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Immitance based stability assessment for multi paralleled 3-ø pv inverters connected to grid

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The main objective of this work is to analyze and investigation on Immitance Based Stability Assessment for Multi paralleled 3-Ø PV Inverters connected to Grid is checked by using the Impedance based Stability Criterion (IBSC), The causes for Harmonically stabilized/destabilize the Multi paralleled PV inverter Connected to the grid by varying grid impedance is Analysed by the impedance-based stability criterion.Here Two case studies are Considered with the different grid Inductances to demonstrate the overall system is stable/unstable. The Third case study is projects the overall stability of the System with the constant grid impedance and variable Load Impedance/ Admittance. The Overall System is stable up to grid Inductance 5 mH even though there is change in Load Admittance The stability of the system depending on the grid impedance and not depending on the Load Admittance. The Harmonic content in the grid current of the stable system is in the acceptable limit. It is verified in the Time domain Simulation is provided in MATLAB- Simulink™

Keywords: *PV Array, Maximum Power Point Tracking (MPPT), Proportional, Resonant Current Controller, Inverter output impedance, Impedance Based Stability Criterion(IBSC)*

1.0 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 they are commercialized. Renewable sources may be solar, wind or geothermal etc. 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 fed voltage source inverters 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 [2], 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 analysed and solved by impedance base stability criterion (IBSC) analysis (or) passivity based analysis, Previously the impedance based stability criterion (IBSC) was used in 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 Results

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of the nyquist plot analysis we can judge 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° ,90°],then the system is in stable otherwise unstable

2.0 MODELING OF PV ARRAY AND MPPT

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 equivalent circuit is shown in Fig.1. simple modeling where series and shunt resistances are neglected [8],[9] & [10].

The PV Cell Output urrent

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

Diode Current

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

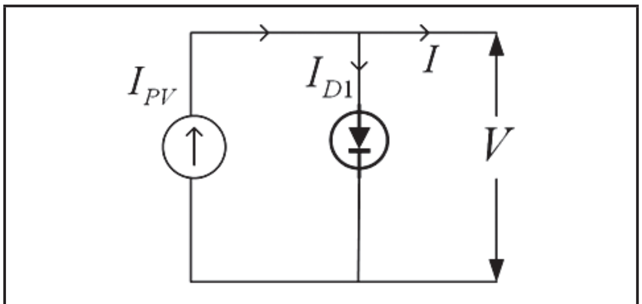

FIG.1. PV CELL EQUIVALENT CIRCUIT.

Photo voltaic Current is given by

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

$$I = N_p I_{pv} - N_p I_D \quad ...(4)$$

Module Current is given by

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

Here

N_S = The number of series cell branches connected in a module,

N_P = The number of parallel cell branches connected in a module.

q = Electron charge (Coulombs),

V = Open circuit voltage (volts),

λ = The solar irradiation (Watt / m 2)

I_{scr} = cell shorted current (Amp).

T_K = Actual temperature(kelvin),

T_{refk} = Standard temperature(kelvin),

K = Temperature coefficient of short-circuit current (A/ K)

A_1 = The diode ideality factor,

I_o = The reverse saturation currents of Diode(Amp)

Reference Temperature = 300k

I_{PV} = Photo Current (Amp),

TABLE 1

PARAMETERS OF THE PV MODULE

Sl. No.	Parameters	Value
1	Current at Maximum Power (Im)	8.30A
2	Voltage at Maximum Power(Vm)	30.2V
3	Open Circuit Voltage(Voc)	37.3V
4	Short Circuit Current (Isc)	8.71A
5	Internal Series Resistance(Rs)	0.217oh m
6	Reference Solar Radiation(Sref)	1000W/ m2
7	Reference Temperature	300k

The Parameters of the PV Module are is shown in the Table.1.In this work PV Array is Designed in Matlab Simulation of PV Module Power of 7 KW, 350V and two modules are connected in series to get the voltage of 700 V. This used as DC link to the 3- φ Inverter Tied to the grid.

2.1 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 controllable duty cycle is generated given to the boost converter to extract the maximum power from the PV Panel [11], The Simulated Results of the PV voltage, PV Current, PV Power are shown in Fig.2,Fig.3 &Fig.4.

