Modelling of PR Controller For A Grid Connected Single Phase Inverter

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***Abstract*— Single-phase grid-connected inverters are widely used to connect small-scale distributed renewable resources to the grid. However, unlike a three-phase system, control for a single-phase inverter is more challenging, especially when the inverter is used with an *LCL* filter. This paper proposes the modelling of PR (proportional resonant) controller for a grid connected single phase inverter and observation of its performance during load fluctuation condition. From Simulation results of the system it is demonstrated that the modelled PR controller exhibits good transient response over the conventional PI controller when system subjected to load disturbance.**

***Index Terms*— Single phase inverter, LCL filter, PR controller, PI controller, current control loop.**

I. INTRODUCTION

In recent years, distributed generation has been put on the agenda, distributed generation has the merits of less pollution, high reliability, high energy efficiency and installation flexibility, it can solve many potential problems of the large scale centralized power effectively, however, electricity produced by distributed power generation can't supply to AC load directly, grid-connected interface equipment must be inserted[7].

Power inverter is an important part of many DC to AC conversion equipments such as uninterruptable power supply (UPS), induction motor drive and automatic voltage regulator (AVR) systems. In these systems, it is the major requirement for the power inverter to be capable of producing and maintaining a stable and clean sinusoidal output voltage waveform regardless of the type of load connected to it. The main key to successfully maintain this ability is to have a feedback controller.

Currently, grid-connected inverter generally use control strategy of the output current control, nowadays, the most commonly used method have PI control[6] and so on. It has the merits of good control performance, robustness, and simple algorithm, clear physical meanings of parameters, easy to implement and high reliability, so it is widely applied in industry field as yet but conventional control can't reach perfect control effects for sine reference current, because this method has relatively more rise and settling time.

In order to settle this problem, PR controller is designed in this paper. PR-controllers provide theoretical infinite gain in a narrow bandwidth that is centered at a predefined resonance frequency, hence eliminating the steady state error at that frequency and allowing effective tracking behavior with sinusoidal reference signals. Another advantage associated with the PR controllers is the possibility of implementing certain harmonics compensation without requiring excessive computational resources. This controller is highly suited to operate with sinusoidal references like the reference used in Grid-Connected PV Inverters, thus making it an optimal solution for this application.

II. SINGLE PHASE GRID CONNECTED INVERTER

Figure 1, shows the schematic circuit diagram of a single-phase full bridge inverter with connected to grid. In this study, control based on the PR strategy theory is presented.

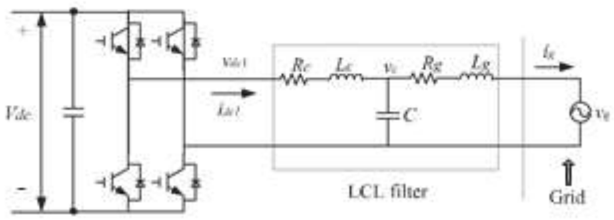


Fig.1 Schematic diagram of grid connected single phase inverter

A full bridge configuration with sinusoidal pulse width modulation (SPWM) unipolar voltage switching scheme is used as the switching circuit of the inverter. By selecting the full bridge configuration, the minimal allowed DC-link voltage can be set to be the peak value of the AC grid voltage (plus margins). In this, power IGBT is used in order to get high switching frequency with minimal switching losses as IGBT provides high switching character of MOSFET and minimal switching losses of BJT.

A. output filter design

A third order LCL filter[1,2], was used in order to reduce the harmonics and to achieve the reduced harmonic target. Figure2 describes the interconnection of LCL filter[3] between inverter and grid.

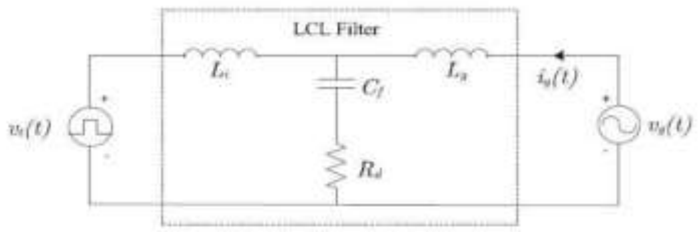


Figure.2: interconnection diagram of LCL filter

Here *$v_t(t)$ represents* the inverter output voltage which acts as input to the filter consists of a fundamental component and higher, *$v_g(t)$* is the grid voltage and *$i_g(t)$* is the grid current. Analyzing the filter in the s-domain gives the following transfer function equations

