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Comparative Analysis of Linear Controllers used for Grid Connected PV System

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ABSTRACT

Requirement for electrical energy is increasing in a ramp function manner. To meet the steady increasing in energy demand it is required to find some alternate source of energy. Except the conventional source of energy one type of renewable energy i.e PV may be regarded as a clean source of energy to meet the energy demand. PV modules generating DC power cannot be directly connected to the electrical infrastructure as most of the grid infrastructure uses either 230volt or 120 volt. Therefore power electronic device most be connected (inverter) between PV and grid. In order to make a competitive market between the renewable generated power and conventional way of generating the power it is required to design a cost effective inverter, qualitative output which is pure sinusoidal and harmonics free. In this paper a comparative analysis among the various linear controllers are presented. Proposed Optimised PID Controller is Presented through MATLAB Simulink based environment.

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1. INTRODUCTION

Power generation through photo voltaic module is increasing throughout the global and their by gaining popularity in the PV application, C.F Figure 1. This is mainly to create a sustainable environment by storing As conventional energy sources creates a lots of pollution, so importance of grid connected PV system increases.Due to increase in solar photo voltaic production volume and avalability of material and govt incentives the per unit generation cost of solar photovoltaic module is moving in down word tendency. Renewable purchase obligation for industry has increased to a great extent, hence most of the industry are now tending towards establishment of renewable based power plant to meet their RPO. According to IEEE 1547 maximum allowable grid interconnection of solar power most not increase 30% of the grid capacity.

The ongoing discussion clearly indicates that the power electronics inverter plays an important role in the power conversion technology. Power electronics interference inverter perform two important tasks such as:

a. To amplify the generated DC power to grid level and to convert it into AC power before injecting into the grid.
b. Extracting maximum amount of power through MPPT and their by maintaining sufficient DC voltage at the input level.

The two tasks as depicted above must be compiled with highest efficiency and a large bandwidth of power. Inverter used in the grid connected photo voltaic system must be free from maintenance during the entire life span operation of the solar PV module. It is recomended that inverter should have life span of 25 years with plug and play enabled features.Some of the grid interface inverter requires a transformer before injecting the AC voltage into the grid because presnce of DC in AC cause distortion. Some of the countries like Australia, Italy, England, and japan made it mandatory to use transformer while injecting the AC power into the grid.

2. GRID SYNCHRONISATION METHOD

The main task while interconnecting the inverter with the grid requires proper tracking of three phase grid frequency phase angle and maintenance of proper voltage level at the terminal of inverter. Both voltage control and current control method uses pulse width modulation techniques for inverter switching frequency or pulse generation. Two types of current control techniques have been described over here. These current control techniques can be classified as linear controller and non-linear controller. Linear controller mainly consists of PI controller, PR controller, dead beat controller, repetitive current controller. Whereas non-linear controller consists of hysteresis controller, ANN based controller, fuzzy inference controller and a new type fractional order controller.

2.1. Stationary Reference Frame of Control

Stationary reference frame of control usually employs a PI controller to regulate the power flow from the inverter side into the grid side. It usually consists of three number of PI error compensator, which is further processed. Output of the PI controller has two parts integration and proportional parts integration part provides compensation against low frequency of operation whereas proportion part provides compensation against zero placement. Figure 1 shows the stationary reference frame of control.

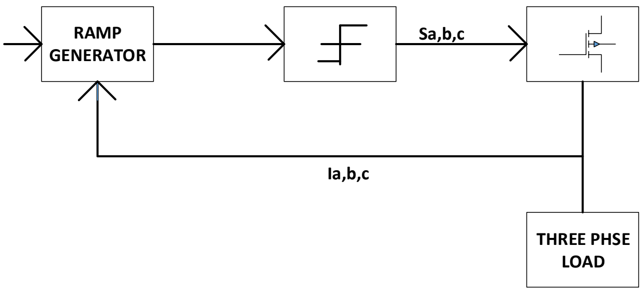


Figure 1. Stationary Ref. Frame of Control

2.2. Synchronous Reference Frame of Control

Some typical and precise industrial application required un-distorted source of current. A small distortion in phase and amplitude may cause some undesirable effect in the industrial drivers. This type of system requires space vector modulation approach to be implemented for the control of system. Therefore synchronous ref. frame of control requires a module transformation which can transfer abc reference frame into dq reference frame. Schematic diagram showing synchronous reference frame of control is shown in Figure 2 with a PI Controller.