SIMULATION RESULTS

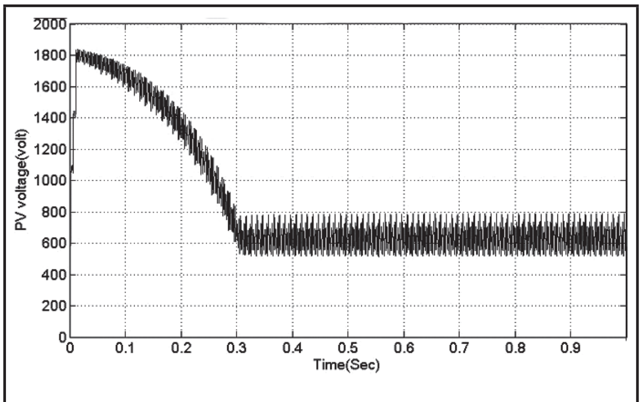

FIG.2. PV VOLTAGE (VOLT).

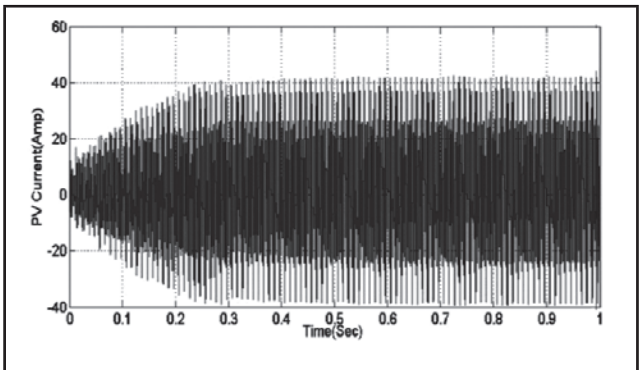

FIG.3. PV CURRENT (AMP).

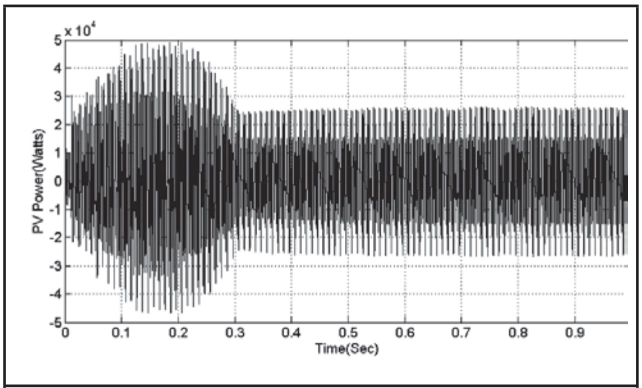

FIG.4. PV POWER (WATTS).

3.0 PROPORTIONAL RESONANT (PR) CURRENT CONTROLLER AND MODELING OF INVERTER OUTPUT ADMITTANCE

3.1 PR Current Controller

It is well known that a PR controller exhibits a good performance in tracking a reference sinusoidal signal. The transfer function of an ideal PR controller is given by [12], [13].In this study, the PR controller is used to follow the grid current same as Reference Current. The Transfer function of the Ideal PR Controller is give below [14].

Ideal PR Controller

$$G_{PR}(s) = K_P + \frac{2K_r s}{s^2 + \omega^2} \qquad ...(6)$$

Non Ideal PR Controller

$$G_{PR}(s) = K_P + \frac{2K_r \omega_c s}{s^2 + 2\omega_c s + \omega^2} \qquad ...(7)$$

Where

K_P = Proportional gain,

K_r = Resonant gain,

ω = Resonant frequency.

ω_c = Corner frequency

3.2 Modelling of Closed Loop of Inverter Output Admittance

In order to model the inverter output impedance and the averaged switching model is shown in Fig.5 & Fig.6 and the feedback path having the components are current controller (G_c), delay gain (G_d) and modulator gain (K_{PWM}) are defined as:[16 17]

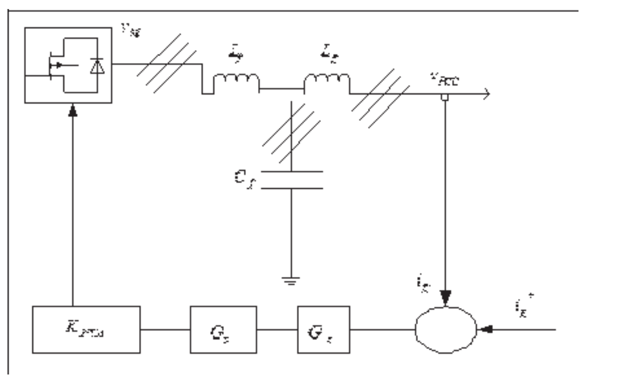

FIG.5 SINGLE-PHASE REPRESENTATION OF LCL-FILTERED INVERTER WITH GRID CURRENT CONTROL.

