ADAPTIVE HYSTERESIS CURRENT CONTROL OF INVERTER FOR SOLAR PHOTOVOLTAIC APPLICATIONS

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Abstract – *Power inverters are used to convert the D.C power produced by the solar photovoltaic cell into AC. This paper presents a novel Adaptive Hysteresis Current Controller to control the inverter, used in the solar photovoltaic cell. The proposed controller is capable of reducing the total harmonic distortion and to provide constant switching frequency. The mathematical model of Photovoltaic array is developed using the Newton's method using the parameter obtained from a commercial photovoltaic data sheet under variable weather conditions, in which the effect of irradiance and temperature are considered. The modeled Photovoltaic array is interfaced with DC-DC boost converter, AC-DC inverter and load. A DC-DC boost converter is used to step up the input DC voltage of the Photovoltaic array while the DC-AC single-phase inverter converts the input DC comes from boost converter into AC. The performance of the proposed controller of inverter is evaluated through MATLAB-Simulation. The results obtained with the proposed algorithm are compared with those obtained when using conventional fixed hysteresis current controller for single-phase photovoltaic inverter in terms of THD and switching frequency.*

Keywords: *- Photovoltaic cell, Adaptive hysteresis controller, Boost converter, Inverter.*

I. Introduction

Many renewable energy technologies today are well developed, reliable and cost competitive with the conventional fuel generators. Among various renewable energy technologies, the solar energy has several advantages like clean, power, unlimited, and provides sustainable electricity. However, the solar energy produces the dc power, and hence power electronics and control equipment are required to convert DC to AC power. The performance of the power inverter depends on the control strategy

adopted to generate the gate pulses. To control the inverters, current control methods are normally used. There are several current control strategies proposed, namely, PI control [11], Average Current Mode Control (ACMC), Sliding Mode Control (SMC) [13] and hysteresis control [3]. Among the various current control techniques, hysteresis control is the most popular one for voltage source inverter [2]. As the photovoltaic arrays are good approximation to a current source, most of photovoltaic inverters are voltage-source inverters. The conventional fixed hysteresis band is very simple, has robust current control performance with good stability; very fast response, an inherent ability to control peak current and easy to implement. But this technique has the disadvantage that the switching

Frequency varies within a band because peak - to – peak current ripple is required to be controlled at all points of the fundamental frequency wave [3]. Variable switching frequency has been recognized as solution for motor drive systems to minimize mechanical noise [9], but it is not recommended for power system applications due to generation of sub harmonics and low order harmonics which affect the quality of the power system. In order to solve this problem, in this paper an adaptive hysteresis band controller is proposed. An adaptive hysteresis band controller changes the hysteresis bandwidth as a function of reference compensator current variation to optimize switching frequency and THD of supply current.

MATLAB simulations are carried out for modeling solar photovoltaic array based on its mathematical equation and that model is used to interconnect DC to DC converter, proposed Adaptive hysteresis current controlled DC to AC converter and load. The performance of the proposed controller are evaluated by comparing with the results obtained when using conventional fixed hysteresis current

controller at the point of THD and switching requency.

This paper is organized as follows. Section II, introduces the model of photovoltaic system description, Section III describes the proposed adaptive hysteresis controller. Simulation results and conclusions are presented in the last section. The appendix is devoted to the mathematical modeling technique and basic characteristics simulation results for the photovoltaic cell.

II. Photovoltaic System Description

Figure 1 shows the block diagram of a photovoltaic system, which includes solar photovoltaic panel with DC to DC converter, Single phase inverter and load. The solar photovoltaic panel produces electricity when the photons of the sun light strike on the photovoltaic cell array. The output of the photovoltaic panel is directly connected to the DC to DC boost converter to step up the DC output of photovoltaic panel. Then it is fed to an inverter which converts DC into AC power at the desired voltage and frequency. A current controller is normally preferred due to its advantages like flexibility-modify easily through of software, simplicity-possible implementation in fixed point computation etc. The main task of the control systems in current controlled inverters is to force the current of single phase load according to a reference signal. There are many current control techniques in the literature as mentioned in the Introduction. The simplest current control technique is hysteresis current control technique. The actual value of the output current is controlled in order to remain in a defined area. This method is fast and simple and provides good results. The only problem is the variable switching frequency of the semiconductor switches that is a direct consequence of this control strategy. An adaptive hysteresis current controller is proposed in this paper for the control of inverter to obtain the better result in terms of less total harmonic distortion and constant switching frequency.