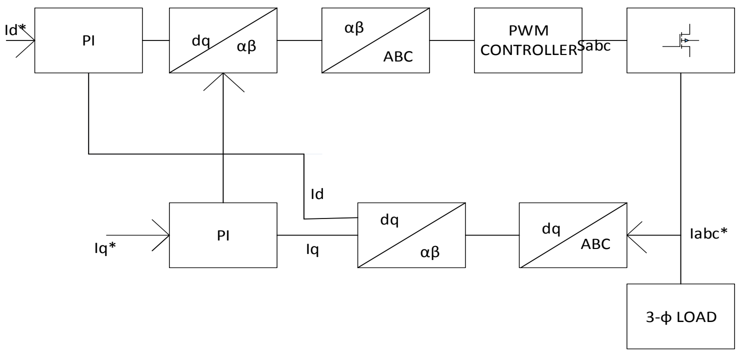


Figure 2. Schematic Diagram of Synchronous Ref. Frame of Control

Here the required dc-link voltage is controlled depending upon the output requirement through a filter capacity. Two independent controller one for voltage and one for current is applied. The reference voltage for the controller depends upon the peak grid voltage and voltage loss on drop occurring at the switches, therefore minimum dc reference that is to be maintained can be found by using Equation (1)

$$V_{DC,\min} = V_{DC,ave} - V_{DC,ripple} \tag{1}$$

Where

$$V_{DC,ripple} = \frac{P_{DC}}{2\omega . V_{DC,ave} . C_{DC}} \tag{2}$$

Comparing Equation (1) and (2)

$$V_{DC,ave} = V_{DC,\min} + V_{DC,ripple} \tag{3}$$

Multiplying $V_{DC,avg}$ on both side of Equation (3), it becomes

$$V_{DC,ave}{}^{2} = V_{DC,\min}(V_{DC,ave}) + \frac{P_{dc}}{2wC_{DC}} \tag{4}$$

Equation (6) clearly revels that, it is a second order polynomial equation, whose solution may be written as:

$$V_{DC,avg}{}^{1} = \frac{V_{DC,\min} \pm \sqrt{(V_{DC,\min})^{2} + \frac{4P_{DC}}{2\omega C_{DC}}}}{2} \tag{5}$$

Or,

$$V_{DC,ref} = V_{DC,nominal} + \alpha(P_{DC} - P_{DC,nominal}) + \beta(V_{grid} - V_{grid,nominal}) \tag{6}$$

Where,

$$\alpha = \frac{1}{\sqrt{2}} . \frac{2.Z_{conductance} + \frac{1}{2\omega C_{DC}}}{V_{grid,nominal}} \tag{7}$$

And $\beta = \sqrt{2}$ (8)

Therefore from (7) and (8) it is clear that α can be controlled through frequency domain whereas β is maintained constant.

In order to maintain a constant DC reference, it is required to implement the DC, Controller.

$$H(s) = \frac{K_{sqs} . K_{p} . (ST+1)}{S^{2} T . C_{c} + K_{sys} K_{P} (ST+1)} \tag{9}$$

where

$$K_{sys} = \frac{V_{grid,nominal,ripple}}{2.V_{DC,Nominal}}$$

Equation (9) shows that close loop control action of the considered controller. Therefore the controller can be evaluated through natural frequency and damping ratio.
where,

$$\omega_n = \sqrt{\frac{K_{sys} \cdot K_P}{T \cdot C_{DC}}} \qquad \xi = \frac{K_{sys} \cdot K_P}{2 \cdot \omega_n \cdot C_{DC}} \qquad K_P = \frac{2 \cdot I_{grid.3,THD}}{V_{DC,ripple}}$$

2.3. PR Controller

Limitation of PI controller while tracking the sinusoidal signal for compensation against error leads to the designing of PR controller. The controller matrix of PR controller provides infinite gain at the resonant frequency. Due to absence of cross coupling of control for a three phase voltage source converter.

Three phase voltages and currents are transformed into α, β reference frame using dark transformation. Equation used for co-ordinate transformation is shown in the Equation (10). Figure 3 is shows the PR Controller Strategies

$$\begin{bmatrix} V_\alpha \\ V\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} i_\alpha \\ i\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{10}$$

