# Comparative Study of PI and Proportional Resonant Control for Single-Phase Grid-Connected Inverter System

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## ABSTRACT
A new control approach based on Proportional Resonant control for grid connected current is presented in this paper. The working principle is analyzed, parameter design and implementation method for PR control are given. This controller is different from traditional PI control, PR control can introduce the infinite gain at the fundamental frequency, so it not only can eliminate steady-state amplitude and phase errors of grid connected current, and the function of anti interference isn't good, Simulation study is made with the tool- boxes of SEMULESK in the MATLAB through theoretical analysis and simulation, effectiveness of PR control is verified.

***Keywords** - grid-connected inverter, Small scale modeling, zero steady-state error, PI control, PR control.*

## 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[1] . There are two schemes to realize the grid-connected interface conveniently at present inverter and rotating electric machinery comparison., former is better than rotating electric machine in size, weight, conversion efficiency, reliability, electrical performance, etc. therefore, the control of grid-connected inverter is also the focus of research at present.

Currently, grid-connected inverter generally use control strategy of the output current control, nowadays, the most commonly used method have PI control 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 stable state error. In order to settle this problem, PR control is studied in this paper; it can achieve zero steady-state error. This paper analyzes system model of grid-connected inverter, revealing the essence which PI control exist stable state error for AC.

## II. THE PRINCIPLE OF SINGLE PHASE GRID CONNECTED INVERTER SYSTEM

### A. System Structure
Figure 1 illustrates the principle of single-phase grid-connected inverter System, DC Side Voltage is 400V, which is supplied with The Distributed Generation based on renewable energy resource, inverter is connected by filter inductance and grid-connected switch, filter filters high harmonics caused by fast switching of IGBT, (making) output current is in phase and frequency with the network voltage through reasonable control strategy to accomplish system run under unit power factor. Table 1 shows the inverter main parameters.

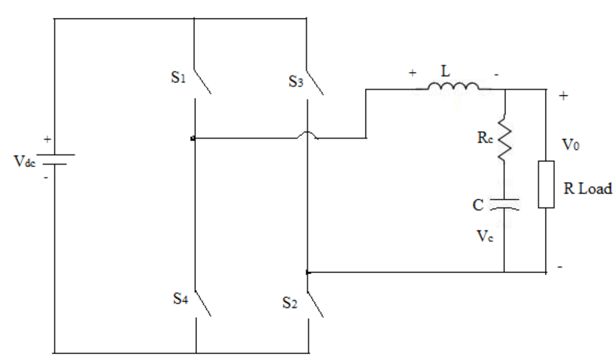



Fig. l Schematic diagram of grid-connected inverter

TABLE I

INVERTER MAIN PARAMETERS

| **Parameter** | **Values** |
|---|---|
| Nominal active power (P) | 440W |
| DC Link voltage ($V_{DC}$) | 400V |
| Inverter output voltage ($V_0$) | $230V_{rms}$ |
| Inverter output frequency ($f_g$) | 50Hz |
| Inverter inductance (L) | 19mH |
| Inverter output capacitor (C) | 600nF |
| Damping resistance (Rd) | 51 Ω |
| Inverter switching frequency ($f_{si}$) | 20kHz |
| Load resistance ($R_{LOAD}$) | 120.22 Ω |

B. SMALL SIGNAL MODEL

To perform a linear feedback control from a circuit that is nonlinear as a switched converter, the power stage must be linearized. The switched converter has a small signal linear model for small perturbations around an operating point. From this model linear controllers can be designed to close control loops with different characteristics. For the design of the controllers it is necessary to identify the transfer functions of the variables to control. The transfer functions are extracted using the technique of switch modeling PWM.

