

Study of PR Controller to the Voltage Source Inverter

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Abstract

In this Present scenario the PV systems are mainly focusing on the interconnection between the grid and the power source which is like Inverter. This document presenting a Proportional + Resonant (PR) controller design for Controlling the Active as well as Reactive Power output of a Three-phase inverter system which is grid connected. The PV inverter which is used for either single-phase or three-phase, can be considered as the heart or core of the whole system because of an important role in the grid interconnecting operation. In this Inverter Control load current regulation is major important thing. In this present document, the Proportional + Integral (PI) controller, normally widely used in the Current-controlled Voltage Source Inverter (VSI), but it can't be a satisfactory controller for an AC system because of the poor disturbance rejection as well as steady-state error, especially in the range of high-frequencies. The system employs a grid connected Voltage Sourced Inverter (VSI). The Voltage Source Inverter is configured to operate as a current source through an interfacing with L-filter. The inverter's output current indirectly controls the Power. For this stationary reference frame strategy is choose to take up or follow to design the PR controller. Hence model of a grid connected inverter and a brief design of the inverter's PR based control scheme are discussed briefly in the following. The control scheme of this objective is developed and simulated in MATLAB/Simulink platform. Damping should be introduced to improve the control of the system. The Proportional Resonant (PR) current controller presents gains at a certain frequency i.e. also called (resonant frequency) and eliminates steady state errors. So the P+R controller can be successfully

applied for this single grid-connected PV inverter current control.

Keywords—Inverters, Active Damping, Proportional-Integral Controller, Proportional-Resonant Controller, Renewable Energy Sources, Photovoltaic.

Introduction

Microgrid is can convert AC to DC or DC to AC from Renewable Energy Sources i.e. Solar or Fuel cells. Primary component of an AC Micro-Grid is a VSI(Voltage Source Inverter). The dissimilar Renewable Energy Sources (RES) within the Micro-Grid system can operate independently or interconnected to a common DC link which supplies DC voltage as input for the VSI.

Mainly environmental affects are get reduced by Interfacing an AC Micro-Grid system of RES to the transmission or utility grid may give lower and improved security of electrical power supply [2],[3]. However, it introduces technical problems like affected quality of the power, increase in harmonic distortion, unreliable power supply, unstable Grid voltage and control. A Grid connected Micro-Grid system must provide that the grid's rated voltage and frequency remains unchanged [1].

Control problems are very common in designing of Micro-Grid systems. Generally the control is normally implemented to control active and/or reactive power transfer between the transmission or utility grid system and the Micro-Grid.

The power(active or reactive) is controlled indirectly by controlling the Voltage Source Inverter's output current through by interfacing with L-filter(active low

pass). In order to improve reference current tracking ability the filter inductor is made smaller too.

Normally PI Controller is used in grid connected inverter systems in order to control the output power using Inverter output current, however its performance is not up to the mark, since poor disturbance rejection and steady-state error, especially for high range of frequencies. So In this paper, a PR(Proportional +Resonant controller is designed for the inner current control loop of a 3Φ VSI in stationary frame of reference. In general a 3Φ Voltage Source Inverter requires three simultaneous control loops [1], one for each phase. In order reduce the number of control loops to two [1], the Alpha-Beta ($\alpha\beta$) frame is adopted.

The $\alpha\beta$ frame represents transformed balanced 3Φ quantities in their equivalent 2Φ counterparts. The PR controller is found using the transfer function $G_{AC}(s)$ [5]. An ideal PR controller has infinite gain at the frequency of operation [5], [6], [7]. Thus it's capable to track sinusoidal commands with no steady state error [8] as opposed to classical control strategies.

The control scheme is designed with an outer power control loop, which sets the $\alpha\beta$ reference currents for the inner current control loop. The outer control loop uses a classical Proportional Integral (PI) controller and the reference currents are calculated in the synchronous $d-q$ reference frame (also known as the Park's transform) and transformed back to $\alpha\beta$ frame with aid of a Phase Locked-Loop (PLL). MATLAB/Simulink development software environment is used for the control scheme model development and simulation.

In Section II, a three-phase grid connected voltage source Inverter is modelled. The PR control strategy using $\alpha\beta$ stationary reference frame is presented in Section III. The model of the implemented control scheme and simulation results are presented and discussed in Section IV. Section V gives the respected results the paper. Section VI concludes the Paper.