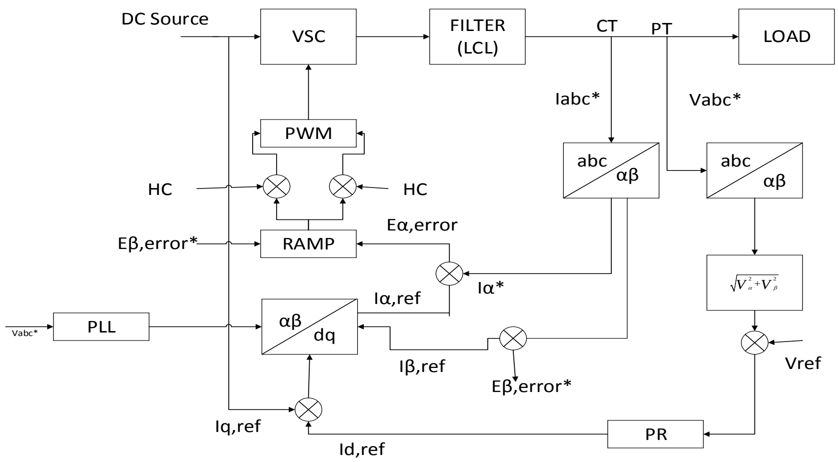


Figure 3. PR Controller Strategies

The grid voltage thus transferred to α, β reference frame is used to calculate the grid voltage amplitude through stationary ref. frame of control by using Equation (14)

$$|V| = \sqrt{V_\alpha^2 + V_\beta^2} \tag{11}$$

Error between the grid voltage and ref. voltage is fed to a PI controller whose transfer function is shown in Equation (12) as G_{pf}^{dq} and Current reference for PR controller can be obtained by applying reverse park transformation which is shown in Equation (12) as current

$$G_{PI}^{dq} = \begin{bmatrix} K_P + \frac{K_i}{S} & 0 \\ 0 & K_P + \frac{K_i}{S} \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} i_\alpha^{ref.} \\ i_\beta^{ref.} \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}^{-1} \begin{bmatrix} i_d \\ i_q \end{bmatrix} \tag{12}$$

Equation (13) represent two gain matrix,1st one rerevels that presence of high gain around the resonance frequency helps in elimination of steady state error and However in order to achieve infinite gain, modified PR controller may be used as second matrix of equation(13).

$$G_{PR}^{\alpha\beta}=\begin{bmatrix} K_P+\frac{K_iS}{S^2+\omega^2} & 0 \\ 0 & K_P+\frac{K_iS}{S^2+\omega^2} \end{bmatrix} G_{PR}^{\alpha\beta}=\begin{bmatrix} K_P+K_i\frac{2\omega_C S}{S^2+2\omega^2 S+\omega_0^2} & 0 \\ 0 & K_P+K_i\frac{2\omega_C S}{S^2+2\omega^2 S+\omega_0^2} \end{bmatrix} \quad (13)$$

Natural reference frame of control or abc controller uses three independent controller for three no. of phases individually. However use of star, delta connection and isolated design system (Neutral) are some of the critical issues which needs to be addressed while designing the controller. Therefore it can be assumed that by using two controller for two different phases, current in other phases can be automatically adjusted.

Real time implementation of controller is an issue. The advantages of the controller can be found out through the implementation of controller in digital electronics. Non-linear controller at the cost of linear controller have many advantages. Transfer matrix implementing PI and PR controller in abc natural frame of reference is shown in Equation (14) and Equation (15) respectively.

$$G_{PI}^{abc}=\begin{bmatrix} K_p+\frac{K_iS}{S^2+\omega_0^2} & -\frac{K_p}{2}-\frac{K_iS+\sqrt{3}K_i\omega_0}{2(S^2+\omega^2)} & -\frac{K_p}{2}-\frac{K_iS+\sqrt{3}K_i\omega_0}{2(S^2+\omega^2)} \\ -\frac{K_p}{2}-\frac{K_iS-\sqrt{3}K_i\omega_0}{2(S^2+\omega^2)} & K_p+\frac{K_iS}{S^2+\omega_0^2} & -\frac{K_p}{2}-\frac{K_iS+\sqrt{3}K_i\omega_0}{2(S^2+\omega^2)} \\ -\frac{K_p}{2}-\frac{K_iS+\sqrt{3}K_i\omega_0}{2(S^2+\omega^2)} & -\frac{K_p}{2}-\frac{K_iS-\sqrt{3}K_i\omega_0}{2(S^2+\omega^2)} & K_p+\frac{K_iS}{S^2+\omega_0^2} \end{bmatrix} \quad (14)$$

$$G_{PR}^{abc}=\begin{bmatrix} K_p+\frac{K_iS}{S^2+\omega_0^2} & 0 & 0 \\ 0 & K_p+\frac{K_iS}{S^2+\omega_0^2} & 0 \\ 0 & 0 & K_p+\frac{K_iS}{S^2+\omega_0^2} \end{bmatrix} \quad (15)$$

3. EXPERIMENTAL RESULTS

An inverter prototype for 100Kwatt solar PV grid connected system has been designed with MATLAB Simulink. Grid connectd system is designed to inject maximum amount of power strictly to the maximum outgoing feeder connected to that particular system. PWM controller has been used to generate pulses so as to inject maximum amount of power.

