An Improved Control Scheme for Grid Connected Voltage Source Inverter

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***Abstract*— In grid connected Distribution Generation systems, Voltage Source Inverters are used for interfacing the renewable energy source to the utility grid. DG has variety of problems during grid integration. Hence the control of the grid connected inverter plays an important role in feeding a grid with high quality power. This report presents an analysis of the stability problem of a grid connected with Voltage Source Inverter and with a LC filter. The possible grid-impedance variations have a significant influence on the system stability. Whenever the grid inductive impedance increases, the low frequency gain and the bandwidth of the Proportional Integral (PI) controller have to be decreased to maintain the system stable, thereby degrading the tracking performance and disturbance rejection capability. To overcome this problem an H∞ controller is proposed with an explicit robustness in terms of grid impedance variations to incorporate the desired tracking performance and stability margin. The proposed method is simulated by using MATLAB/SIMULINK. The results of the proposed H∞ controller and the conventional PI controller are compared, which validates the performance of the proposed control scheme.**

Keywords—Distributed Generation (DG), Voltage Source Inverter (VSC), LC Filter, H∞ Controller, Total Harmonic Distortion (THD).

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I.INTRODUCTION

Increasing demand for electricity under limited availability and supply from conventional resources has resulted in an energy crisis. Each and every development in the present age depends mainly on the electrical energy. To have sustained and continuous development, the depletion of non-renewable sources should be compensated with some other sources of energy. A feasible solution to this problem is to generate energy from a renewable resource wherever it is available and utilize it to meet the demands.

IEEE defines Distributed Generation (DG) as the generation of electricity by facilities that are sufficiently smaller than central generating plants so as to allow interconnection at nearly any point in a power system. The utilization of environmentally clean Renewable Energy Sources (RES) results in improved reliability and energy security for the existing power system network. As the distributed energy sources are very close to the utility systems, transmission losses are reduced to a great extent. The distributed generation has other advantages as well improved grid asset utilization, reduced Transmission and Distribution congestion, improved grid reliability and power quality, better energy and load management, ancillary services such as voltage stability and national security.

Though the Distributed Generation has many advantages, it has variety of problems during grid integration. For example: protection of Distributed Generators [3, 4] when it is connected with the existing utility grid. These issues should be addressed effectively or else the reliability and the quality of electrical power supply will be poor. When connecting the inverter to the utility grid, either a pure inductor (L) or an LCL filter can be used as the inverter output stage. The LCL filter instead of L filter is more attractive because it cannot only provide higher high-frequency harmonic attenuation with the same inductance value but can also allow the inverter to operate in both stand-alone and grid-connected modes, which makes it a universal inverter for DG applications [8-11]. However, the system incorporating LCL filters is of third order, and it has an inherent high-resonant peak at the resonant frequency of the LCL filter, which will make the current control unstable if the controller is not suitably designed. To avoid this stability problem, the passive or active damping methods are usually used [1].

In [8], an admittance compensator along with a quasi-resonant-proportional controller was proposed. Using the inverter-output current instead of the grid current as the feedback signal, the control system can be simplified to a first order system, thus, it is possible to keep the control loop stable with high loop gain and bandwidth. However, from the whole system view, the filter capacitor and the grid-side inductor form a parallel resonant circuit, and harmonic current from inverter output in the vicinity of resonant frequency can be amplified excessively and may cause the resonance of the grid current. Reference [10] proposed a new control strategy with feedback of grid current plus part of the capacitor current. In this way, the inverter control system can also be degraded from third order to first order due to the counteraction between zeros and poles

This proposed project analyses the stability problem of the grid connected Voltage Source Inverters with LC filters, which illustrates that the possible grid-impedance variations have a significant influence on the system stability. Whenever the grid inductive impedance increases, the low frequency gain and the bandwidth of the PI controller have to be decreased to maintain the system stable, thereby degrading the tracking performance and disturbance rejection capability. To overcome this problem an H∞ controller is proposed with explicit robustness in terms of grid impedance variations to incorporate the desired tracking performance and stability margin.

