

Modeling and Performance Analysis of Partial Feedback Linear Controlling Technique in Single Phase Grid Connected PV System

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Abstract: During the last few decades, intense research on the detection of crack using the vibration based techniques has been done and various approaches have been developed by researchers. In the present paper, detection of the crack presence on the surface of composite cantilever beam -type structural element using natural frequency is presented. First three natural frequencies of the cracked beam have been obtained experimentally and used for detection of crack location and size. Detected crack locations and size are compared with the actual results and found to be in good agreement. Also, the effect of the crack location and the crack depth on the natural frequency is presented. Experimental Modal Analysis (EMA) was performed on beams with cracks and the measuring first three natural frequencies changes. To identify the crack, contour of each normalized frequency in terms of the normalized crack depth and location are plotted. The point of intersection of three curves gives crack location & depth. It is observed that, results obtained from experimental method have a very good agreement with actual results also we can justify the results through simulation.

Keywords: PV systems, Current controller, Hysteresis controllers, nonlinear system, partial feedback linear controller

1. Introduction

Photovoltaic (PV) energy is fascinating the world as a promising alternative to conventional energy sources. It is the energy which is pervasive, free, clean and environment friendly. As the people and organization are more aware about the environment, installations of PV systems are increasing. The PV source could be used to supply a standalone and grid-connected PV systems. The standalone system requires energy storage system but grid connected PV system does not require storage[1]. Due to feed-in-tariff and reduction of battery cost grid-connected PV is widely used. The grid-connected PV systems are nonlinear system. The variation in sunlight, change in load demand, faults in the system such as line to ground fault and the switching functions of the converters and inverters are the causes of nonlinearity. Under these condition stable operation of the system can be achieved by proper exercise controlling approach.

Current controller technique is used to achieve the desired performance. Feedback linearization is a widely used technique for model based nonlinear controller design for power systems. The main approach is to algebraically transform a nonlinear system into a linear representation, so that linear control techniques can be applied on the linear part to enhance the stability of the whole system. If feedback linearization transforms a nonlinear system into a is partially linear representation, the system is partially transformed, the controller design approach is known as partial feedback linearization [2]. It also introduces an autonomous system whose dynamics are called internal dynamics and these dynamics need to be stable. The main advantage of partial

feedback linearizing controllers is that the dynamics of the full model is not essential [3].

The aim of this paper is to design the model of current controller using partial feedback linear controlling technique to control the current injected into a single phase grid. The performance analysis is carried out by comparing the performance of this controlling technique to hysteresis current controller under the same operating conditions.

2. Review on Current Controlling Techniques

The integral term in the PI controller improves the tracking by reducing the instantaneous error between the reference and the actual current. The resulting error signal is used to control the pulse-width modulation for the switches. Below the minimum power condition or above the maximum power condition, the inverter should not operate to ensure the safety of the PV panel [4]. Although PI (D) controllers are common and well known, they are often poorly tuned[4]. PI controller suffered from a steady state error when following a sinusoidal reference [5].

Hysteresis controller's method is an instantaneous feedback current control method in which the actual current continuously tracks the command current within a pre assigned hysteresis band. The harmonic quality of the wave will improve, but the switching frequency will increase, which will in turn cause higher switching losses[5]-[7]. Hysteresis technique exhibits also several undesirable features; such as uneven switching frequency that causes acoustic noise[8].

The ideal proportional resonant controllers (PR) widely used in directly when the control variables are sinusoidal. PR controllers present a high gain around the natural resonant frequency. Therefore it can omit the steady state error between the reference and the controlled signal. Since the distorted currents usually contain more than one order harmonics, it would be preferable to use many resonant compensators, which are tuned at different harmonic frequencies, and cascaded together or nested in different rotating reference frames to achieve the multiple harmonics compensation[9].

