEMENTATION.

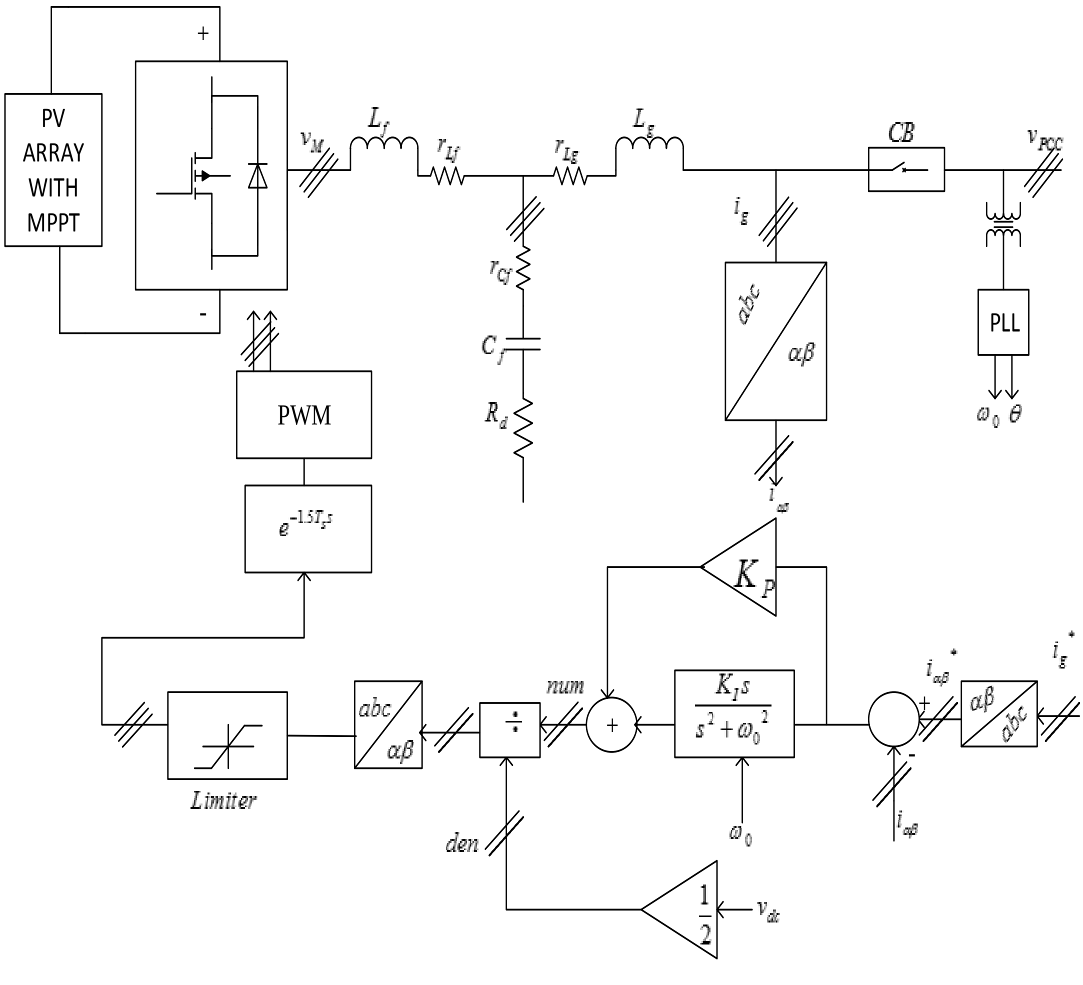

Fig 4. PV Inverter Connected to grid Control Diagram.

Table 1: Specifications and parameters of the Grid Inverter.