At $v_g = 0$

$$\frac{I_g(s)}{V_t(s)} = -\frac{sC_fR_d+1}{s^3L_iL_gC_f+s^2C_fR_d(L_i+L_g)+s(L_i+L_g)} \quad (1)$$

At $V_t = 0$

$$\frac{I_g(s)}{V_g(s)} = \frac{s^2L_iC_f+sC_fR_d+1}{s^3L_iL_gC_f+s^2C_fR_d(L_i+L_g)+s(L_i+L_g)} \quad (2)$$

Therefore, Equation (1) is used as the transfer function of the filter from the filter circuit. From equation (1) we can calculate the resonant frequency of the filter which is ω_r and

$$\omega_r = \sqrt{\frac{(L_i+L_g)}{L_iL_gC_f}}$$

Finally, the LCL filter components are chosen following this guideline and the values of each component are shown in Table.1

Filter element	Value
Li- inverter side inductor	15.7mH
Lg-grid side inductor	0.57mH
Cf-filter capacitance	10μF
Rd-filter damping resistance	0.1ohm

Table 1: filter design parameters

III. CONTROLLER MODELLING

A. Proportional resonant controller

The current controller can have a significant effect on the quality of the current supplied to the grid by the PV inverter, and therefore it is important that the controller provides a high quality sinusoidal output with minimal distortion to avoid creating harmonics

A single phase feed back current loop is used to regulate the grid current. A proportional resonant control strategy is used as compensator to track a sinusoidal current reference frame. The basic control loop diagram[4] with PR control is as shown in figure 3.

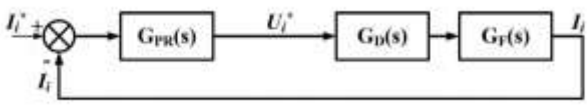


Fig. 3 control loop diagram with PR controller

Transfer function of the ideal PR controller is as below:

$$G_{PR}(s) = K_p + K_R \frac{s}{s^2+{w_o}^2} \quad (3)$$

Where K_p − proportional gain of the controller

K_R −resonant gain of the controller

w_{o-} resonant frequency of the controller in general which is frequency of the grid

Unfortunately, the ideal PR controller acts like a network with an infinite quality factor, which is hard to implement the PR controller in reality. Firstly, the infinite gain introduced by PR controller leads to an infinite quality factor which cannot be achieved in either analog or digital system.

Secondly, the gain of PR controller is much reduced at other frequencies and it is no adequate to eliminate harmonic influence caused by grid voltage. Therefore, an approximating ideal (non-ideal) PR controller, is given by

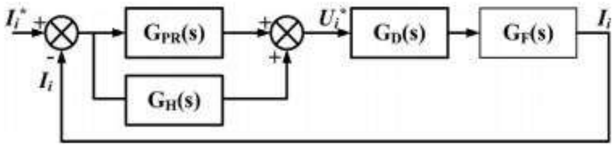
$$G_{PR}(s) = K_p + K_R \frac{2\omega_c s}{s^2+2\omega_c s+w_o{}^2} \qquad (4)$$

Where ω_c- bandwidth around the ac frequency of w_o

The frequency response of (4) is shown in Fig. 3(b), where the resonant peak now has a finite gain of 40 dB which is satisfactorily high for eliminating the voltage tracking error. In addition, a wider bandwidth is observed around the resonant frequency, which minimizes the sensitivity of the controller to slight grid frequency variations. At other harmonic frequencies, the response of the non-ideal PR controller is comparable to that of the ideal PR controller.

B. PR Controller with compensator

In order to reduce the harmonics generated during load fluctuations within short time interval we use PR harmonic compensator[4,5] along with our PR controller. The basic control loop diagram of PR with compensator as shown in figure 4



IV.

Fig. 4 control loop diagram of PR controller with compensator.

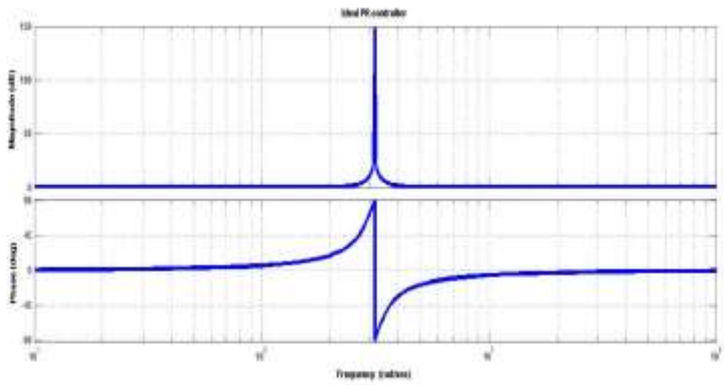
The harmonic compensator $G_H(s)$ is represented by