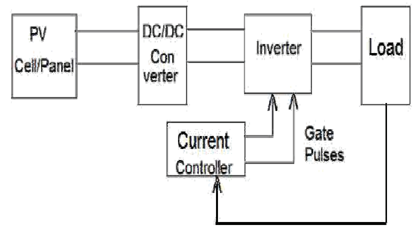


Figure1. Structure of Photovoltaic System

III. Proposed Adaptive Hysteresis Current Controller Design

The inverters used for photovoltaic energy generators are classified as voltage-source inverter (VSI) and current-source inverter (CSI). Each type of the inverters can be subdivided based on the control schemes; which are voltage-control inverter (VCI) and current-control inverter (CCI). In the voltage-source inverters, a capacitor is connected in parallel with the dc input. In the current source inverters, on the contrary, an inductor is connected in series with the dc input. Photovoltaic arrays are fairy good approximation to a current source. However, most of photovoltaic inverters are voltage-source inverters. The performance of inverter mainly depends on the control strategy adopted to generate the gate pulses. The dynamic responses of the system are controlled by the current controllers. Among the various current control techniques, hysteresis control is the most popular one for voltage source inverter. The basic structure of single phase inverter with hysteresis controller is shown in Figure 2.

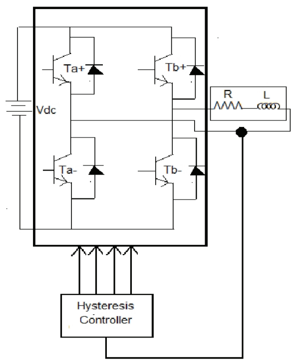
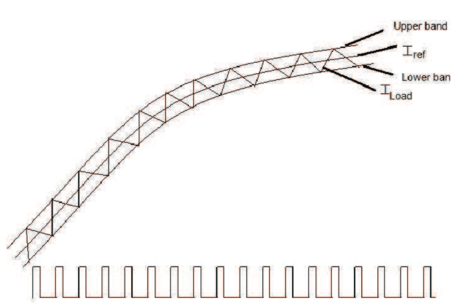


Figure 2 Single phase inverter

The principle of hysteresis current control is very simple. The purpose of the current controller is to control the load current by forcing it to follow a reference one. It is achieved by the switching action of the inverter by forcing it to follow a reference one. It is achieved by the switching action of the inverter to keep the current within the hysteresis band. The load currents are sensed and compared with respective command currents by hysteresis comparators having a hysteresis band "HB". The output signal of the comparator is used to activate the inverter power switches. The switching logic for an inverter is given below:

If IL < (IL –HB), the switch Ta+ and Tb- are turned OFF (Ta- and Tb+ are turned ON). If IL > (IL + HB), the switch Ta- and Tb+ are turned OFF (Ta+ and Tb- are turned ON).The switching function can be seen in Figure 3 below,



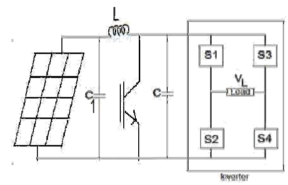


Fig. 3 Traditional Hysteresis current Controller

The fixed hysteresis band technique is very simple, has robust current control performance with good stability; very fast response, inherent ability to control peak current and easy to implement. The technique does not need any information about system parameters. But, this method has the drawbacks of variable switching frequency, heavy interference, harmonic content around switching side band and irregularity of the modulation pulse position [7]. These drawbacks result in high current ripples and acoustic noise. To overcome these undesirable drawbacks, this paper presents an adaptive hysteresis band control [3, 5]. The proposed adaptive hysteresis band controller adjust the hysteresis band width, according to the load current. The concept of adaptive hysteresis controller is shown in figure 4 where derivative of the load current and the reference current determines the switching time and frequency.

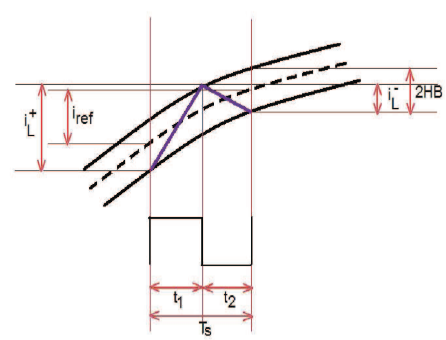


Figure4a. Adaptive Hysteresis Current Controller concept

During the current in increasing and decreasing state of the inverter in fig. 4b the following equations can be established.The equation (17) defines the hysteresis band that depends on the system parameters. By substituting the switching frequency we can get the hysteresis band value. Adaptive hysteresis band method allows operating at nearly constant frequencyand is usually performed by software using the system parameters.