Inverter Name		INV.1	INV.2	INV.3	INV.4	INV.5
Power Rating[KVA]		5.6	3.5	10.5	4.2	7
Switching Frequency[Hz]		10		15	10	
DC Link Voltage		600V				
Filter Values	L_f [mH]	20	22	24	25	15
	C_f[uf]/r_d	22/0.2	15/0.4	2/7	3/42	15/0.9
	L_g[mH]	0.22	0.3	1.7	1.3	0.2
Parasitic Values	r_{Lf}[mH]	11.4	15.7	66.8	49.7	10
	r_{Cf}[mf]	7.5	11	21.5	14.5	11
	r_{Lg}[mΩ]	2.9	3.9	22.3	17	2.5
Control Gain	K_p	8.05	28.8	16.6	6.5	5.6
	K_I	1000	1500	1500	1000	1000

IV. CASE STUDY 1: VARYING GRID IMPEDANCE

From the impedance based stability analysis the Nyquist plot of The Minor loop gain of the overallsystem should not encircles the (-1, j0) to be a stable otherwise system becomes unstable.

$$T_{MG} = \frac{Y_{SG}}{Y_{LA}} \quad (10)$$

$$\mathrm{Y_{LA} = Y_G + Y_{CPFC} + Y_{CLA} + Y_{CLB} + Y_{CLC} + Y_{CLD} + Y_{CLE}} \quad (11)$$

Simulation Results of grid impedance Variation: $\mathrm{L_s = 155uH}$

Fig.5. Representing the Nyquist plot of the system with $\mathrm{L_s = 155uH}$ which does not encircle the (-1,j0) so the system is stable shown in Fig.5. and simulation results are shown below from Fig.6. to8.

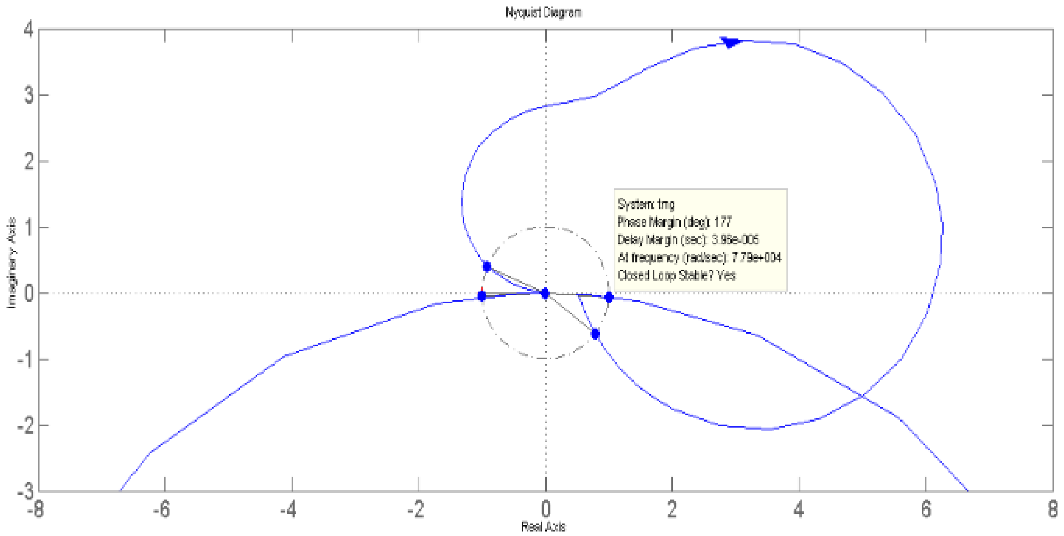

Fig.5. Nyquiest Plot.