$$G_H(s) = \sum_{h=3,5,7,..} K_{lh} \frac{s}{s^2+(h\omega_o)^2} \qquad (5)$$

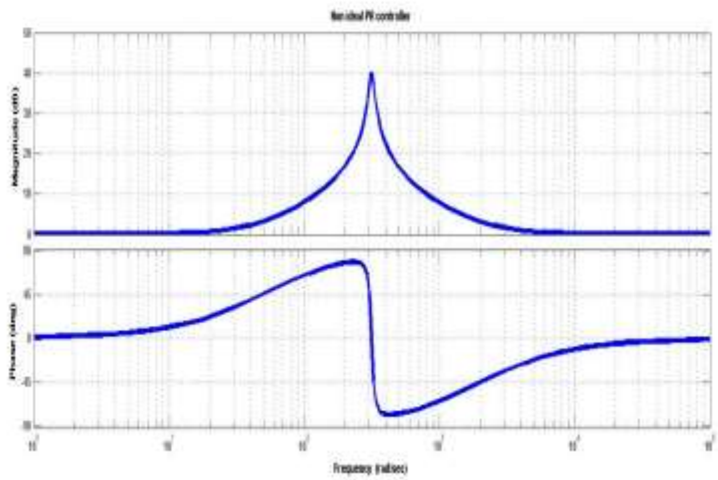
Where K_{lh} resonant gain term of particular harmonic and $h\omega_o$ is the resonant frequency of that harmonic.

Eq. (5) represents an ideal harmonic compensator which as stated for the fundamental PR controller, can give stability problems due to the infinite gain. To avoid these problems, the harmonic compensator equation[9] can be made non-ideal by representing it using (6)

$$G_H(s) = \sum_{h=3,5,7,..} K_{lh} \frac{2\omega_c s}{s^2+2\omega_c s+(h\omega_o)^2} \qquad (6)$$



(a) ideal PR controller

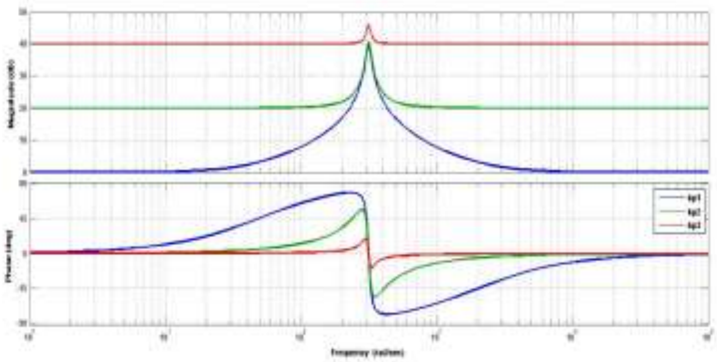


(b) Non ideal PR controller

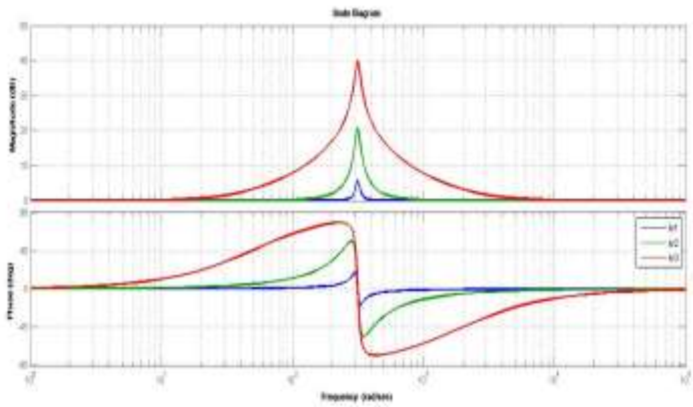
Fig. 5 Frequency responses of (a) ideal PR controller and (b) non-ideal PR controller with K_p=1, K_R=100, ω_{cut}=10 (rad/s).

As for the case of the fundamental PR controller, with (6) the gain of the harmonic compensator at the harmonic frequency $h\omega_0$ is now finite but it is still large enough to provide compensation.