3. Hysteresis Current Controller

Hysteresis controller is one of the most preferred technique used for all the applications of current controlled and voltage source inverters. It exhibit very good dynamical properties as well as robustness, property of inherent peak current limiting and simple hardware implementation makes it most popular [10][11]. The bandwidth of the hysteresis current controller computed by comparing the load current with the reference current using hysteresis comparators as shown in fig.1 By varying in the inverter operating frequency current waveform can be compensated. [12]. The Mathematical equation for bandwidth control is given as follows. Fig. 2 shows the MATLAB simulation of hysteresis current controller. The average witching frequency of VSC can be controlled by varying the bandwidth.

$$i_{ref} = I_{max} \sin \omega t \quad (1)$$

$$i_{up} = I_{ref} + H \quad (2)$$

$$i_{lo} = I_{ref} - H \quad (3)$$

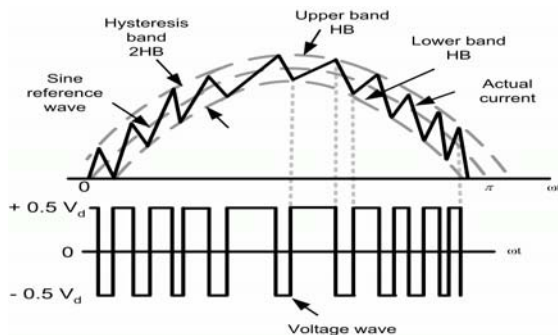


Figure 1: Current and voltage waves with hysteresis band current control

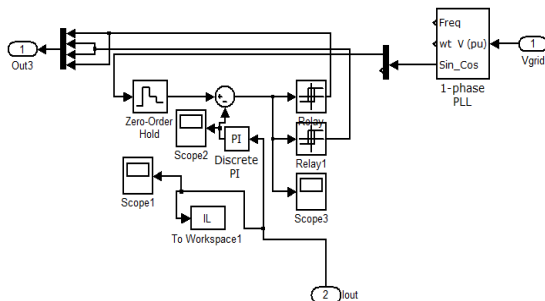


Figure 2: MATLAB simulation of hysteresis current controller

4. Advantages of nonlinear Control System

Linear control is a powerful method successfully used in industrial applications. Though it has great history, it has

limitations which may overcome by nonlinear system, explained as follows [15][16].

i) Improvement of existing control systems

When the linear control system is having large operation range, due to the nonlinearities in the system, it fails to provide stable operation. Nonlinear controllers may handle the nonlinearities in large range operation directly.

ii) Analysis of hard nonlinearities

In control systems there are many nonlinearities whose discontinuous nature does not allow linear approximation. Linear control methods cannot derive their effect while nonlinear controlling method can analysis the system with the these inherent nonlinearities.

iii) Dealing with model uncertainties

The slow time variation and an abrupt change in parameters, the controlsystem encompass uncertainties. A linear controller may exhibit significant performance degradation or even instability on other hand nonlinear controller can tolerate uncertainties.

iv) Design Simplicity

Good nonlinear control designs may be simpler and more intuitive than the linear control system.

5. Modeling of Partial Linear Feedback System

The partial linearization controlling method is designed for single phase grid connected PV system. General nonlinear system can be expressed as [14]

$$\dot{x} = f(x, u) \quad (4)$$

$$y = h(x) \quad (5)$$

where

$$x = [v \ i]^T$$

$$y = i$$

A nonlinear coordinate transformation is given by[14-16]

$$\tilde{z} = \tilde{\phi}(x) \quad (6)$$

For a single-phase grid-connected PV system, consider

$$\tilde{z} = \tilde{\phi}(x) = h(x) = i \quad (7)$$

Now partially linearize the system using

$$\tilde{z} = \frac{\partial h(x)}{\partial x} x \quad (8)$$

For grid connected PV system

$$\dot{\tilde{z}} = \frac{-Ri - \epsilon}{L} + \frac{v}{L} u \quad (9)$$

$$\dot{\tilde{v}} = \frac{-Ri - \epsilon}{L} + \frac{v}{L} u \quad (10)$$

$$\tilde{z} = \tilde{v}$$

From the definition of the Lyapunov function or energy Function if in each state it is possible to find out a control law to reduce the energy of the system, it is possible to bring the energy of the system to zero, i.e., to bring the system to a stop which means the stable condition of the system. Considering the only the current equation. [15][17]]Lyapunov function can be constructed. Energy