Case 1

When switches $S_1$ and $S_2$ are ON, then circuit is shown in Fig. 2

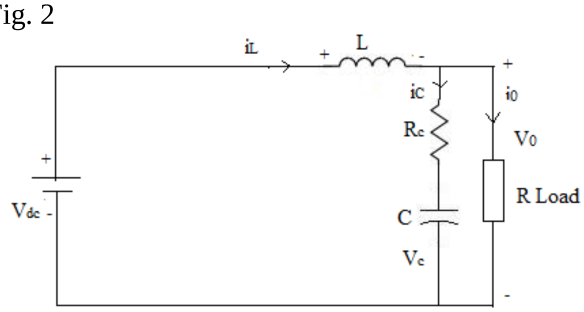



Fig. 2 Equivalent circuit when switches $S_1$ and $S_2$ are ON.

Applying KVL in Fig. 2

$$L\frac{di}{dt} = V_{dc} - V_o \qquad (1)$$

$$i_C = i_L - i_o$$

$$C\frac{dv_c}{dt} = i_L - \frac{V_o}{R} \qquad (2)$$

Case 2

When switches $S_3$ & $S_4$ are ON, the resultant circuit will be as shown in Fig. 3.

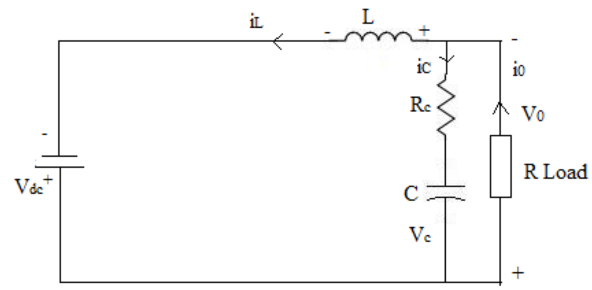



Fig. 3 Equivalent circuit when switches $S_3$ and $S_4$ are ON

By applying KVL in the above circuit

$$L\frac{di_L}{dt} = V_o - V_{dc} \qquad (3)$$

And

$$i_c = -i_L - i_o$$

$$C\frac{dV_c}{dt} = -i_L - \frac{V_o}{R} \qquad (4)$$

Let's consider average value of the inductor current and capacitor voltage over a switching period $T_s$.

$$\Rightarrow L\frac{d<i_L>_{T_s}}{dt} = d.<V_{dc} - V_o>_{T_s} + d'.<V_o - V_{dc}>_{T_s}$$

(5)

Where d= duty cycle and $d' = 1 - d$

And

$$C\frac{d<V_c>_{T_s}}{dt} = d.<i_L - \frac{V_o}{R}>_{T_s} + d'<-i_L - \frac{V_o}{R}>_{T_s}$$

(6)

Let's define an operating point as follows Duty cycle = D

Input voltage = $V_{dc}$

Output voltage = $V_o$

Capacitor voltage= $V_c$

Inductor current = $i_L$

Source current = $i_s$

In order to design a small signal model we will have to consider a small perturbation along with its steady state values.

$$<V_{dc}>_{T_s} = V_{dc} + \widehat{v_{dc}}$$
$$<V_o>_{T_s} = V_o + \widehat{v_o}$$
$$<D>_{T_s} = D + \hat{d}$$
$$<I_L>_{T_s} = V_c + \widehat{v_c}$$

Putting above values in equation (5) and (6)

$$L\frac{d(I_L + \widehat{i_L})}{dt} = (D + \hat{d}) * \{V_{dc} + \widehat{v_{dc}} - V_o - \widehat{v_o}\} + (1 - D - \hat{d}) * \{-V_{dc} - \widehat{v_{dc}} + V_o + \widehat{v_o}\}$$

(7)

On simplification the equation (7) gives rise to multiplication of steady state value terms along with linear and non-linear terms. Multiplication of perturbation terms can be neglected as its results are very small. So resulting expression would be

$$L\frac{d\hat{i}_L}{dt} = (D + D')\,\widehat{v_{dc}} - (D - D')\widehat{v_o} + 2\,V_o\hat{d} = (2D-1)\,\widehat{v_{dc}} - (2D-1)\widehat{v_o} + 2V_{dc}\,\hat{d} \qquad (8)$$

Similarly

$$C\frac{d\widehat{v_c}}{dt} = (2D-1)\widehat{i_L} - \frac{\widehat{v_o}}{R} + 2I_L\hat{d} \qquad (9)$$

From the equations (8) & (9) small signal model of the inverter is derived and is depicted in Fig. 4.