2. THREE-PHASE GRID-CONNECTED VSI ANALYSIS

2.1. Alpha-Beta ($\alpha\beta$)Frame and $d-q$ Frame Transformations

The $\alpha\beta$ and $d-q$ frame transformation techniques discussed in [1] transforms balanced 3Φ quantities to their equivalent 2Φ and dc counterparts respectively.

The transformed $\alpha\beta$ measures are in stationary reference frame. Equations (1) and (2) shows the $\alpha\beta$ and $d-q$ frame transformation equations respectively.

$$\begin{bmatrix} x_\alpha \\ x_\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} x_d \\ x_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos(\theta-2\pi/3) & \cos(\theta+2\pi/3) \\ \sin\theta & \sin(\theta-2\pi/3) & \sin(\theta+2\pi/3) \end{bmatrix} \cdot \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix} \quad (2)$$

The PLL control system, is used to obtain the phase angle θ of the grid voltage which is used for the $d-q$ frame space vector transformation as shown in Figure 1. On the other hand the 3Φ variables $x_{a,b,c}$ can be calculated by formulating inverse transformation equations.

2.2. System Modelling

The PR control strategy discussed in this paper is designed for a 3Φ grid connected VSI. Figure 1 depicts a schematic diagram of a grid connected VSI and its control loop setup. The inverter is controlled based on the Pulse Width Modulation (PWM) technique and it is connected to the grid through an interface L-filter. The VSI DC supply Voltage is a DC link common to either one or more DER unit(s).

In-order to obtain the VSI's linear control model, some assumptions where made according to [6]. These assumptions includes; the DC link voltage is constant and that the inverter's switching frequency is sufficiently high that it will have less effect on the dynamics of the control loop.

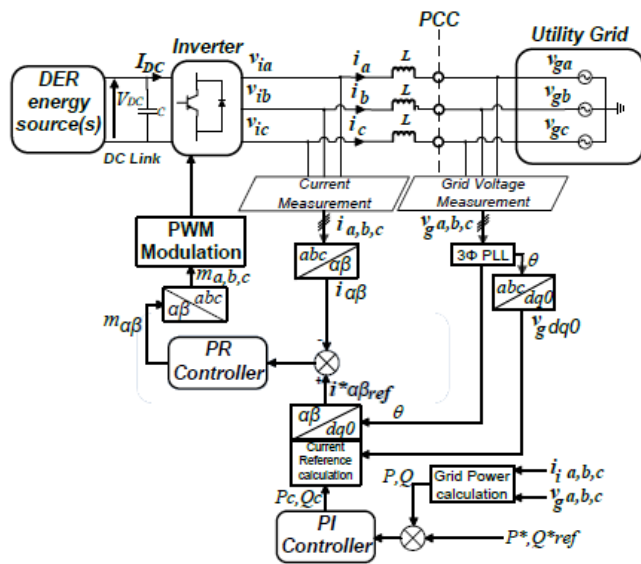


Figure 1 Schematic diagram for a three-phase grid connected VSI

From Figure 1 the mathematical equations for the voltages and currents are written as follows:

$$L \frac{di_n(t)}{dt} + Ri_n(t) = V_{in}(t) - V_{gn}(t) \quad (3)$$

Where, $n = a, b, c$ denotes the phase, $i_n(t)$ is the AC current flowing through the L-filter into the grid, $V_{in}(t)$ is the inverters output voltage, $V_{gn}(t)$ is the grid voltage, and R-L is the interface inductor and its equivalent series resistance.

From Figure 1, the outer power control loop involves calculating the grid active (P) and reactive (Q) power from the measured AC current and grid voltage and comparing it to the reference power signals P^*_{ref} and Q^*_{ref} . The P and Q are calculated based on the power equations (4) and (5) severally.

$$P(t) = V_a(t)I_a(t) + V_b(t)I_b(t) + V_c(t)I_c(t) \quad (4)$$

$$Q(t) = 1/\sqrt{3} [V_a(t)I_b(t) - V_b(t)I_a(t) + V_b(t)I_c(t) - V_c(t)I_b(t) + V_c(t)I_a(t) - V_a(t)I_c(t)] \quad (5)$$