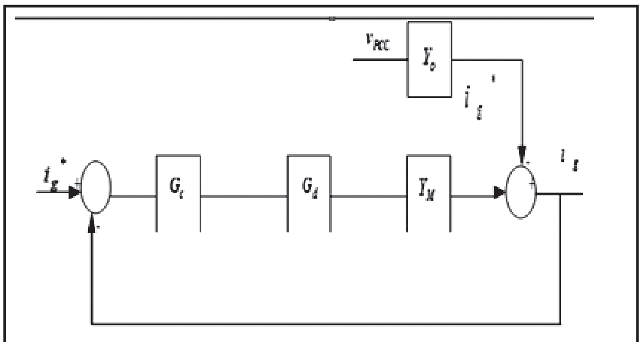

FIG.6 AVERAGED SWITCHING MODEL OF THE GRID INVERTER

$$G_C(s) = K\,, G_d(s) = e^{-1.5T_S s}\,, K_{PWM} = 1 \qquad ...(8)$$

The Inverter output to filter input relation is

$$Y_o(s) = \left.\frac{-i_g}{v_{PCC}}\right|_{v_M=0} = \frac{s^2C_fL_f+1}{s(s^2C_fL_fL_g+L_f+L_g)} \qquad ...(9)$$

The filter output to grid (or) load relation is given in Eqa.10.

$$Y_M(s) = \left.\frac{i_g}{v_M}\right|_{v_{PCC}=0} = \frac{1}{s(s^2C_fL_fL_g+L_f+L_g)} \qquad ...(10)$$

Finally, the Inverter output admittance can be define

$$Y_C(s) = \frac{Y_0}{1+G_C\,G_d\,Y_M} \qquad ...(11)$$

$$Y_C(s) = \left.\frac{i_g}{v_{PCC}}\right|_{i_g^*=0} = \frac{Y_O}{1+G_cG_dY_M} = \frac{s^2C_fL_f+1}{s^3C_fL_fL_g+s(L_f+L_g)+Ke^{-1.5T_S s}} \qquad ...(12)$$

Here K- proportional gains 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.

4.0 IMMITANCE BASED STABILITY CRITERION (IBSC)

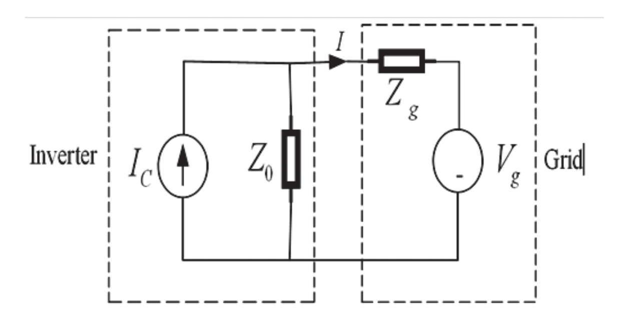

FIG.7 SMALL-SIGNAL REPRESENTATION OF AN INVERTER-GRID SYSTEM

Grid Connected PV Inverter is modeled as Current Source (I_C) with shunt Impedance (Z_0), grid is modeled as voltage source inverter in series with the Impedance (Z_g) as shown in the Fig.7. From the New Impedance Based Stability

Criterion, The ratio of PV Inverter output impedance to grid input impedance must satisfy the Nyquist Stability for the Overall System is Stable [18]&[19].

$$I(s) = [I_C(s) - \frac{V_g(s)}{Z_0(S)}] \times \frac{1}{1 + \frac{Z_g(s)}{Z_0(S)}} \quad ...(13)$$

From The Eqa.(13), PV Source is Stable $I_c(S)$ and Grid Voltage (Vg) Is also Stable. Gird Current I(S) is Stable only when the quantity $\frac{Z_g(s)}{Z_0(S)}$ is obeys the Nyquist Stability Criteria [16].