Based on the design criteria and theory as mentioned above the simulated result is shown in Figure 4 shows that voltage of solar PV system varies in between 302.4 to 303.8V. Voltage across the input of inverter is stepped up to 670V with an allowable ripple conent of 5%.

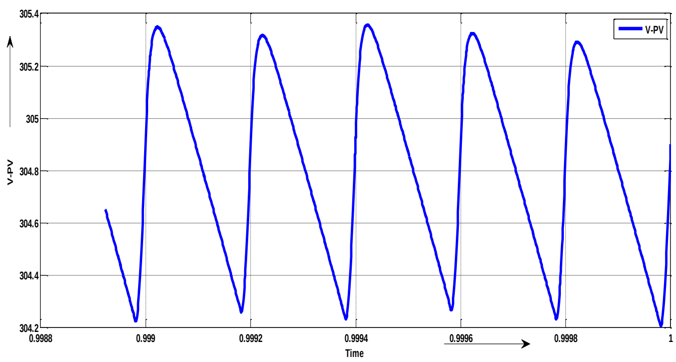
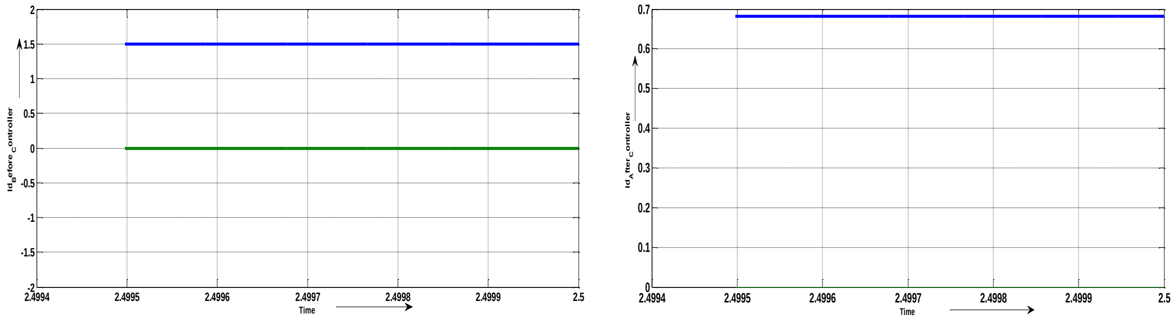


Figure 4. PV Output Voltage

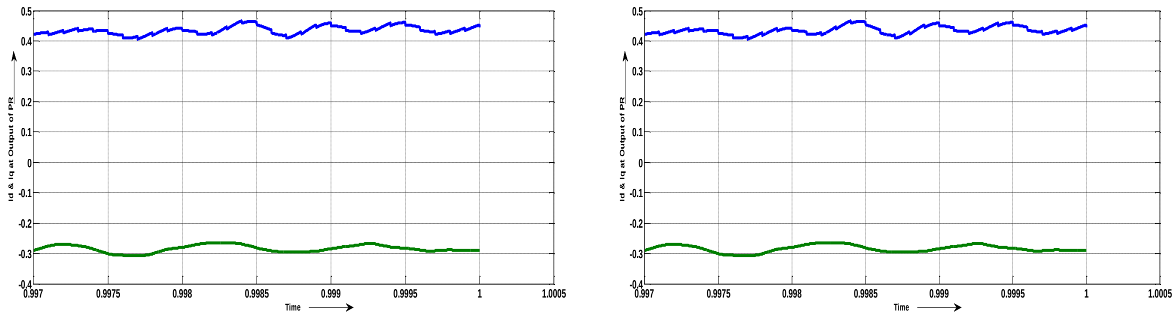
Figure 5 shows that input Id,Iq to state feedback controller and output Id,Iq of state feedback controller.