The outer power control loop's PI controllers are designed such that they have slower dynamic responses than that of the inner current control loop. The inner control loop's reference currents are calculated from the actuating power outputs of the PI controllers. This is achieved by manipulating the $d-q$

frame P and Q power equations [1], [5]. Equations (6) and (7) show how the reference currents $i_{d\ ref}$ and $i_{q\ ref}$ in $d-q$ frame are calculated.

$$i_{d\ ref} = 2 * P_c(t) / V_{gn} \quad (6)$$

$$i_{q\ ref} = 2 * Q_c(t) / V_{gn} \quad (7)$$

Where, $P_c(t)$ and $Q_c(t)$ are the PI controller actuating active and reactive power outputs respectively. The computed reference currents in $d-q$ frame are transformed to $\alpha\beta$ frame current $i^*_{\alpha\ ref}$ and $i^*_{\beta\ ref}$ using the inverse transformation equations of (1) and (2).

The reference currents could have been calculated directly from the $P_c(t)$ and $Q_c(t)$ $\alpha\beta$ frame power equations discussed in [1]. But doing so ascertained to have significant impact on the dynamics of the control loop.

3. PR CONTROLLER DESIGN

The PR controller is in essence a grouping of a proportional K_p and resonant controller discussed in [5], which results in an ideal controller transfer function $G_{AC}(s)$ shown in (8).

$$G_{AC}(s) = K_p + \frac{2K_i}{s^2 + \omega^2} \quad (8)$$

Where, ω is the AC frequency and K_i is a constant that is carefully selected to shift the controller's magnitude response vertically [5], [7]. The ideal PR controller has an infinite gain at the AC frequency and no phase shift and gain at other frequencies.

The controller's infinite gain may cause stability problems and due to practical limitations of signal processing systems that implements it, a non-ideal transfer function $G_{AC}(s)$ (9) is used instead of (8).

$$G_{AC}(s) = K_p + \frac{2K_i \omega_c s}{s^2 + 2\omega_c s + \omega^2} \quad (9)$$

With the practical PR transfer function (9), its gain is finite, but it is still relatively high for enforcing a small steady-state error. The controller's bandwidth can be widened by setting ω_c appropriately, which helps to reduce sensitivity towards slight frequency variations [5].

4. MODEL SIMULATION

The Grid connected inverter control scheme model in Figure 1 is developed and simulated in MATLAB/Simulink development software. The Simulink software offers a flexible power electronics toolbox with already modeled power systems components. The PR controller was implemented for the inverter's output current regulation. In addition, a PI controller for the outer power control loop which generates reference currents for the PR calculation was also implemented. Simulink model of the overall system is presented below