5. 0 STABILITY ANALYSIS FOR DIFFERENT GRID IMPEDANCES

Single line diagram of the grid connected five parallel PV inverters is shown in Fig.8 and Matlab-Simulink diagram is shown in Fig.9 g is obeys the Nyquist Stability Z0 (S) Capacitor bank is connected parallel at PCC to improve power factor. Its value is taken as 12uF and grid voltage is taken as 400 V, 50Hz with grid impedance of Z_g = (0.1 + j 400). PV Inverter is controlled by PR Current Controller and LCL filter is used to reduce Lower order harmonics in grid current [19]. The firing pulses generated by Sinusoidal Pulse Width Modulation (SPWM) method to trigger the inverter switches. The Specification and Parameters of the Five Parallel inverters are given in the Table.2

5.1 Case Study 1

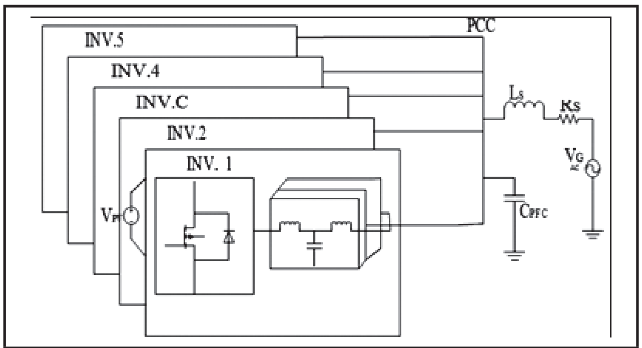

FIG.8 SINGLE LINE DIAGRAM OF FIVE PARALLELED PV FED 3-Ø INVERTER CONNECTED TO THE GRID

There are multi paralleled PV inverters are working with parallel connection of power factor correction capacitor (PFC) and grid impedance (Z_s).Thereafter calculate the source admittance (Y_{SG}) and the load admittance (YLG) are given in the Eqa.(14) & (15).

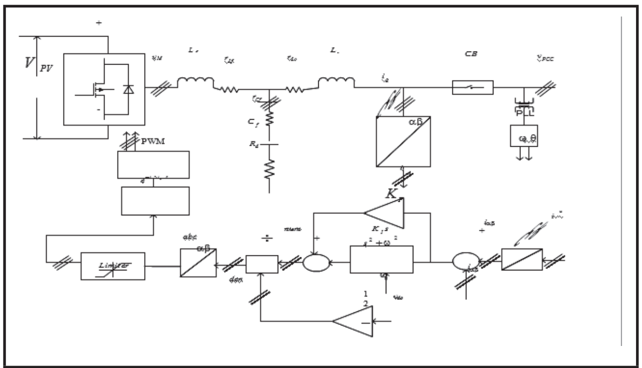

FIG.9 THE CONTROL DIAGRAM OF INVERTER CONNECTED TO GRID IN MATLAB-SIMULINK.

$$Y_{SG} = \frac{1}{R_S + sL_S} \quad ...(14)$$

Where R_S - Grid resistance, L_S - Grid LS inductance as

$$Y_{LG} = Y_{CPFC} + \sum_{X=1}^{5} Y_{CLX}$$

$$Y_{LG} = SC_{PFC} + Y_{CL1} + Y_{CL2} + Y_{CL3} + Y_{CL4} + Y_{CL5} \quad ...(15)$$

Where YCPFC denotes the admittance of capacitor CPFC as shown in Fig.8. Finally, the Minor loop gain follows:

$$T_{MG} = \frac{Y_{SG}}{Y_{LG}} \quad ...(16)$$

The minor loop gains (T_{MG}) is highly Eqa (16), admittance (Y_{LG}) are given in the Eqa.(14) & (15). In this Study load Impedance is constant means all five inverters are connected to the grid, whereas grid Inductance is Varied from 1uH to 1000mH ,Keeping the grid resistance is Constant. If the minor loop gain of the overall System Obeys the Nyquiest Criteria with different grid impedance,then the system becomes Stable, Otherwise overall System becomes unstable

TABLE 2						
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	5.6	8.05	28.8	16.6	6.5
	K_I	1000	1500	1500	1000	1000

CASE STUDY 1

Here keeping the grid resistance is constant, whereas grid inductance is varied .The System becomes Stable upto L_s = 5m Hand in this case All five inverters connected to grid through supply Total grid current of 44A.The Nyquist Plot of the minor loop gain and the simulation results of grid voltage and current , Individual grid current,THD of the Grid currents for the overal System are