Figure 1 shows the overall block diagram of the system. The inverter is fed by a PV module. The output from the three phase Voltage Source Inverter is given to LC filter to eliminate the ripples in the current and voltage and the out coming output from the filter is fed to the grid.

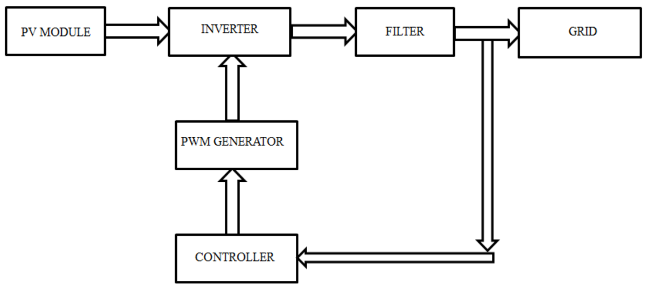

Figure 1 Overall Block Diagram

The feedback is taken from the grid parameters and is given to the controller to achieve better disturbance rejection capability and low THD of the grid current. The output from the controller is given to the PWM generator in order to control the gate pulse given to the inverter.

II.PV MODULE

Typically, a PV cell generates a voltage around 0.5 to 0.8 volts depending on the semiconductor and the built-up technology. This voltage is so low that it cannot be directly used. Therefore, to get benefit from this technology, tens of PV cells (involving 36 to 72 cells) are connected in series to form a PV module. These modules can be interconnected in series and/or parallel to form a PV panel. In case these modules are connected in series, their voltages are added with the same current. Nevertheless, when they are connected in parallel, their currents are added while the voltage is the same.

The solar array characteristics profoundly influence the converter and control system. The array cell static characteristics, as a function of light intensity and temperature, are given by the equations as follows,

$$I = I_{LG} - I_O\{\exp[\frac{q}{AKT}(V + I_A R_S) - 1]\} \qquad (1)$$

$$I_O = I_{OR}[\frac{T}{Tr}]^3 \exp[\frac{qE_{GO}}{BK}\{\frac{1}{T_R} - \frac{1}{T}\}] \qquad (2)$$

$$I_{LG} = [I_{SCR} + K_1(T_C - 298)]\lambda/100 \qquad (3)$$

$$V_{PV} = \frac{AKT}{qN}(\ln(I_{ph} - I_{pv} + I_O)/I_O) \qquad (4)$$

where,

V	cell output voltage
I	cell output current
I_o	cell saturation current
T cell	temperature in K
K/q	Boltzmann's constant divided by electronic charge 8.62*10^-5 eV/K
Tc	cell temperature in degree Celsius
Ki	short circuit current temperature coefficient at Iscr 0.0017 A/degree Celsius
λ	Cell irradiance (mW/cm^2)
I_{SCR}	cell short circuit current at 28 degree Celsius and 100mW/cm2→4.57A
I_{LG}	light generated current
E_{GO}	band gap for silicon=1.11eV
A	ideality factors=1.6
Tr	reference temperature =301.18K
I_{or}	saturation current at Tr=19.963*10^-6
Rs	series resistance=0.001

Thus the output of the PV module is performed by using PV cell basic equations in MATLAB/SIMULINK.

III.H∞ CONTROLLER

To deal with the stability problem caused by the uncertainty of the grid impedance, an H∞ controller is proposed. The design goal is to get the desired tracking performance, such as small steady-state tracking error and low THD of the grid current, while keeping the system stable in the predefined variational range of the grid impedance. The H∞ controller theory was introduced in the early 1980 s by G.H.hardy, who has investigated the behaviour of many transfer functions and opened a new direction in robust control design.