Figure4b. Block Diagram of solar Photovoltaic System

The expression for hysteresis bandwidth is derived below

The fig. 4a shows the output current of the inverter. The error signal can be written as [12].

$$e = i_L - i_{ref} \tag{9}$$

The above equation can be modified for each switching period.

For on state (rising edge of the inverter load current)

$$\frac{de}{dt} = \frac{di_L}{dt} - \frac{di_{ref}}{dt} \tag{10}$$

$$\frac{2HB}{t1} = \frac{di_L^{+}}{t1} - \frac{di_{ref}}{Ts} \tag{11}$$

For off state (t2)

$$\frac{2HB}{t2} = -\frac{di_L^{-}}{t2} - \frac{di_{ref}}{Ts} \tag{12}$$

During the current in increasing and decreasing state of the inverter in fig. 4b the following equations can be established.

$$V_{dc} - V_L = L\left(\frac{di_{ref}}{dt} + \frac{de}{dt}\right) \tag{13}$$

$$0 - V_L = L\left(\frac{di_{ref}}{dt} + \frac{de}{dt}\right) \tag{14}$$

Substituting equation (11) and (12) in equations (13) and (14) and then adding the resultant expressions are t1 and HB

$$t1 = \frac{1}{V_{dc} f_s}\left(V_L + L\frac{di_{ref}}{dt}\right) \tag{15}$$

$$HB = \frac{1}{2Lf_s}\left(V_L + L\frac{di_{ref}}{dt}\right)\left[1 - \frac{1}{V_{dc}}\left(V_L + L\frac{di_{ref}}{dt}\right)\right] \tag{16}$$

$$HB = \frac{V_{dc}^2 t_1 f_s - \left(V_L + L\frac{di_{ref}}{dt}\right)^2}{2 f_s L V_{dc}} \tag{17}$$

IV. Simulation Result

Computer simulation of Photovoltaic system has been carried out using Matlab/Simulink. The performance measurement includes total harmonic distortion (THD) level of load currents and switching frequency. The system consists of solar photovoltaic module, DC-DC converter, DC-AC inverter and RL load. The photovoltaic module generates the DC voltage from solar temperature and irradiation.

A photovoltaic array has been modeled. It consists of 32x1 monocrystalline silicon solar cells each one, connected in series and parallel. Each module can produce DC electrical power. To let the interaction between a DC/DC converter and photovoltaic array, a simulation model for a photovoltaic array has been developed, with the provision of variable irradiance and temperature input. The model was implemented in simulink, helped by the SimPowerSystem block set based on its equivalent circuit (Figure 5) and the electrical characteristics of the photovoltaic module given by datasheet are shown in Table I [1].

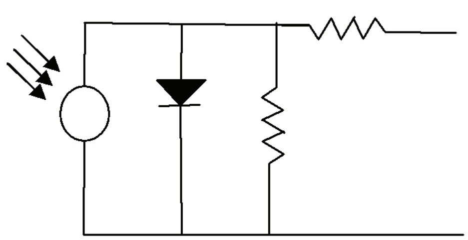


Figure 5. Equivalent circuit of a photovoltaic cell

Table I – Electrical characteristics of solar photovoltaic module

Maximum Power	40 W
Maximum Voltage	17.3 V
Maximum current	3.31 A
Short-circuit current	3.54 A
Open-circuit voltage	21.8 V
Temperature coefficient	(80±10)mV/℃

Figures 6(a) and 6(b) show the voltage- current and voltage- power output characteristics of a photovoltaic array model for different solar isolation with temperature of 25^0C.

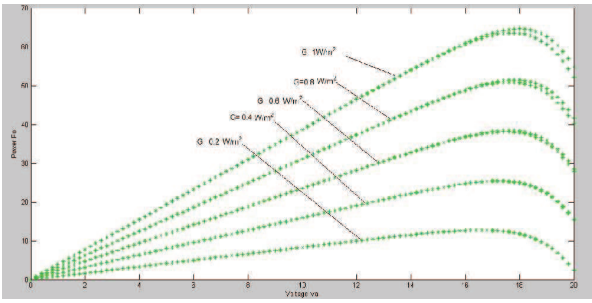


Figure 6a.Current Vs Voltage at Irradiant G= 1 W/m^2, 0.8W/m^2, 0.6W/m^2,0.4W/m^2,.2W/m^2