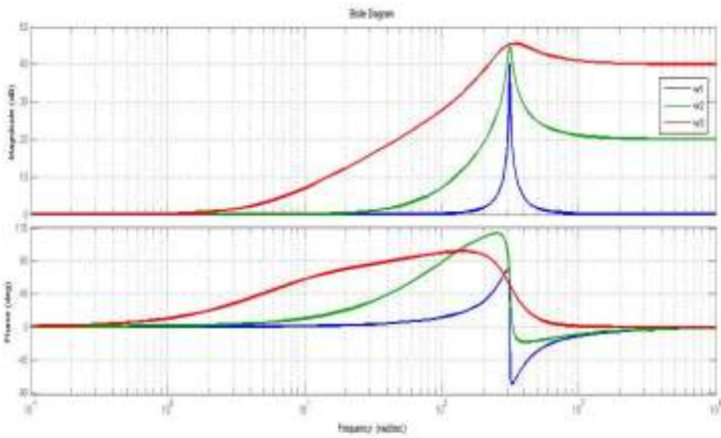
From the below frequency responses we can observe the variations in the performance and stability of the PR controller with the variation of controller gains and parameters.
Based Based on the theory analysis, in this paper, the PR controller gains are chosen as: $K_p = 6.8$, $K_R = 1498.72$ and $\omega_{cut} = 0.5$(rad/s).



(a) Frequency response when Kp changes



(b) Frequency response when Kr changes



(c) Frequency response when ω_{cut} changes

Fig.6 Frequency responses of a non ideal PR controller for changes in (a)Kp (b)Kr (c)ω_{cut}

Load disturbance:

The basic disturbance which frequently occurs on the power system is the load disturbance. Load disturbance effects both current and voltage of the grid and inverter[9]. Based on the ratings of the inverter, grid and also on reliability i.e whether the system can afford that load, the load sharing and fluctuations will be settled in lesser time. In general slight changes may not effect system very much but the heavy load change on system and also drastic changes effects the system severely. The use of controller[8] makes much difference in the system which severely influences the settling time, fluctuations of the system parameters and system stability

IV SIMULATION AND RESULTS

Figure 7 below shows the basic Simulink model of the implemented single phase inverter connected to grid along with the controller. The parameters taken into consideration for the implementation of grid are listed in table 2.

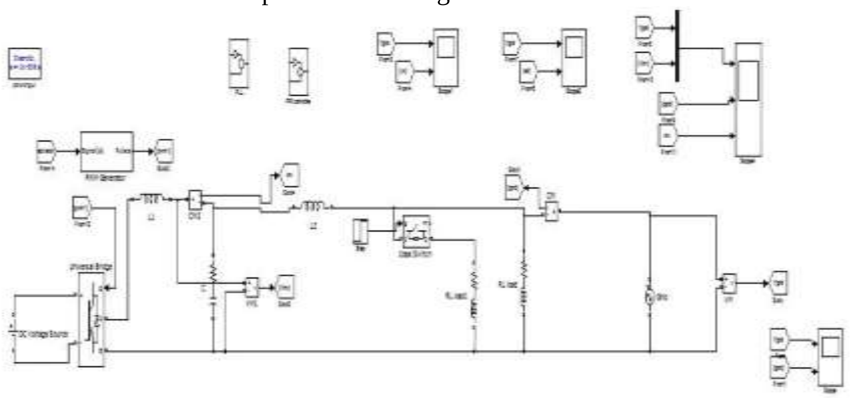


Fig.7 Simulink model of grid connected single phase inverter with controller

Parameter	Value
V_g −Grid voltage	220v RMS
F -- Grid frequency	50Hz
V_{dc}-DC voltage	400
Li- inverter side inductor	15.7mH
Lg-grid side inductor	0.57mH
Cf-filter capacitance	10μF
Rd-filter damping resistance	0.1ohm