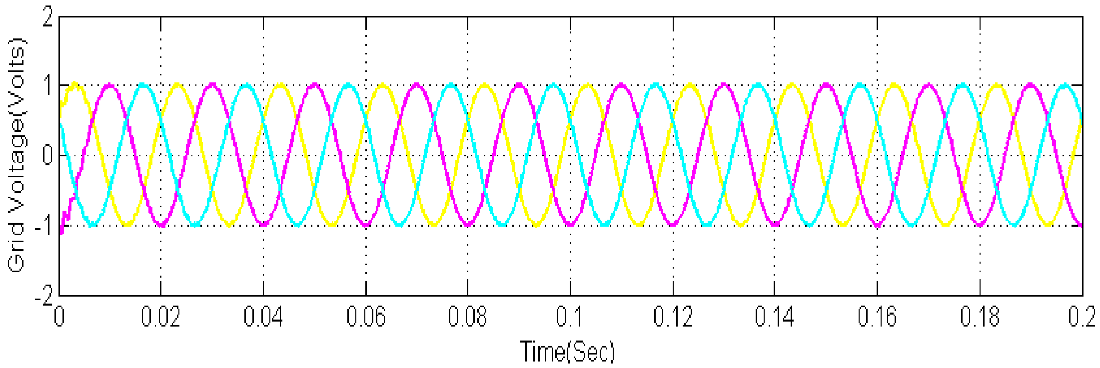

Fig.6. Grid Voltage.