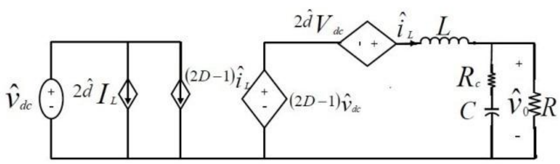


Fig. 4 Small signal model of 1-Φ inverter

From Fig. 4 it can be observed that a small signal ac current $\widehat{i_L}$ is drawn by the inverter out of the input voltage source $\widehat{v_{dc}}$ . As the concerned VSI of bridge type configuration the duty cycle is (2D −1). The term $(2D-1)\widehat{i_L}$ is dependent on the inductor current variation $\widehat{i_L}$ and is represented by a dependent source. The term $2\hat{d}\,i_L$ is driven by the control variations and is modelled by an independent source. This is an equivalent circuit that models the low frequency small signal variations in the inverter waveforms and it can be solved to using conventional linear circuit analysis techniques to find the inverter transfer functions.

## III. A SYSTEM MODEL WITH PI CONTROLLER

Based on fig. 1, System Model with PI controller can be established, as shown in the fig. 5, switching frequency exceed Working frequency m of inverter by far, in order to analyze conveniently, so influence of switch action upon System can be omitted, SPWM inverter could be equivalent as a proportion loop *K*, $G_0(S)$ is transfer function of controller in the fig. 5, R is equivalent resistance of Inductor *L*, $U_{grid}$ is network voltage, $I_{ref}$ is reference signal of grid-connected current and which is in phase and frequency with the network voltage.

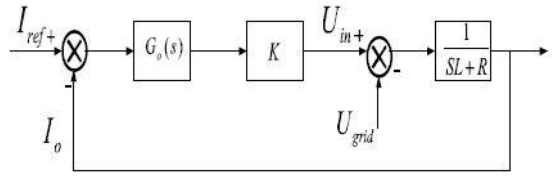


Fig. 5 System Model with PI control

Based on the above model transfer function of output current is given by (10)

$$I_o(s) = \frac{KG(s)}{SL+R+KG(s)}I_{ref} - \frac{1}{SL+R+KG(s)}U_{grid}$$
$$= \frac{1}{1+\frac{SL+R}{KG_o(s)}}I_{ref} - \frac{1}{SL+R+KG(s)}U_{grid} \qquad (10)$$

According to equation (10), we could see that output current of grid-connected inverter is relevant to reference current, if current want to achieve zero steady-state error at the fundamental frequency, that is, $I_0 = I_{ref}$, Necessary condition is $|G_o(s)|_{j\omega_o} = \infty$. The transfer function of traditional PI controller is-

$G_o(s) = K_p + \frac{K_i}{s}$, Gains reached at $\sqrt{\{K_p^2 + \left(\frac{K_i}{\omega_o}\right)^2\}}$ at the fundamental frequency, it is impossible to reach infinite, so grid-connected has steady state error, but stability margin of system will reduce, system can change from stable to unstable, if the $K_p$ or $K_i$ is enlarged excessively.

B. System model with PR controller

PR controllers are equivalent to conventional PI controller implemented in two synchronous rotating frames (positive sequence and negative sequence) and hence able to track sinusoidal references with variable frequency of both positive and negative sequences with zero steady state error. The transfer function of PR controller can be derived by using internal control model with modified state transformation or frequency domain approach. Fig. 6 shows the equivalent single phase PR control inverter system.