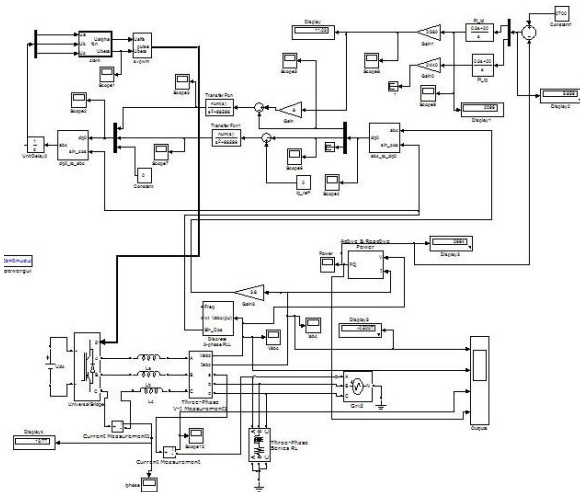


Figure 2 Overall Simulink diagram for a three-phase grid connected VSI

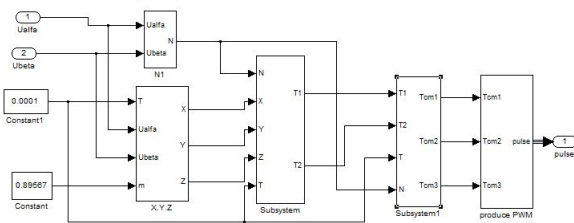


Figure 3 Simulink diagram for svpwm

Here subsystems of above svpwm are shown below

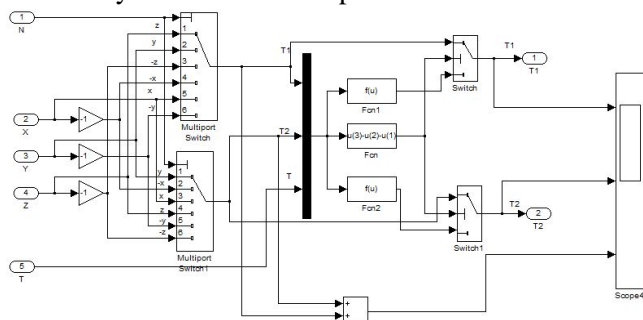


Figure3 (a) Simulink model for Subsystem

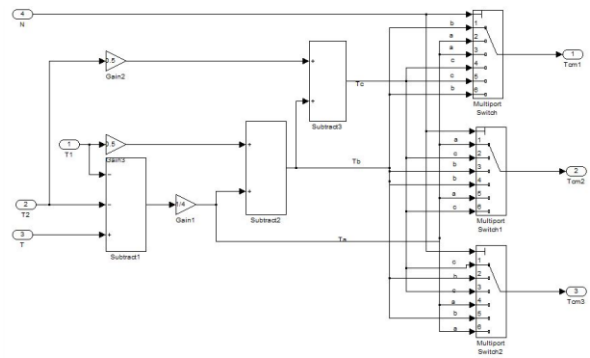


Figure3 (b) Simulink model for Subsystem1

5.RESULTS

a)Simulation Results of Grid Connected Inverter without PR Controller

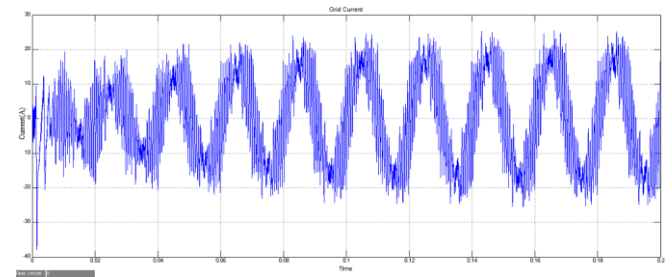


Figure .4 Single Phase Current of the system without PR Controller

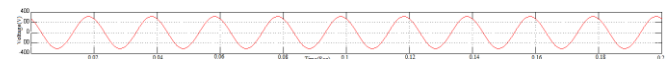


Figure.5 Single Phase Voltage of the system Without PR Controller

The above Graph represents the Grid current of the Inverter showing that the system is consists of harmonics as well as the Current is not fully controlled, that means that the current is increases as time increases. Moreover ripple content of Current is more when controller is absent.

b)Simulation Results of Grid Connected Inverter with PR Controller

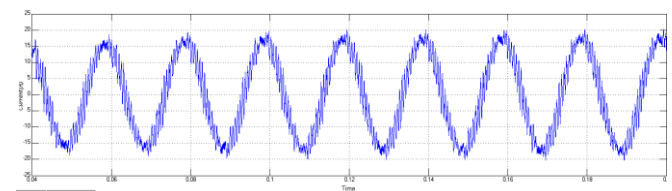


Figure.6 Single Phase Current of the system with PI and PR Controllers

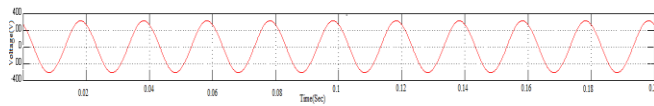


Figure.7 Single Phase Voltage of the system with PR Controller.

From Fig.10 represents the Output Current using PR Controller. It's is clear that the current waveform is merely Sinusoidal with some harmonics but in output current ripple content is less as compared to the output current in absence of controller. In Fig 11.the voltage waveforms are shown represents Inverter output voltage is 300v.

c) Simulation Results of Grid Connected Inverter without PR Controller under fault Condition

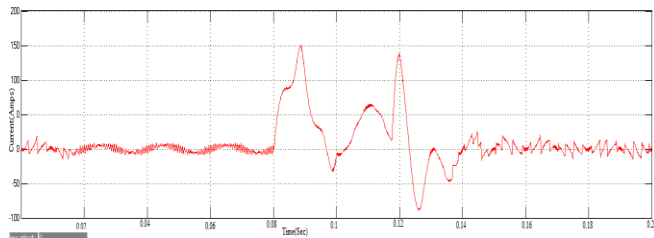


Figure.8 Output Current of Inverter(I_b) without Controller under Fault Condition