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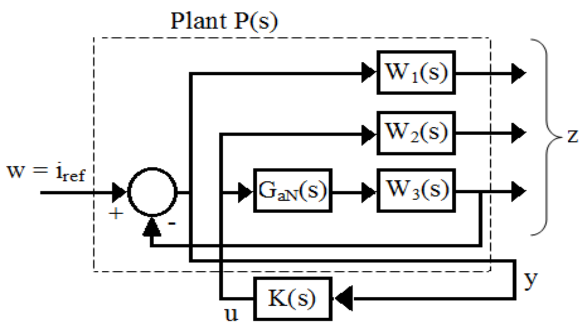

Figure 2 Standard H∞ controller configuration

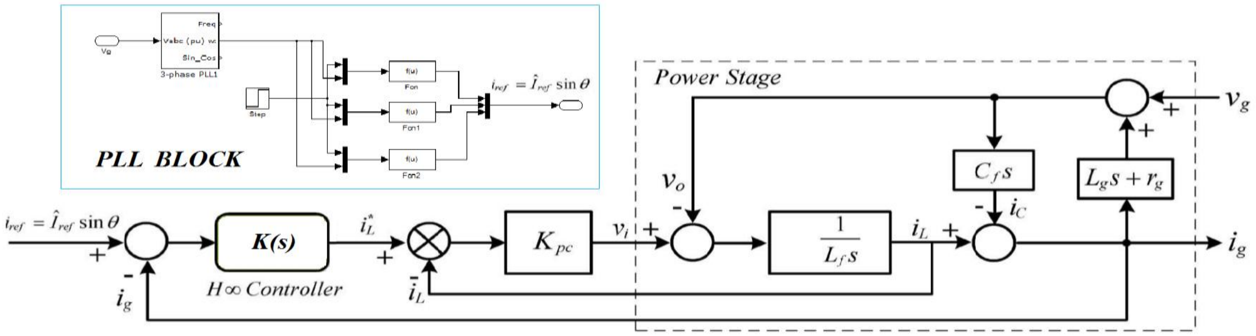

Figure 3 H∞ controller combined with an inner inverter-output-current control loop

Figure 2 shows the Standard H∞ controller configuration. $G_{aN}(s)$ is the nominal plant; z, y, w, and u are the controlled output, the measured output, the exogenous input, and the control input, respectively, and W_1, W_2, and W_3 are the weighting functions for tracking error performance, the weight on the controller transfer function, and robust performance, respectively. The objective is to synthesize the stabilizing controller K(s) so that the H∞ gain from w to z is less than one, i.e,

$$\|T_{WZ}\|_\infty < \text{ or equivalently } \left\| \begin{matrix} W_1 S \\ W_3 T \end{matrix} \right\|_\infty < 1$$

where $S(s) = 1/(1 + G_{aN}(s)K(s))$ is the sensitivity transfer function and $T(s) = G_{aN}(s)K(s)/(1 + G_{aN}(s)K(s))$ is called the complementary sensitivity transfer function since they satisfy $T(s) + S(s) = 1$.

The H∞ loop-shaping design may be processed by the following steps.

- Weighting-Function Selection for Tracking-Error Performance

$$W_1 = \frac{K_1\omega_0^2}{s^2 + 2\xi\omega_0 s + \omega_o^2} \quad (5)$$

- Weighting-Function Selection for Robust Performance

$$G_{aN}(s) = \frac{1}{L_{gN}C_f S^2 + C_f r_{gN} s + 1} \quad (6)$$

$$W_3 = k_3 (2.066 \ \ 10^{-7} s^2 + 0.909 \ \ 10^{-3} s + 1) \quad (7)$$

The H∞ controller can be synthesized with the defined values of weighting functions as mentioned. Thus the third order transfer function of K(s) is obtained as,

$$K(s) = \frac{608.4s^2 + 2.825e6s + 3.65e8}{s^3 + 2122s^2 + 1.581e5s + 3.005e8} \quad (8)$$

Figure 3 shows the overall control bock diagram: the H∞ controller combined with an inner inverter-output-current control loop and the three phase phase-locked loop (PLL) for grid synchronization.

For each phase, the three-phase grid-current reference is given as,

$$i_{refa} = i_{ref} \sin\theta$$
$$i_{refb} = i_{ref} \sin(\theta - 120°) \quad (9)$$
$$i_{refc} = i_{ref} \sin(\theta + 120°)$$

Where θ is the output of the PLL as shown in the Figure.3.

A simple proportional compensator K_{pc} is used in the inner inverter-output-current feedback loop to get better control performance. Ideally, the loop gain and bandwidth of the inner loop should be maximized by using a higher value of K_{pc}, to achieve perfect reference tracking at all input frequencies, a faster dynamic response, and a complete disturbance rejection.