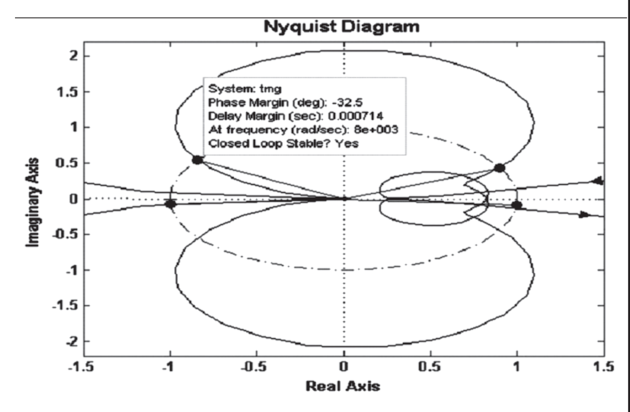

FIG.10 NYQUIEST PLOT OF MINOR LOOP GAIN WITH GRID INDUCATANE AT UPTO LS = 5MH .

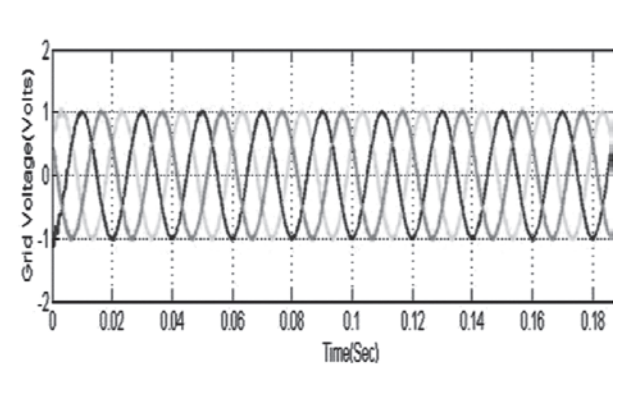

FIG.11 GRID VOLTAGE (VOLTS).

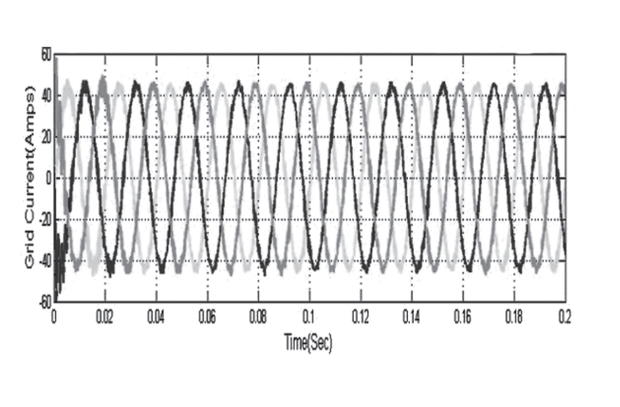

FIG.12 GRID CURRENT (AMP).

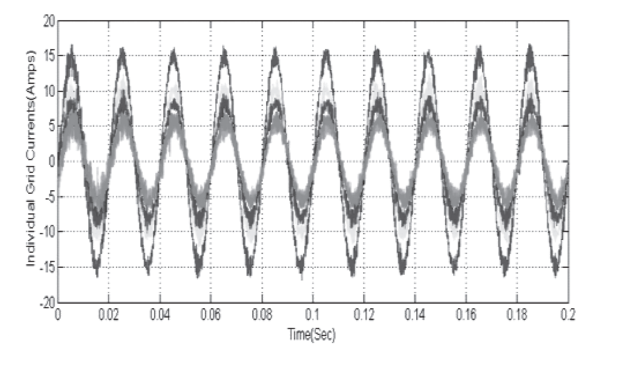

FIG.13 INDIVIDUAL INVERTERS CURRENT (AMP).

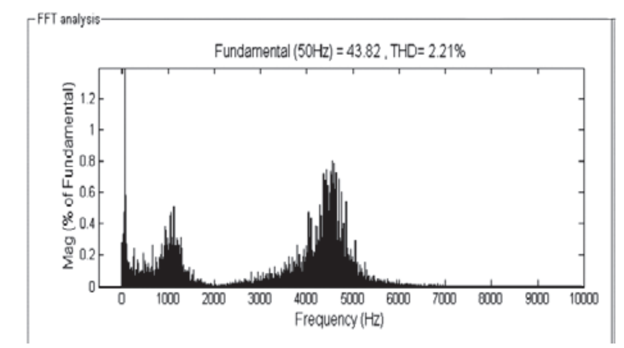

FIG.14 THD ANALYSIS OF THE GRID CURRENT.