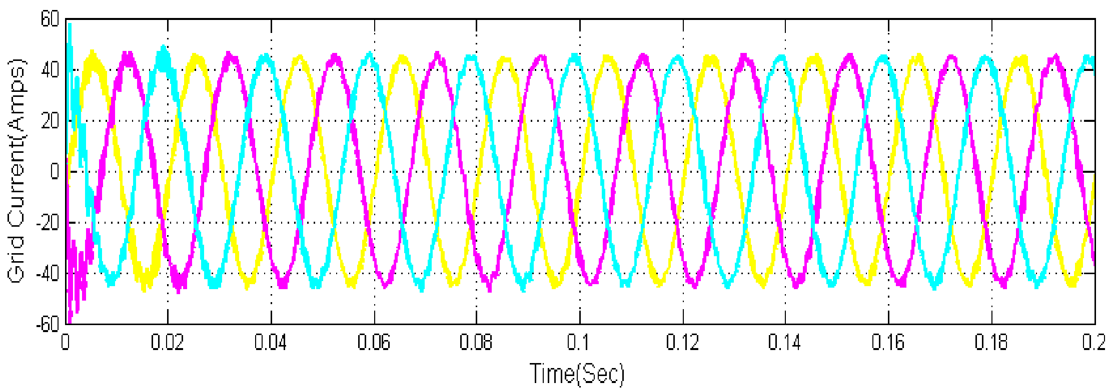

Fig.7. Grid Current

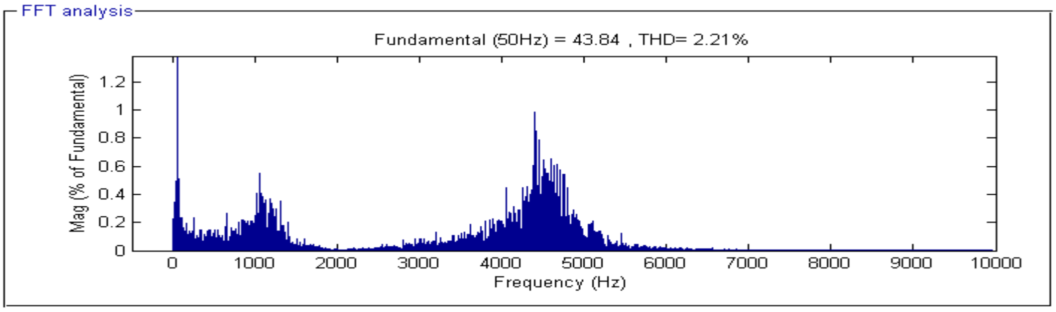

Fig.8. THD Analysises

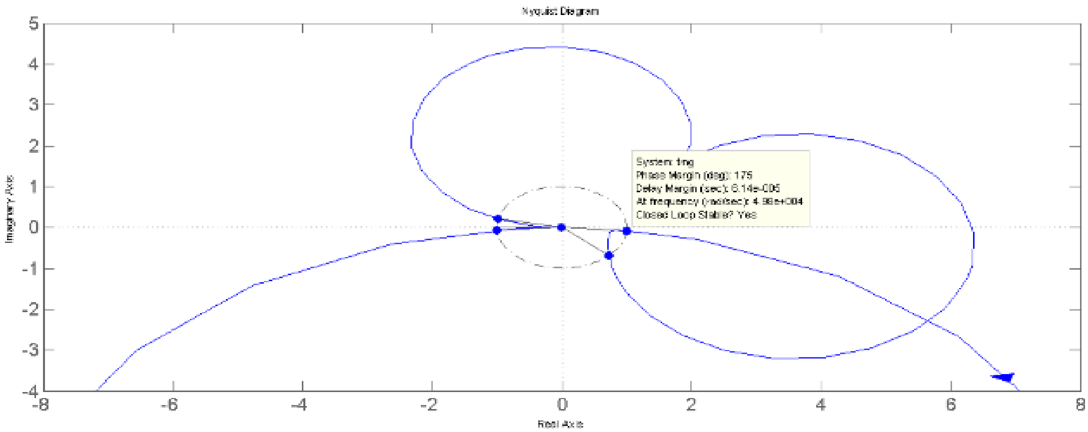

Fig.9. Nyquiest Plot**.**

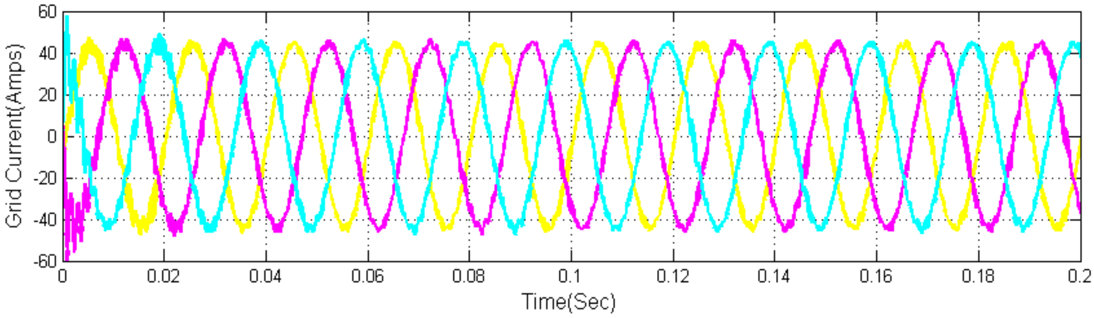

Fig.10. Grid Current.

Fig.9. Representing the nyquiest plot of the minor loop gain of the system when Grid impedance $L_s = 400uH$ which does not encircles the (-1,j0) so the system is stable

and when the same system is implemented in Matlab Simulation Fig.10. is Representing the grid Current.

CASE STUDY 2: Influence of Inverter Disconnection

$$\textbf{CASE1:}\, Y_{LA} = Y_G + Y_{CPFC} + Y_{CLB} + Y_{CLC} + Y_{CLD} + Y_{CLE}$$

$$\textbf{CASE2:}\, Y_{LA} = Y_G + Y_{CPFC} + Y_{CLB} + Y_{CLC} + Y_{CLD}$$

The Inverter are supplying the current of INV A=10A, INV B=8A, INV C=5A, INV D=15A, INV E=6A, CASE 1: In this case INVA is disconnected from the system. Remaining Inverters are supplying the grid current of the 34A.The Nyquist plot of Minor loop gain by Taking the grid impedance is Constant which is not encircles the (-1, J0).so the system is stable as shown in the Fig.11. and MATLAB Simulation diagrams are shown in Fig.12 to 14.