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IV .SIMULATION AND RESULTS

The simulations have been carried out with switching frequency of 10 kHz under different grid conditions so as to investigate the tracking performance as well as the system stability. Table 1 shows the System Parameters.

Table 1: System Parameters

	PARAMETER	VALUE
GRID	Grid phase voltage	120 V_{RMS}
	frequency	60 HZ
	Grid resistance r_g	0.2Ω
	Grid inductance L_g	0.15mH, 0.3mH
INVERTER	Switching frequency	10kHz
	L_f	20 mH
	C_f	50µF

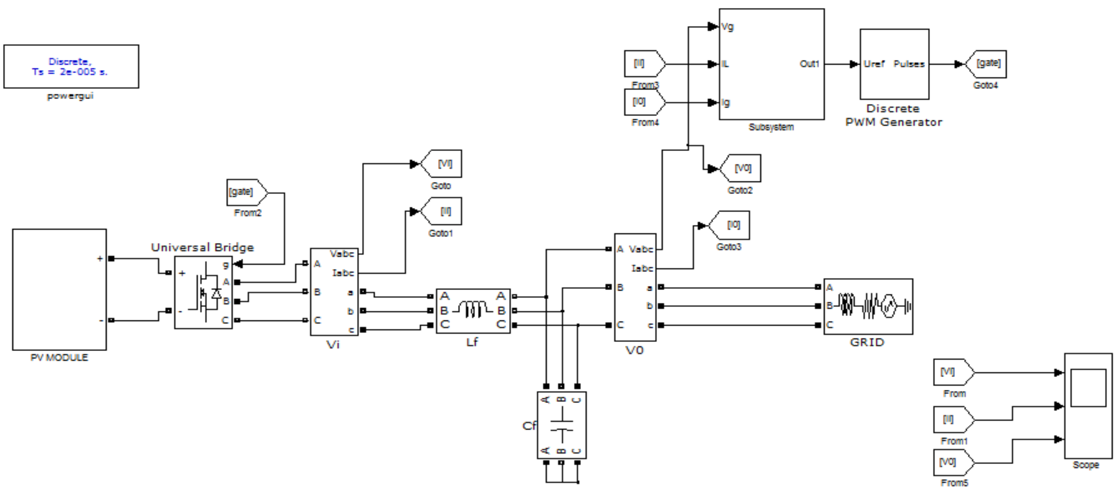

Figure 4 Overall Simulink Model

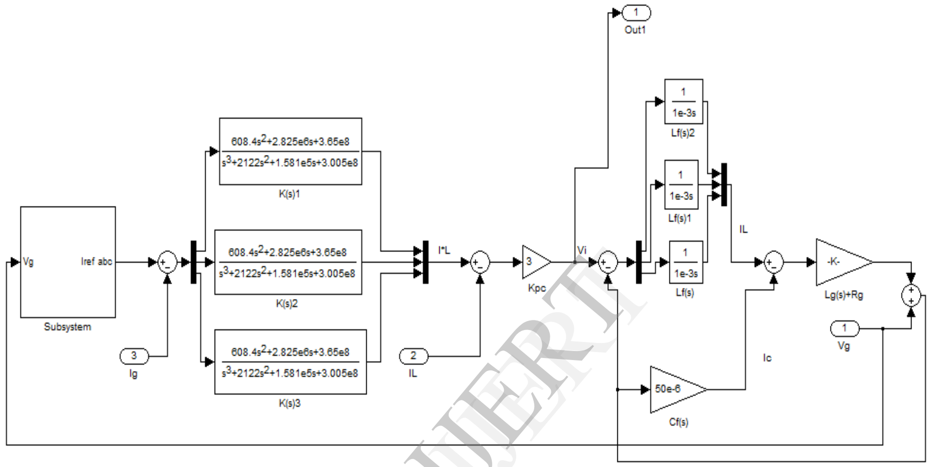

Figure 6 Simulink model of H∞ controller

A. Overall Simulink model

Figure 4 shows the simulation model for the overall circuit of the system. The inverter is fed by a PV module. The three phase Voltage Source inverter is connected to the measurement block such that inverter voltage (V_i) and inverter current (I_i) values are taken and are given to the scope to analyze the waveform. LC filter is connected after the measurement block with L_f =20 mH and C_f =50μF. The output from the filter is given to another measurement block in order to get the values of V_o and I_o. These values are given to the subsystem consisting of PLL block and H∞ controller. The output from the controller is given to the PWM generator in order to control the gate pulse given to the inverter.