function for the purpose of controlling current can be written as

$$V = \frac{1}{2} Li^2 \quad (11)$$

Derivative of V is always zero or negative and gives the Lyapunov

$$\dot{V} = 0 \quad (12)$$

i_{ref} is the reference output tracked by using PI controller

$$\dot{v} = K_P(i_{ref} - i) + K_I \int_0^t (i_{ref} - i) \quad (13)$$

The gain of PI controller are given as

$$K_P = 2i_{ref}, K_I = i_{ref}^2, \quad (14)$$

The controlling can be obtained by

$$u = \frac{1}{v} (L\dot{v} + Ri + v) \quad (15)$$

5.1 Reference Value from MPPT

The reference power output generated at maximum power point is given by

$$P_{ref} = v_{pv} * i_{pv} \quad (16)$$

The maximum power supplied to the grid is P_{grid}

$$P_{grid} = ei = V_m \sin \omega t \times I_m \sin \omega t = \frac{V_m I_m}{2} (1 - \cos 2\omega t) \quad (17)$$

The average power injected into grid is given a

$$P_{av} = \frac{2}{T} \int_0^{\frac{T}{2}} \left(\frac{V_m I_m}{2} \right) (1 - \cos 2\omega t) dt = \frac{V_m I_m}{2} \quad (18)$$

The average power P_{av} follows the reference power P_{ref} therefore I_{refm} will be I_{refm}

$$P_{ref} = \frac{V_m I_{refm}}{2} \quad (19)$$

It will give

$$I_{refm} = \frac{2P_{ref}}{V_m} \quad (20)$$

The reference current injected into grid is given as

$$i_{refm} = \frac{2P_{ref}}{V_m} \sin \omega t \quad (21)$$

5.2 Block diagram of partial linearizing controller

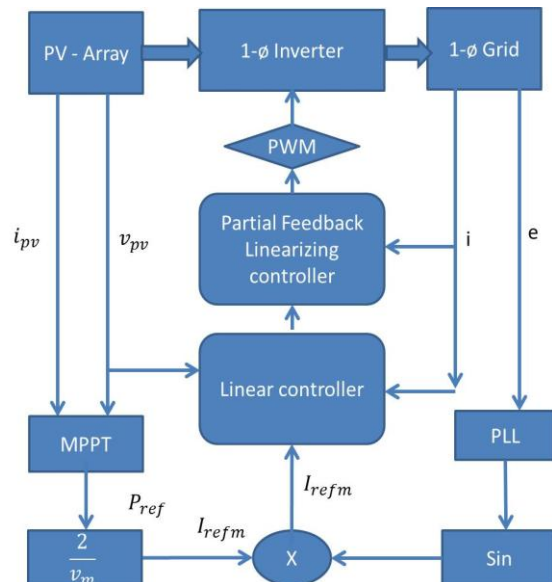


Figure 3: Block diagram of partial linearizing controller

The block diagram shown in figure 3 shows the partial linearizing controller designed from the discussion in this article. The current and voltage signal of PV system fed to the MPPT, which gives the reference power and magnitude of reference current. The Phase Loop Locking will give phase angle in comparison of grid voltage[17]. A linear and partial feedback linearizing controller will give the controlling scheme. The signals of controller fed to pulse width modulation (PWM) to control the voltage source inverter.