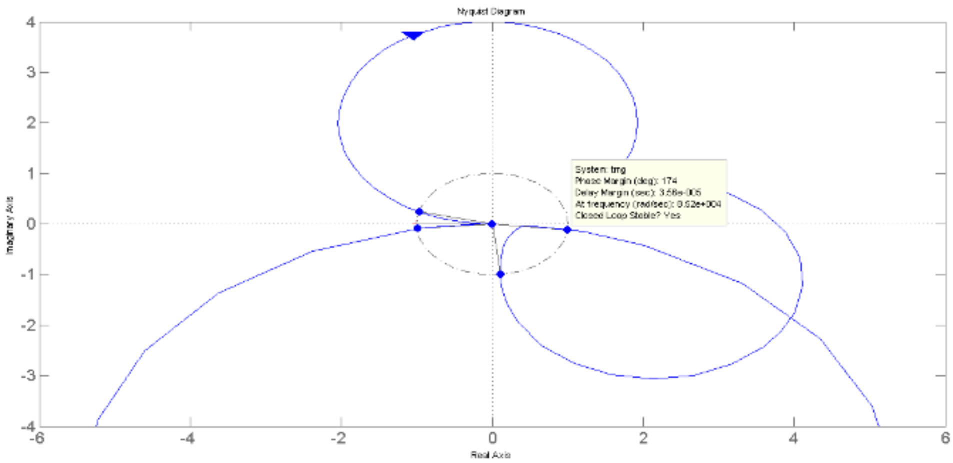

Fig.11. Nyquiest Plot

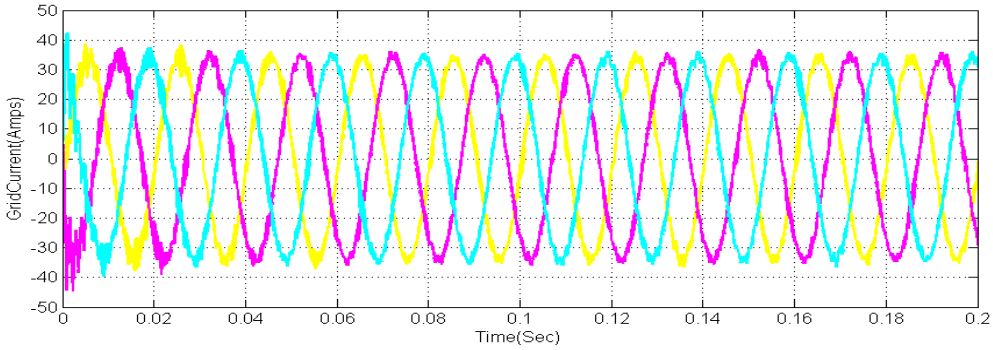

Fig.12. Grid Current**.**

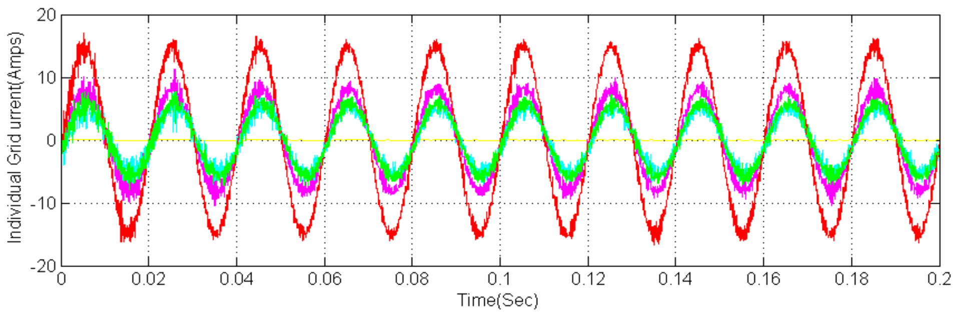

Fig.13. Invidual Inverter Currents

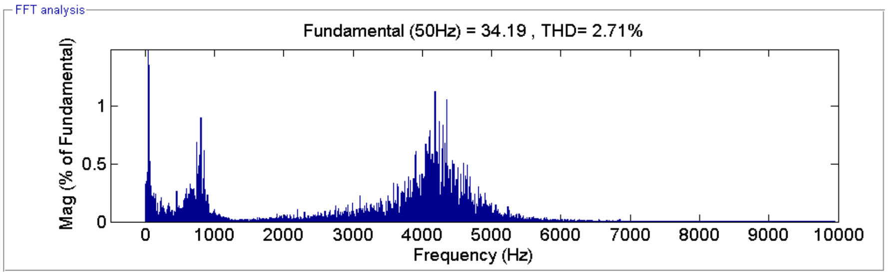

Fig.14. THD of The Grid Current

CASE2: In this case INVA and INV E is disconnected from the system. Remaining Inverters are supplying the grid current of the 28A.The Nyquist plot of Minor loop gain by Taking the grid impedance is Constant which is not encircles the (-1, j0). so the system is stable as shown in the Fig.15. and Matlab Simulation diagrams are shown in Fig.16 to 18

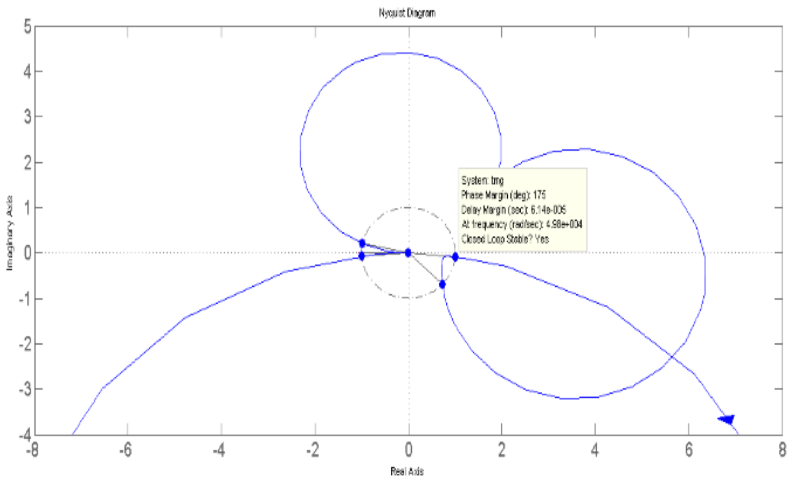

Fig.15. Nyquiest Plot.