B. Simulink Model of PV Module

Simulink model of PV module is shown in Figure 5. It consists of a PV array subsystem, a voltage measurement block, a current measurement block and a scope. The output values of voltage, current and power of a PV module is viewed using a scope

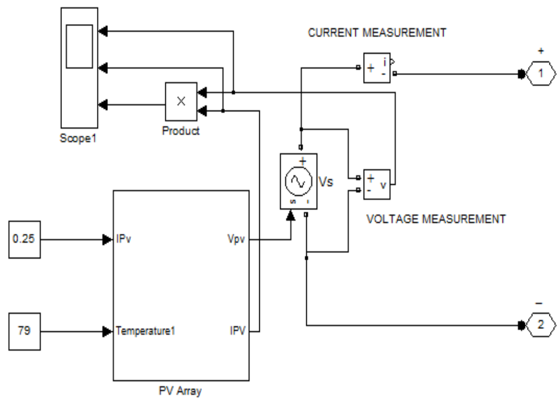

Figure 5 Simulink model of PV module

C. Simulink model of H∞ controller

The Simulink model of H∞ controller with a subsystem is shown in Figure 6. The values of $I_{ref\ abc}$ is generated from a PLL block. The values of $I_{ref\ abc}$ and grid current I_g is demuxed and given to the transfer function loop. The output from this is muxed and is subtracted from the load current I_l. The subtracted value is multiplied with the value of

K_{pc} to get the output, which is given as the input to the PWM generator in order to control the gate pulses given to the inverter. The tuning circuit consists of grid parameters. A simple proportional compensator K_{pc} is used in the inner inverter output current feedback loop to get better control performance.

D. RESULTS

Simulation results are shown in figures 7 and 8. In Figure 7, output waveforms for PV voltage, PV current and PV power are shown. The values obtained are,

- PV voltage = 169 V
- PV current = 4.22 A
- PV power = 713.18 W

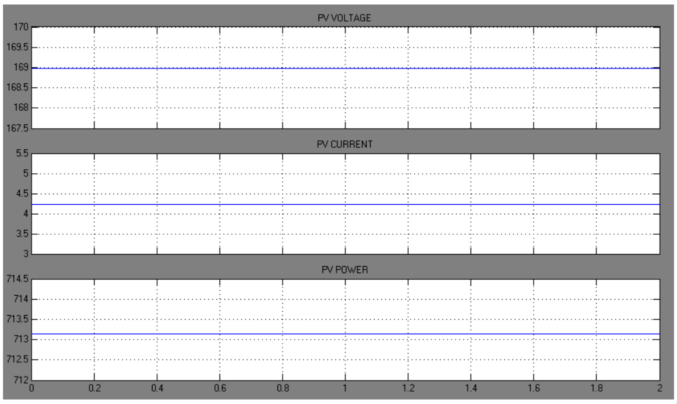

Figure 7 Waveform for output voltage of PV module

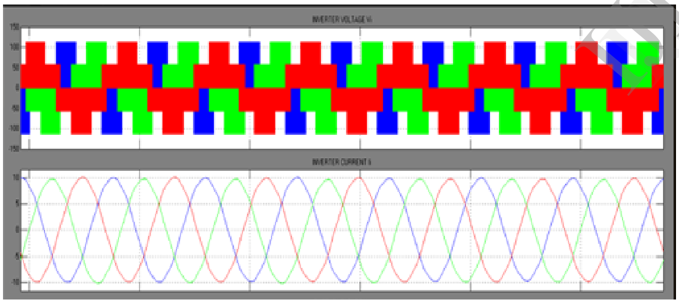

Figure 8 Output current waveform of overall system

Output current waveform of overall system is shown in Figure 8. As we have set the reference current value to 10A, Ii value obtained is also 10A. By properly selecting L_f and C_f values, a pure sine wave is obtained without any harmonics thereby achieving low THD value of grid current. Thus the supply to the grid is sinusoidal.