6. Single Phase Grid Connected PV System

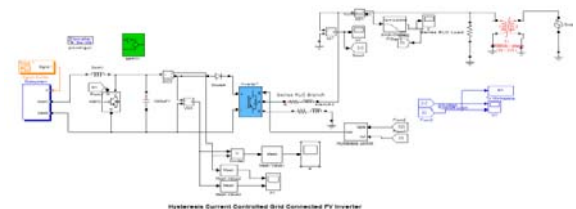


Figure 4: Single phase grid connected PV system with hysteresis current controlling technique

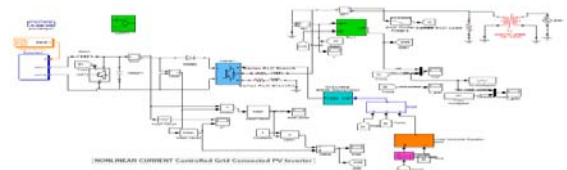


Figure 5: Single phase grid connected PV system by partial linearization controlling technique

By considering the practical aspects of PV system, single-phase grid-connected PV system is designed in MATLAB Simulink. The PV array of rating 160 DC volts and 5 ampere current is connected to the grid by using voltage source inverter. The grid voltage 240 AC volts with frequency of 50Hz. The Perturb & Observe (P&O) algorithm is used to obtain maximum power point. Figure 4 shows the Single phase grid connected PV system which exercises the hysteresis current controlling technique as explained in figure 2. In figure 5, the same system is controlled by partial linearization controlling method. The controlling algorithm

used in this system is shown in figure 3, which converts the nonlinear system into partially linearized.

7. Performance Analysis

The performance of hysteresis current controlling and partial linearization controlling technique is analyzed under following condition.

i) Healthy Condition

Under this condition standard atmospheric parameters are considered. The solar irradiation is 1kW-2 and the temperature as 298 K. The power supplied by the PV array using hysteresis current controller is not constant as shown in figure 6. From figure 7 it is observed that the power output of partial linearization controlling system is more smooth than that of the of hysteresis current controller. The current amplitude is continuously varying in hysteresis current controller, while a steady current is observed in of partial linearization controlling method as shown in figure 8 and figure 9.

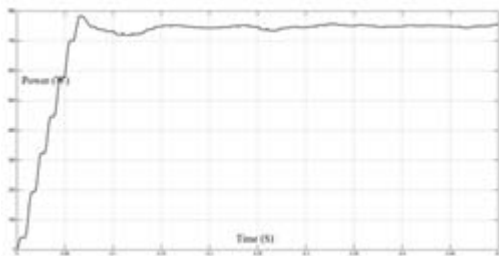


Figure 6: Power of PV array at healthy system using hysteresis current controlling technique

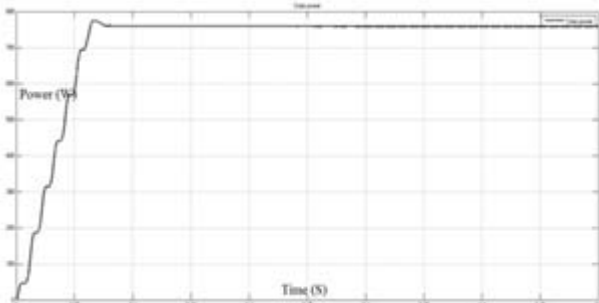


Figure 7: Power of PV array at healthy system partial linearization controlling technique

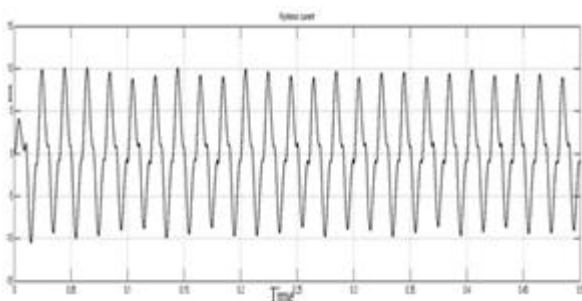


Figure 8: Current injected into grid using hysteresis current controlling technique