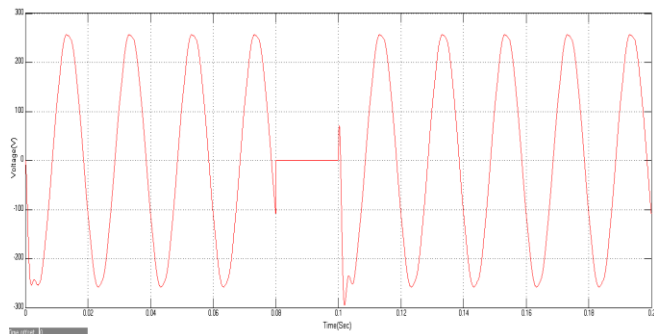


Figure.9 Single Phase Voltage of the system Without PR Controller under fault condition.

In the above fig, a fault is created at the time period of 0.08 to 0.1 sec by short circuiting the output terminals of the Inverter. By observing this, we will note that here there is no controller the systems is taking time to settle itself but time taken by the system to settle is high and the waveform is also consists of ripples. Coming to voltage is not built after the fault also.

d) Simulation Results of Grid Connected Inverter with PR Controller

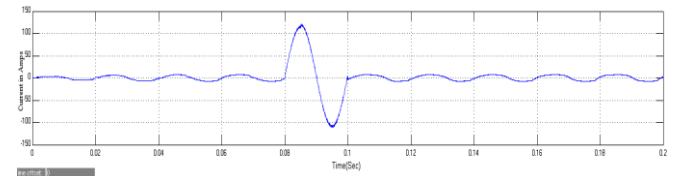


Figure.10 Output Current of Inverter(I_b) with Controller under Fault Condition

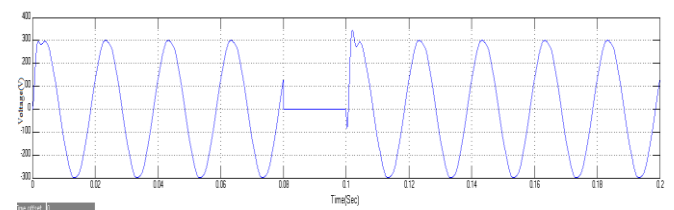


Figure.11 Single Phase Voltage of the system With PR Controller under fault condition

By observing the above plot we have to note that particularly difference when controller used, there are no ripples in current waveform moreover when we see the difference of voltage under with and without Controllers, In the absence of controller current reaches 150 amps and it will reduce to 100 and then it stabilises, amplitude of the output voltage is coming to steady state value taking much amount of time. Time taken by the system without Controller to settle and reaches the steady state value late, but on applying the Controller, the system was attained the required amount of voltage 300v much faster.

6. CONCLUSIONS

This paper has presented the effectiveness of using the Proportional Resonant (PR) control strategy to control active and/or reactive power transfer between the Micro-Grid and the transmission grid system. The PR controller tracks stationary frame reference currents calculated from the active ($P_c(t)$) and reactive ($Q_c(t)$). PI controller actuating power outputs using $d-q$ frame power equations. Consequently this improves the performance of the control loop as opposed to reference currents calculated directly from $\alpha\beta$ frame power equations. The PR controller tracks reference currents with a very small steady-state error.

Analysis of the PI controller bode plot shows that output gain of the controller is fairly uniform across the frequency range. For the PR controller, it is apparent that the controller can be tuned so that the control system has low impedance to the fundamental frequency of interest; in the case of a grid connected inverter system this is the network frequency – typically 50/60 Hz. This is one of the reasons that PR controller are becoming increasingly popular in distributed generation systems Model development and simulations were done using the MATLAB/Simulink software environment.

7. TABLE

1.Parameters for the Simulation of Grid Connected Inverter

DC Voltage	400v
Inverter-side filter inductor L_i	2mH
Grid-side filter inductor L_g	0.86mH
Filter capacitor C_f	5 μ F
Filter damping resistor R_d	2.5 Ω

8. REFERENCES

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