CASE STUDY 2 :

This case study is used to illustrate theGrid inductance (L_S) is more than 5mHThe Overall System become unstable. The Nyquiest Plot of minor loop gain with Gird Inductance Value L_S = 6mH is shown in Fig.15, Grid Current and Individual Inverter currents and THD of the grid Current are shown in Fig. 16, Fig.17 & Fig.18 respecively.

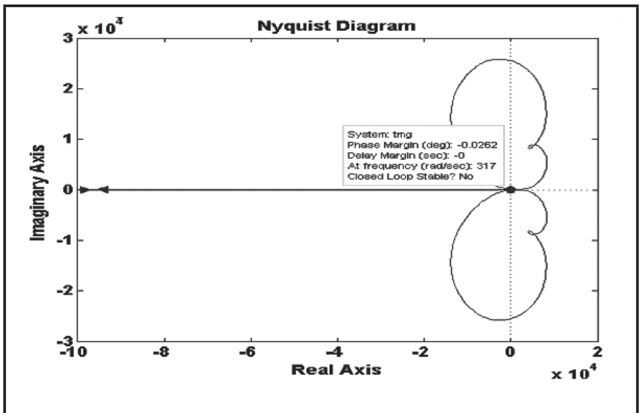

FIG.15 NYQUIEST PLOT OF MINOR LOOP GAIN WITH GRID NDUCATANE AT LS = 6MH.

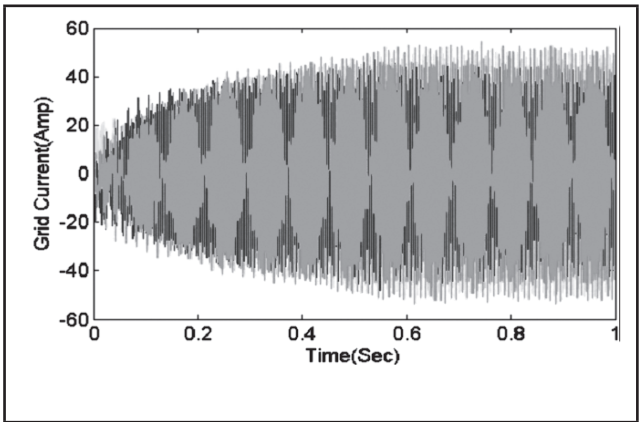

FIG.16 GRID CURRENT (AMP).

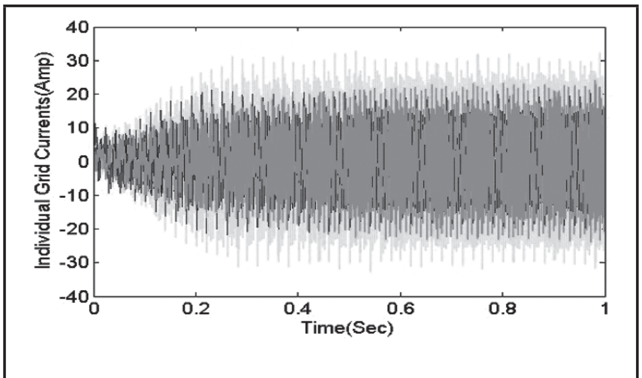

FIG.17 INDIVIDUAL GRID CURRENT (AMP).

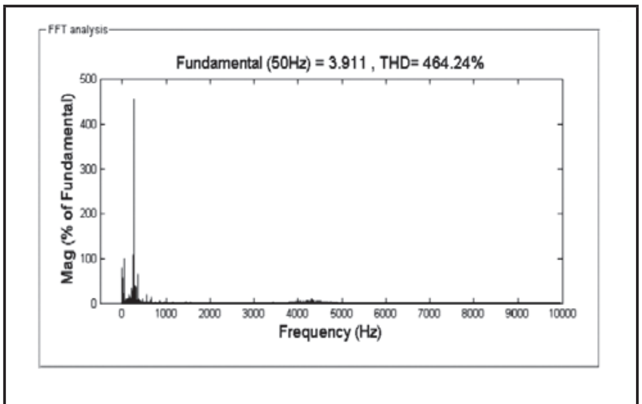

FIG.18 THD ANALYSIS OF THE GRID CURRENT.