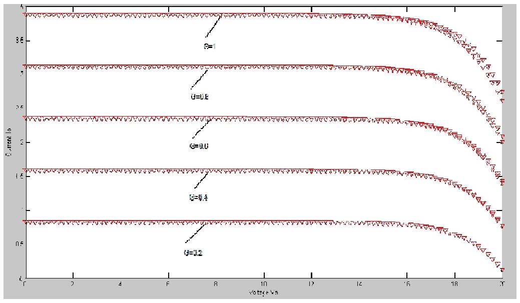


Figure 6b .Power Vs Voltage at Irradiant G= 1W/m,0.8W/m^2,0.6W/m^2,0.4W/m^2, .2W/m^2

Processing the energy obtained from the solar photovoltaic module is coming to the fore. The energy supplied by the module does not have constant values, but fluctuates according to the surrounding condition such as intensity of solar rays and temperature shown in the characteristics curves in fig. 6a and 6b. These supplies are therefore supplemented by additional converters. Here the solar photovoltaic system composed of a DC to DC converter and an inverter. The DC to DC boost converter is used to step up the solar photovoltaic module output and the proposed adaptive hysteresis current controlled inverter is used to produce the output in such a way that the current has low total harmonic distortion and it is in constant switching frequency. For comparison the inverter was controlled using sinusoidal PWM and fixed hysteresis current control techniques. The load current wave forms, its harmonic spectrum and it switching frequency using general sinusoidal pulse width modulation are shown in fig. 7. The total harmonic distortion (THD) in this case is 4.5%. It can be seen in fig7b, the switching frequency is variable over a wide frequency range. Figures.8 shows that the source harmonic current in the case of fixed hysteresis band. Here the THD has decreased from 4.5% to 4.37%.is shown in fig. 8b.

The system was connected with an adaptive hysteresis band current controller. The figure 9 shows the performance of the system with the adaptive control scheme. The performance of the proposed control algorithm is found to be excellent. The THD in this case is 3.29% as shown in fig. 9b. In this case modulation frequency is maintained constant at 10KHz.

The table II shows the system parameters used in experiment using Matlab/simulink . The results in table III shows that the average switching frequncy and the percentage THD values of load current for different techniques which shows the switching frequency is minimum and THD has decreased for the proposed technique compared with other techniques.

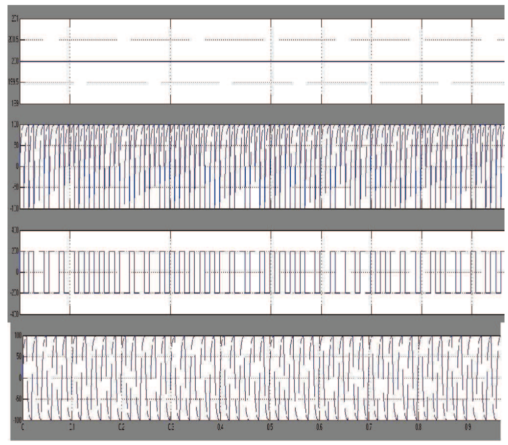


Figure 7a. Input Voltage,Current, Output Voltage and Current of photovoltaic inverter Sinusoidal PWM