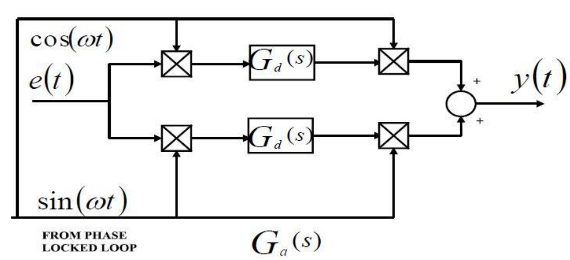



Fig. 6 Single phase equivalent presentation of PR controller

Where $G_a(s)$ is transfer function and $G_d(s)$ is integrator. Transfer function of PR controller for ideal integrator $G_d(s) = \frac{K_i}{s}$ is given by equation (11)

$$G_a(s) = \frac{2K_i s}{s^2 + \omega^2} \quad (11)$$

Transfer function of PR controller for non-ideal integrator $G_d(s) = \frac{K_i}{1+\frac{s}{\omega_c}}$ is given by equation (12).

$$G_a(s) = \frac{2K_i\omega_c s}{s^2 + 2\omega_c + \omega^2} \quad (12)$$

## IV. SIMULATION RESULTS ANALYSIS

In this paper, we use matlab/simulink to simulate. The system parameters have been given in table 1. Fig. 7 and 8 are the simulation results of PR control and PI control for single-phase grid current respectively. From these results, we can see that grid-connected current of PR control can track reference current without static error in steady state after a short transition process. Compared with the PR control, there exists bigger amplitude and phase angle errors in grid- connected current when using PI control. The simulation results are consistent with the theoretical analysis, so we can verify the theoretical analysis is correct. From the view of the total harmonic distortion (THD) of grid-current, its results are smaller than the THD values of PI control, even if the PR control calculated THD from the moment of 0. So the performance of PR control is superior to those of PI control both in steady-state error and in the THD by the comparison.

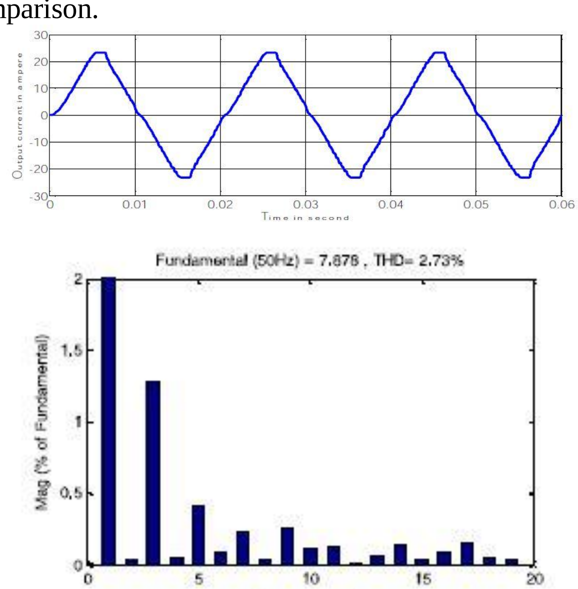
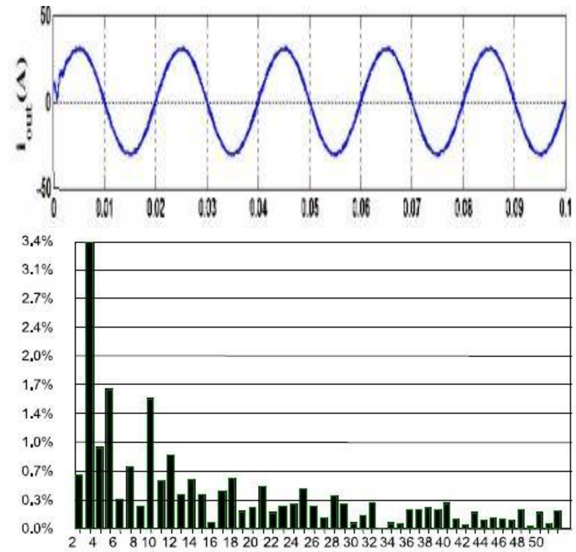



Fig. 7 Simulation Result of PR controller



THD= 4.82%

Fig. 8 Simulation Result of PI controller

## V. CONCLUSION

PR control strategy is discussed in this paper which can eliminate steady-state amplitude and phase errors of grid-connected current, Design Method of Parameters is provided, and this paper shows that PR control how to achieve, On the base of theory analysis, Finally, this paper carried out simulation on grid-connected current for single-phase, The effectiveness of application is verified by comparing PI control in grid-connected inverter system.

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