Table 2: inverter and grid parameters

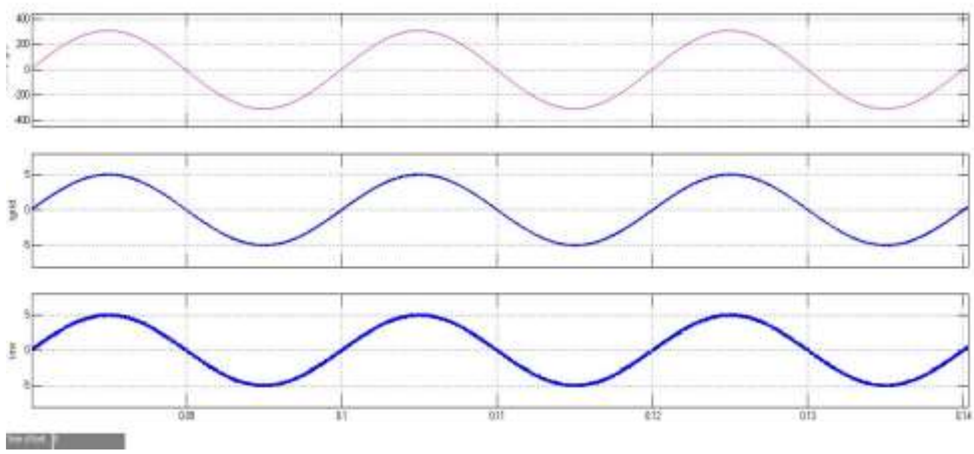


Fig.8: Steady state a)grid voltage b)grid current c)inverter current

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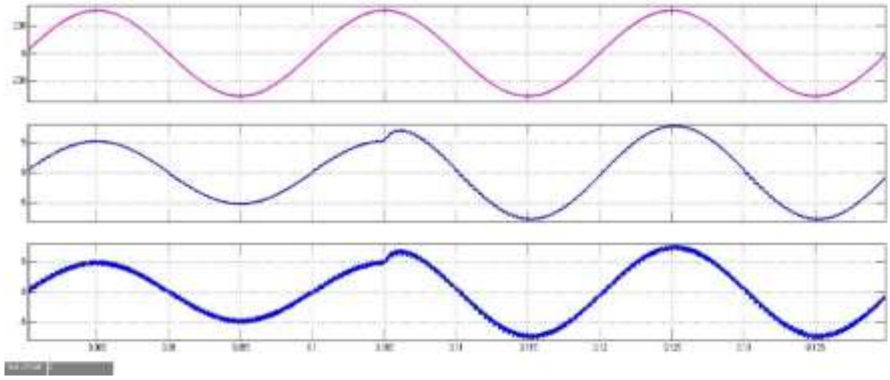

Fig.9 grid voltage , grid current, inverter current using PI controller.

Load fluctions on the system clearly showing the variations in grid current , inverter current and also we can observe the settling time taken by the system in order to settle down the load disturbance occurred

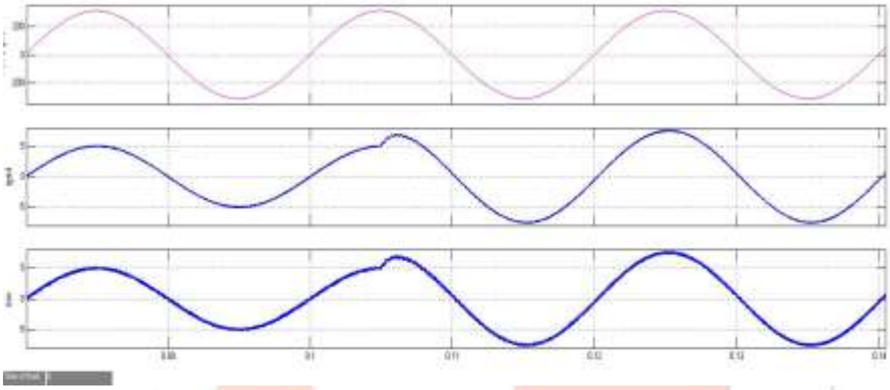

Fig.9 grid voltage , grid current, inverter current using PR controller

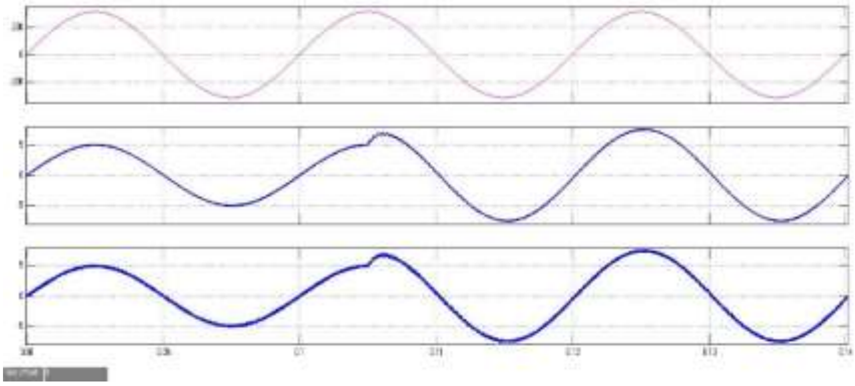

Fig. 10 grid voltage , grid current, inverter current using PR controller with compensator

V. CONCLUSION

The modelling of PR (proportional resonant) controller for a grid connected single phase inverter and observation of its performance during load fluctuation condition is done using MATLAB/Simulink. From Simulation results of the system it is demonstrated that the modelled PR controller exhibits good transient response over the conventional PI controller when system subjected to load disturbance. The better performance is obtained using harmonic compensator along with the modelled PR controller.

VI. REFRENCES

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