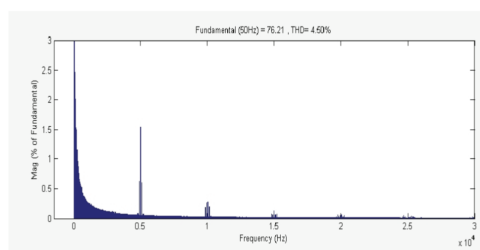


Figure 7b. Switching frequncy of photovoltaic inverter Sinusoidal PWM

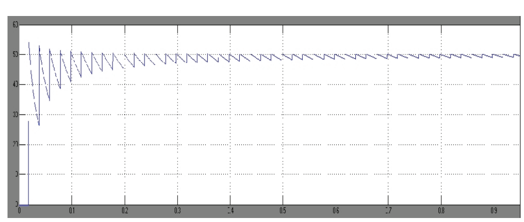


Figure 7c. Switching frequncy of photovoltaic inverter Sinusoidal PWM

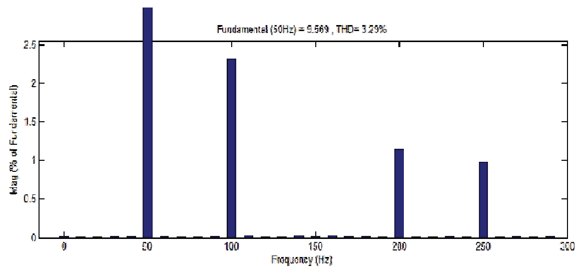


Figure 8a. Output Current of photovoltaic inverter

with fixed hysteresis controller

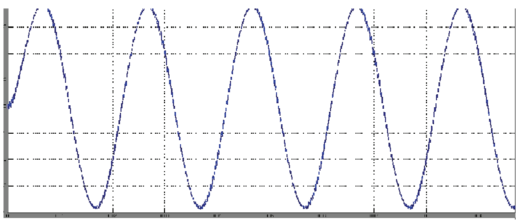


Figure 8b. THD level of Fixed Hysteresis

controller of photovoltaic inverter

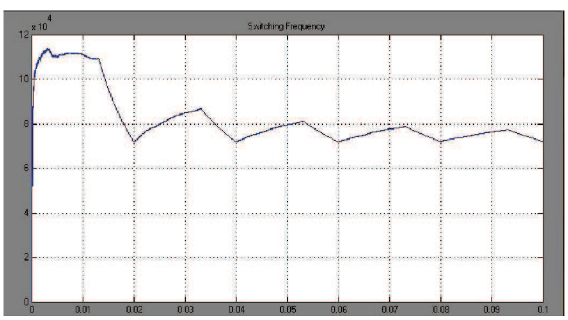


Figure 8c. Switching Frequency of Fixed

Hysteresis controller of photovoltaic inverter

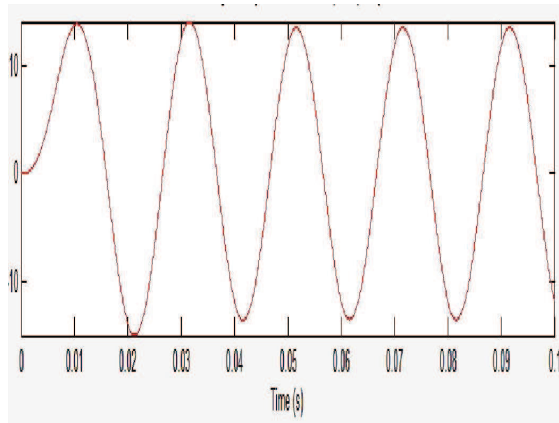


Figure 9a. Output Current of photovoltaic inverter with Adaptive hysteresis controller

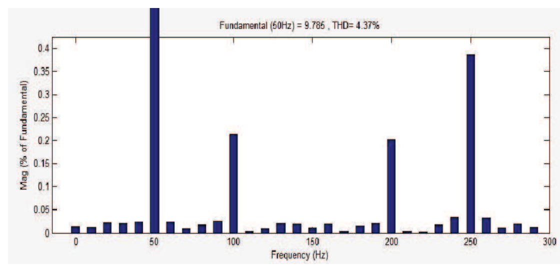


Figure 9b. THD level of Adaptive ysteresis controller of photovoltaic inverter

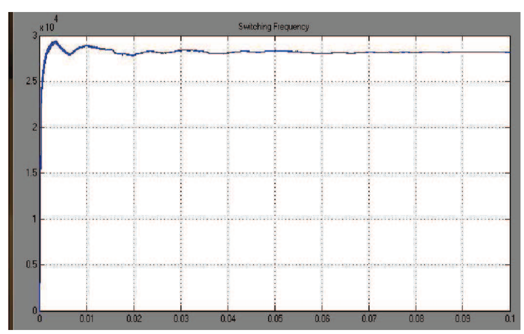


Figure 9c. Switching Frequency of Adaptive Hysteresis

controller of photovoltaic inverter

Load Resistance	1 Ω
Load Inductance	2mH
Reference current	10 sin (2π50)
Fixed band width HB	1A
Dc link capacitors	5 X 10^{-3}F 9 X 10^{-3}F

Table II – System Parameter

Current control Technique	THD %	Average switching frequency
Adaptive Hysteresis band	3.29	10kHz
Fixed Hysteresis band	4.39	14kHz
Sinusoidal PWM	4.5	21kHz

Table III - Results of Various Techniques

Conclusion

An adaptive hysteresis current control technique for single phase photovoltaic inverter has been presented in this paper. The adaptive hysteresis current controller has fast response and it keeps the switching frequency nearly constant with the harmonic content of the load within the limit. The effectiveness of the proposed adaptive hysteresis current controller has been demonstrated through the results of the simulation in MATLAB/Simulink. Simulation was also conducted with fixed hysteresis controller and their performance and THD of load current has been shown. Based on the simulation results it can be concluded that the adaptive hysteresis current controller results in constant switching frequency and limited harmonic content and is suitable for Photovoltaic system.

V. References

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