CASE STUDY 3:

This Case study illustate the overall system is stable/Unstable due to the change in Load admittance (Disconnection of the inverters) with the constant grid Impedance .The grid Impedance upto 5 mH the system is stable,Even Though there is change in Load Impedance. The grid Inductance is more than the 5mH then the Overal system becomes unstable even Though fixed / Variable Load Impedance. The Stability of the overall system is depending on the grid impedance only and It is Independent of the Load Impedance of the overall system. The Nyquist plot of the Minor Loop gain of the System with grid Impedance Z_g=(0.1+400uH) less than the 5 mH and three Inverters supplying currents are INV1 = 8A,INV2 =5A, INV3 =15A respectively Connected to the grid. Here The system is stable observed from nyquist plot response ,The Simulation Results of grid current and Individule Inverter Currents and THD of the grid Current are shown in Fig.19,Fig.20, Fig.21 & Fig.22 respecively.

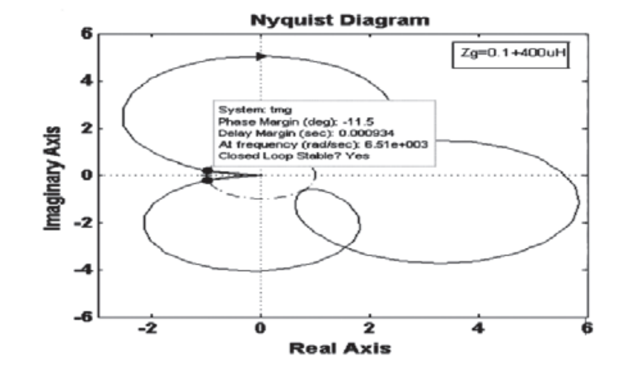

FIG.19 NYQUIEST PLOT OF THE SYSTEM

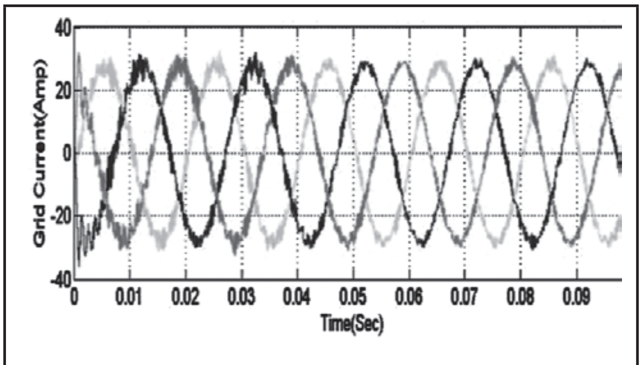

FIG.20 GRID CURRENT(AMP)

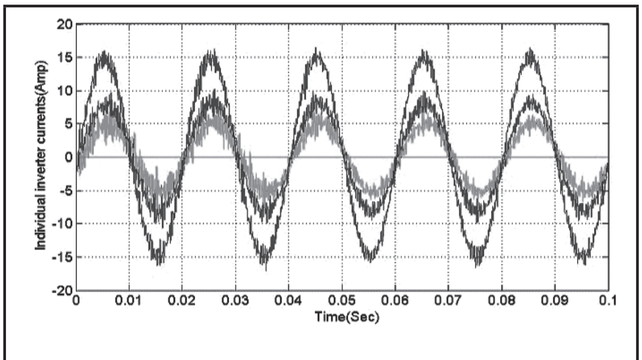

FIG.21 INDIVIDUAL INVERTER CURRENTS (AMP)

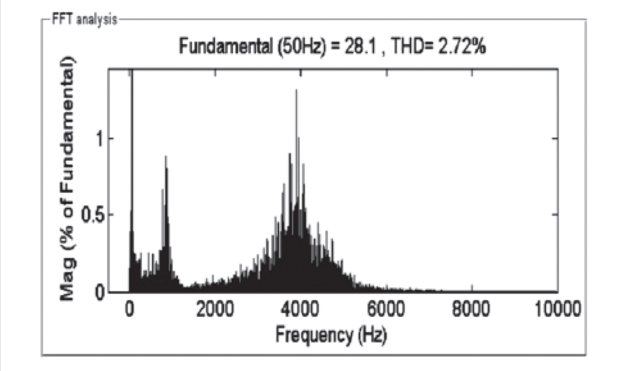

FIG.22 THD OF THE GRID CURRENT

The Nyquist plot of the minor loop gain of the System with grid Impedance Z_g=(0.1+170 mH) grid inductance is more than the 5 mH and Three Inverters are connected to the grid is unstable.The PV inverters injecting currents into the grid are Inv2=8A, Inv3=5A and Inv4=15A respectively. There is a encirclements of (-1+j0)point in the nyquist plot which says that the interconnected (Source to Load) system is unstable is shown in Fig.23.The simulation results of grid current , individual Inverter currents and THD of the grid Current are shown in Fig