(a) (b)

Figure 5. (a) Input Id,Iq to State feedback Controller (b) Output Id,Iq of State feedback Controller

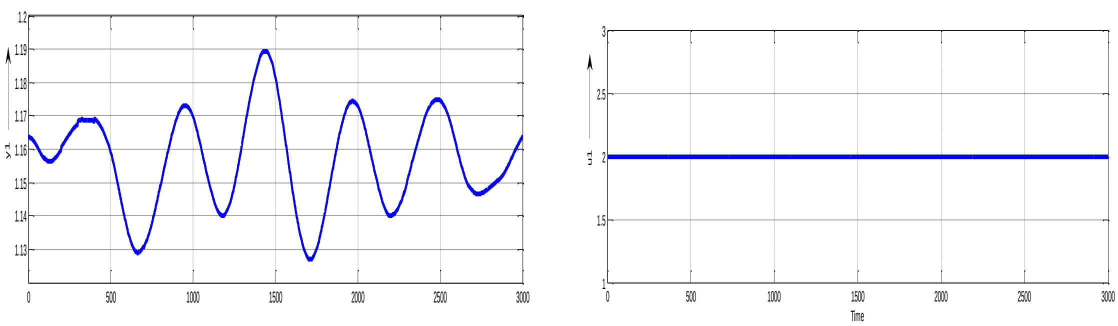
Figure 6 shows that input Id,Iq to PR controller and output of Id,Iq PR controller.



(a) (b)

Figure 6. (a) Input Id,Iq to PR Controller (b) Output of Id,Iq PR Controller

Figure 7 shows that PI controller takes two input i.e. Id and Iq to make it stable to a particular level to generate firing signal for the inverter switch. Figure 8 shows the stability analysis of PI controller.



(a) (b)

Figure 7. (a) Input Id,Iq to PI Controller (b) Output Id,Iq of PI Controller

Figure 9 shows the stability analysis of PR controller.
Figure 10 shows the stability analysis of state feedback controller.

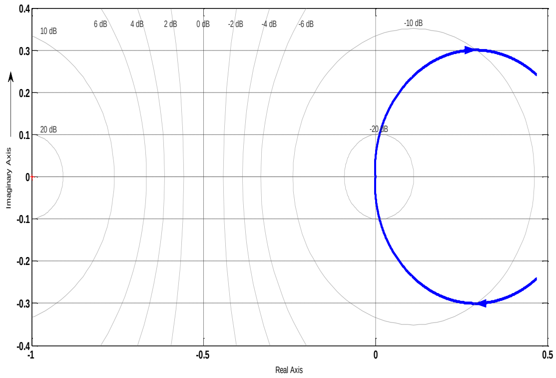


Figure 8. Stability Analysis of PI Controller

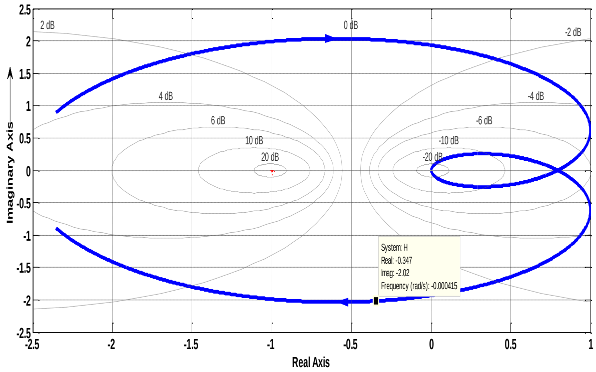


Figure 9. Stability analysis of PR Controller

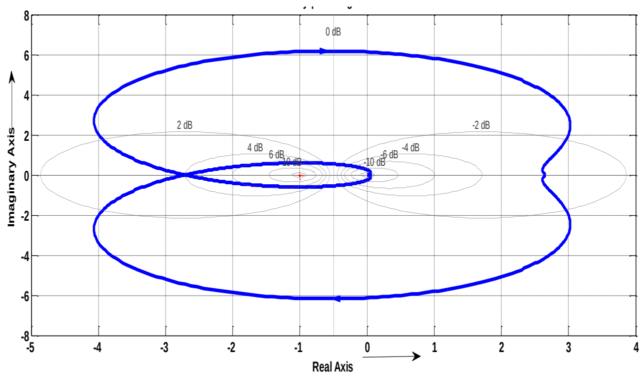


Figure 10. Stability analysis of State feedback Controller

4. CONCLUSION

Evaluation of the linear controller has been carried out under a steady state condition. Power injected into the grid is maintained at aparticular level by fixing the voltage. Current injection quantity has been increasesd by applying different controller. Stability analysis of all the discussed controller has been presented with Nyquist plot to check the stability.Best on the result PI controller is found to be best one under non transient condition. PR- controller shows high gain around the resonance frequency thereby increasing the grid current injection level and real power transmission.

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