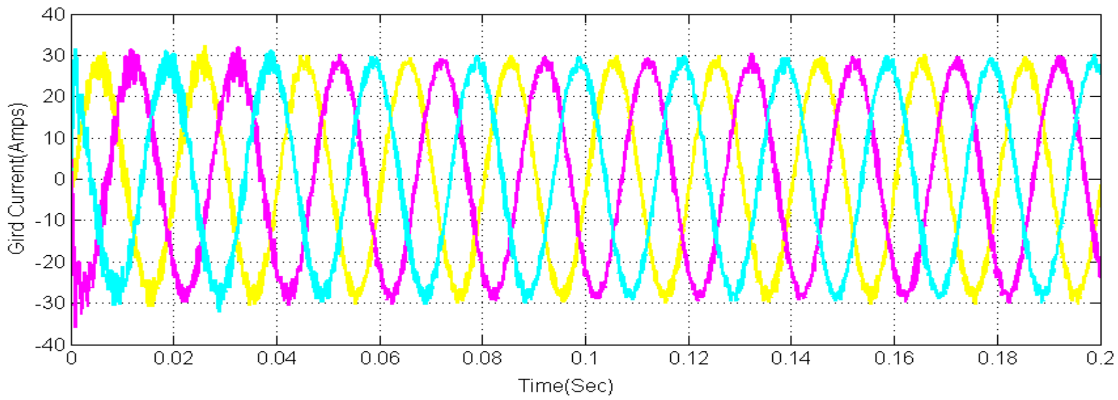

Fig.16. Grid Current

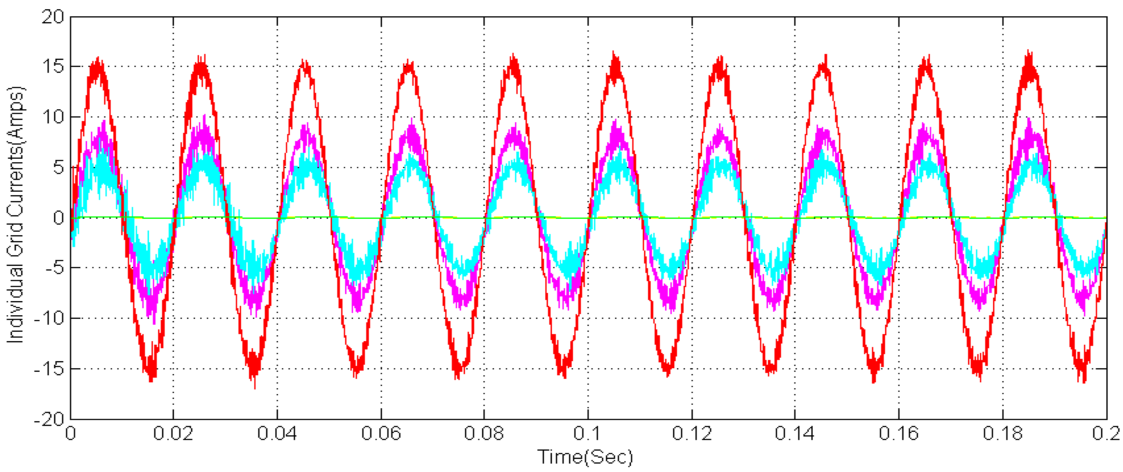

Fig.17. Invidual Inverter Currents

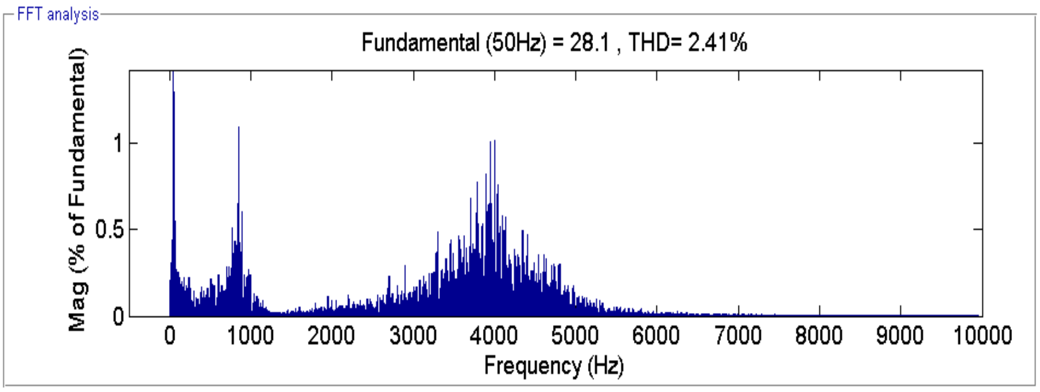

Fig.18. THD of the Grid Current.

VI. CONCLUSION

In this work Harmonic Interaction between the grid connected MultiplePV inverter are investigated with help of the Imedance based stability analysies by Developeing the Nyquiest plotes by Varying the grid Inductance from L_S=155 to 400 uH and keeping the value of grid resistance is constant. Over this Variation the System is Stable and also analysed if the minor loop gain of the System Varies by diconnecting the some of the PV inverters from the grid.To study this two Case studies are considered has given the Stable Operatin from graphical anlysis and it is also realized by means of the MATLAB Simulink. More ever quality of the grid current with in universally acceptable range.

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