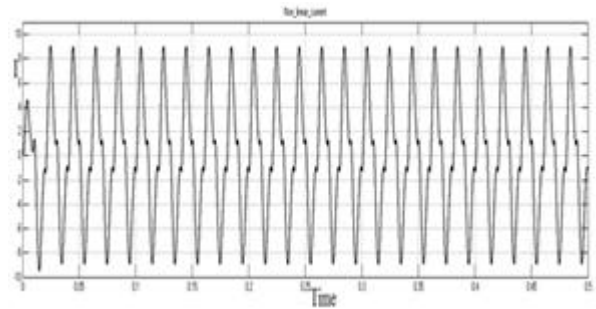


Figure 9: Current injected into grid using partial linearization controlling technique

ii) Line to ground fault condition

A line-to-ground fault is created on the grid at time instance of 0.25s to 0.35 s. The fault is cleared at time instance of 0.35s. At the instance of fault the DC power output of PV array falls to minimum value, but when the fault is cleared at time instance 0.35, power is unstable in hysteresis current controlling method and fails to come its original value shown in figure 10. In figure 11, power output of PV system in which partial linearization controlling system implemented comes to steady state position as soon as fault is cleared. The current injected into the grid after the post fault condition in hysteresis current controlling method continuously fluctuating while in partial linearization controller responds faster, to maintain the post fault steady state condition.

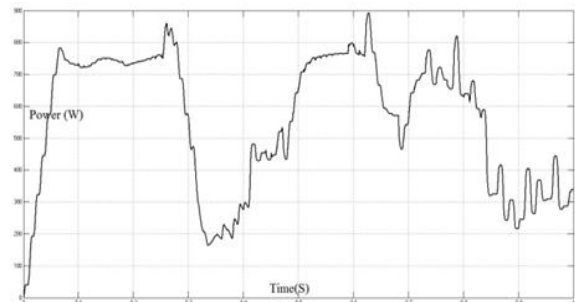


Figure 10: Power of PV array at LG fault using hysteresis current controlling technique

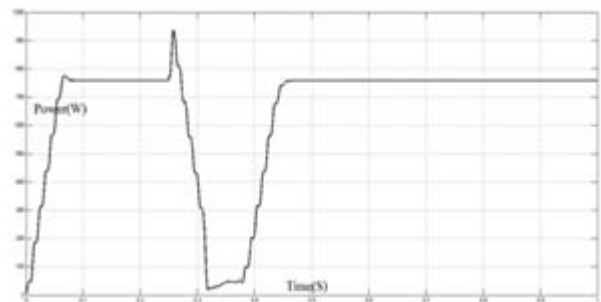


Figure 11: Power of PV array at LG fault using partial linearization controlling technique

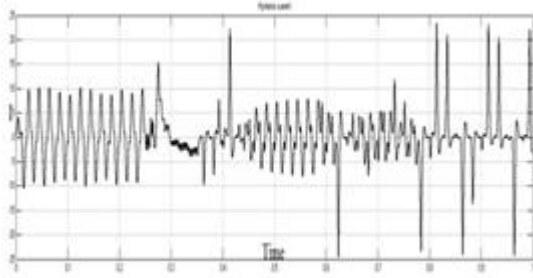


Figure 12: Current injected into grid using hysteresis current controlling technique

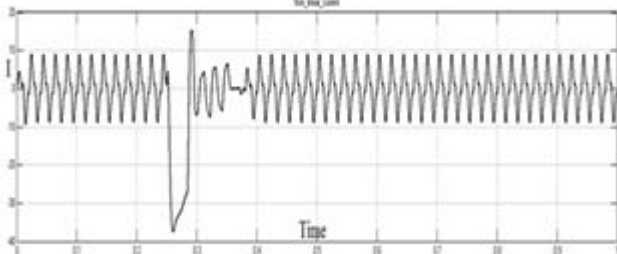


Figure 13: Current injected into grid using partial linearization controlling technique

8. Conclusion

In this paper, the performance analysis of a partial feedback linear controller for single phase grid connected PV system is tested and compared to hysteresis current controller under the same operating conditions. The effectiveness of the partial feedback linear controlling technique and hysteresis current controlling has been demonstrated through the results of the simulation in MATLAB/Simulink. Simulation results validate the performance of the partial feedback linear controller as it achieves the post-fault steady-state operating condition under different conditions with faster settling time, damped oscillations, and smaller steady-state error and also enhances the transient stability limit of systems

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