E. THD Analysis of Grid Current

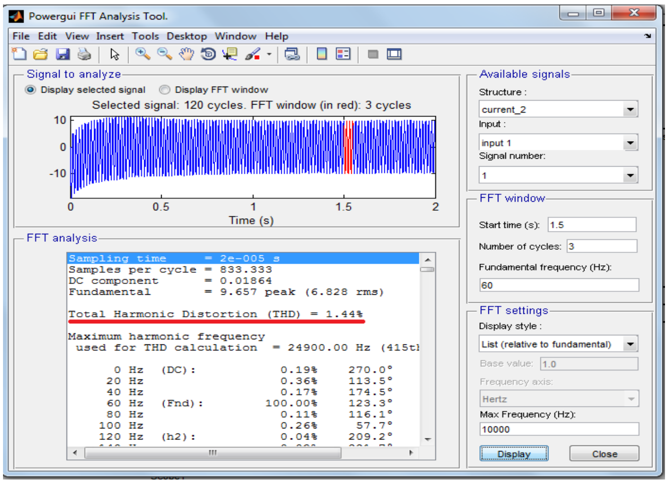

Figure 9 THD analysis with L_g=0.3 mH and r_g= 0.2Ω

Figure 9 shows the THD analysis with L_g=0.3 mH and r_g= 0.2Ω. The value of THD obtained is 1.44%.Figure 10 shows the THD analysis with L_g=0.15 mH and r_g= 0.2Ω. The value of THD obtained is 1.45%.

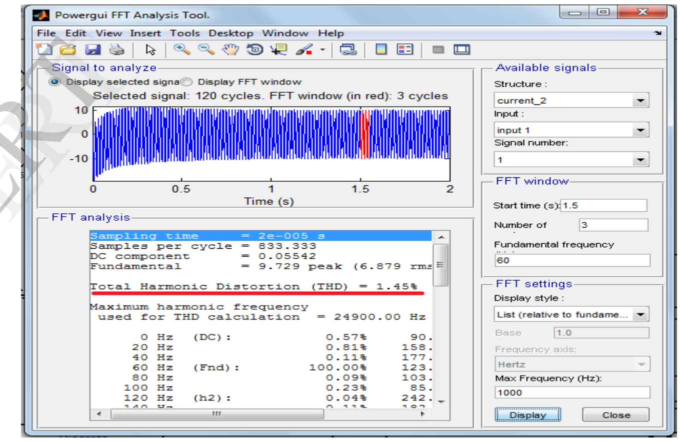

Figure 10 THD analysis with L_g=0.15 mH and r_g=0.2Ω

F. Comparison of The Results

The % THD given in the conventional method for grid impedance with PI controller are given in Table 2. The THD values obtained with H∞ controller are also given in the table. So H∞ controller reduces the THD value considerably.

Table 2 : THD of Grid current

GRID IMPEDANCE	CONTROL METHOD	I_{ref} = 10A
L_g=0.15 mH, r_g= 0.2Ω	PI controller	4.327%
	H∞ controller	1.45%
L_g=0.3 mH, r_g= 0.2Ω	PI controller	5.277%
	H∞ controller	1.44%

V.CONCLUSION

In the grid connected VSI with LC filters, the possible wide range of grid impedance variations can challenge the design of the controller, particularly when the grid impedance is highly inductive. In this project, the suitability of an H∞ controller to get the desired tracking performance and stability margin is investigated. From the experimental results it is seen that the grid current THD of the H∞ controller are always lower than that of the PI controller, which satisfy the THD requirement of IEEE Std.1547-2003 (i.e.,5%). Further simulation work is based on demonstrating the operation of a grid in Grid connected mode and intentional islanded mode. Through this, the system is able to determine whether or not it is safe to remain connected to the grid. An islanding detection algorithm is used to act as a switch between the two controllers and this minimizes the effect of losses in the time of transition, and also to prevent the undesirable feeding of loads during fault conditions.

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