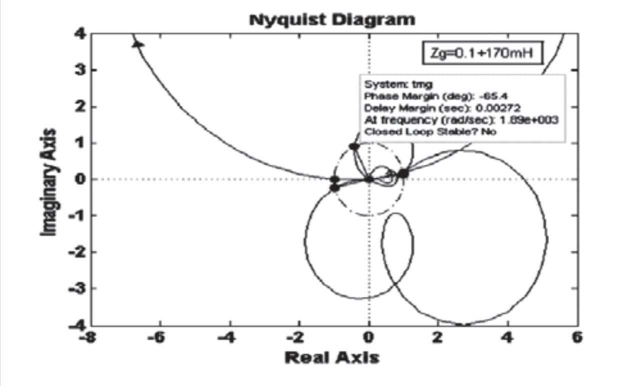

FIG.23 NYQUIEST PLOT OF THE SYSTEM WITH GRID INDACTANCE ZG = 0.1 + 170 MH MORE THAN THE 5MH

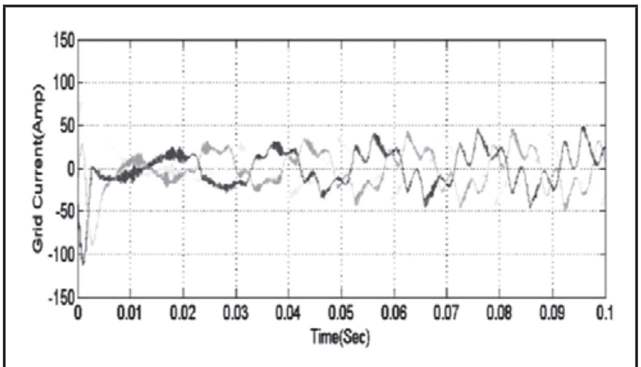

FIG.24 GRID CURRENT (AMP)

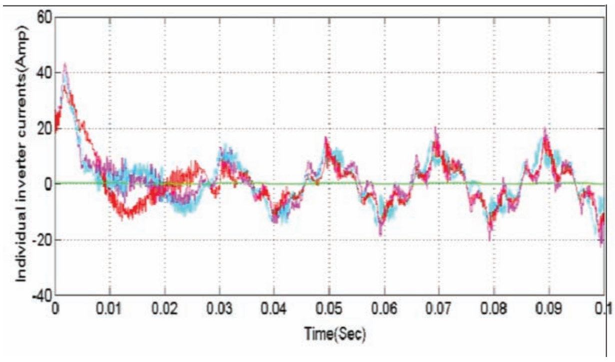

FIG.25 INDIVIDUAL INVERTER CURRENTS

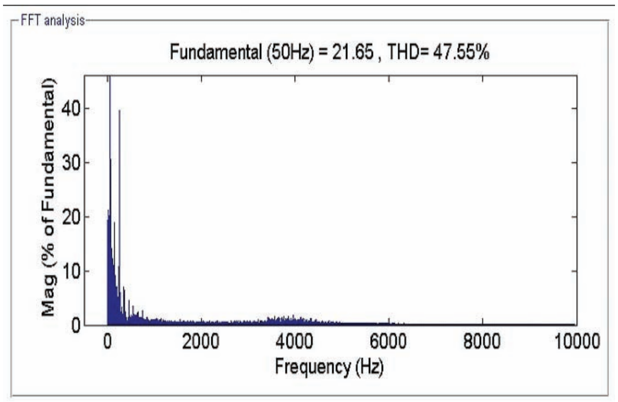

FIG.26 THD OF THE GRID CURRENT

6.0 CONCLUSION

In this work the Investigation of the Harmonic Stability of the grid current is Assessment for PV fed Multi Paralleled 3-Ø Inverters connected to grid is checked by New Impedance Based Stability Criterion (IBSC), The Stability of the system was checked by varying the grid Inductance with constant grid resistance and also by varying load Impedance keeping grid Inductance is constant. The overall system is stable up to the grid inductance is 5mH More than that the System becomes unstable. The stability of the system is only depending on the Grid Impedance and Not depending on the load Impedance (Independent of No. PV Inverters connected to the grid), It verified by means of the graphical and Matlab Simulation Results. The Total Harmonic Distortion (THD) value of the grid current is less than 5% for the Stable System. Which is Internationally accepted and It is more for the unstable System.

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