A Novel Hysteresis Current Control of Single Phase Grid Connected Inverter

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Abstract: This paper describes an improved Hysteresis current control technique for grid connected voltage source inverters (VSI). Hysteresis current control is a method of controlling a VSI where output current of inverter is compared with reference current to produce switching pulses of inverter. Though the conventional hysteresis current control method exhibits several advantages such as simplicity, outstanding stability, insensitive to load parameters and peak current limiting capability, variable switching frequency is a major drawback. To overcome this issue, a switching logic is applied to the conventional method, this logic maintains constant frequency of switching pulses and it is implemented on high speed Field Programmable Gate Array (FPGA) circuit. Simulation and experimental results show good performance of the proposed implementation.

Keywords: -Hysteresis current control, Voltage source inverter, Field Programmable Gate Array (FPGA).

I. INTRODUCTION

Nowadays the development of distributed energy resources (DER) systems is increasing continuously, because they are not centralized and located close to the load. So it does not require electric energy to transmit over long distance. DER systems typically use renewable energy sources, such as solar power, wind power, and geothermal power because it has positive environmental impact in terms of reduced carbon emission and ensure more sustainable future. Among these various sources, Photo Voltaic (PV) or solar power application has received a great attention because it appears to be one of the most viable and effective solutions to the energy issues. The output energy of renewable sources is DC (direct current). It needs to convert to AC (Alternating current) source in order to connect to the grid. Inverter is type of converter it is useful in converting DC into AC for different applications.

Inverters should give quality supply to the grid and its power flow should be controlled. In order to control the output of inverter various techniques are used. Depending on the techniques used, inverter can be classified as voltage-controlled and current-controlled inverter. In the voltage controlled technique, the amplitude of inverter output voltage is compared with the voltage reference. In current controlled inverter, the inverter output current is controlled by comparing it with the reference current. The current controlled inverter is faster in response compared to the voltage controlled inverter. There are various current control techniques which are broadly classified as linear and nonlinear. Linear control methods are not suitable for transient conditions

The commonly used current control techniques are ramp comparison controllers, predictive controllers, and hysteresis controllers [1-4]. Among this various control techniques the hysteresis band current control is used very often because of the simplicity in its implementation, fast response of current loop, the method does not need any knowledge of load parameters. Hysteresis current control is a method of controlling a inverter where the current error that is the difference between the output current and reference current, is compared directly against a predefined band called hysteresis band to produce switching pulses for the inverter. The main drawback of this method is its variable switching frequency which leads to additional switching losses and high frequency harmonics injection into the system [5-8]. In order to solve these issues, a switching logic based hysteresis current control method is proposed. In this method frequency of switching pulses is maintained constant while keeping the current ripple minimum.

This paper is organized as follows: Section II presents conventional Hysteresis current control technique and III presents proposed Hysteresis current control technique. Simulation result of the control techniques is shown in section III. In section IV, experimental results are shown to illustrate the good performance of the proposed method. Section V presents conclusion. Future scope is given in section VI.

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II. CONVENTIONAL HYSTERESIS CURRENT CONTROL METHOD

Consider single phase full bridge inverter connected to grid as shown in figure 1. Fixed DC voltage V_{dc} is given as input and the inverter output is filtered by using LC filter. The output current of the inverter i_L is controlled by the switches S_1, S_2, S_3 and S_4.

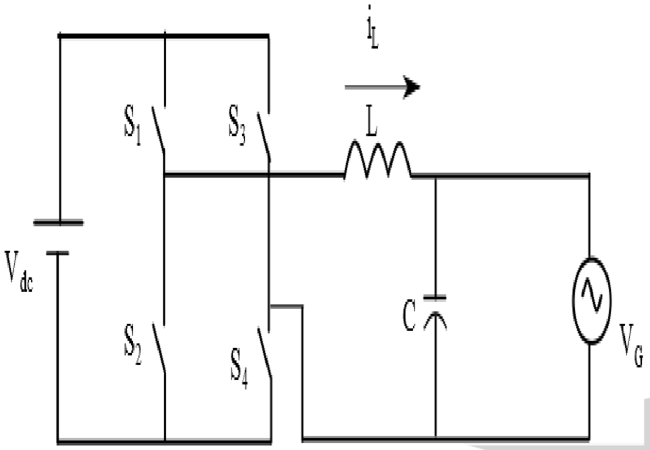


Fig.1.Single Phase VSI

In conventional hysteresis current control method[9] as shown in figure 2, the measured inductor current i_L is compared with the reference current i_{ref} by using a comparator. The comparator output is given to the controller FPGA for making switching pulses for the inverter switches.

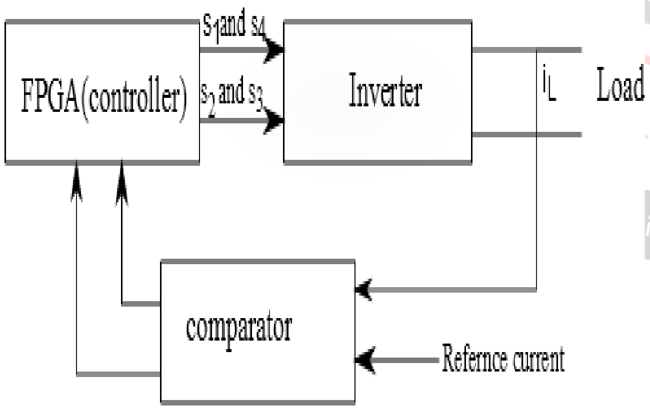


Fig.2 Block diagram of Hysteresis current control method

In this method the output current is controlled within an upper and lower band as shown in figure 3. The area between the upper and lower bound is the dead band where no switching occurs. When the inductor current crosses the lower bound, switches S_1 and S_4 are turned ON and the current starts to rise. The switches S_2 and S_3 are turned ON at the moment it crosses the upper bound and the current starts to fall.

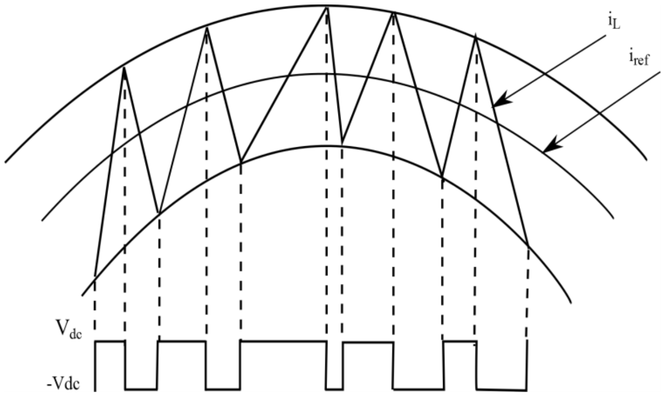
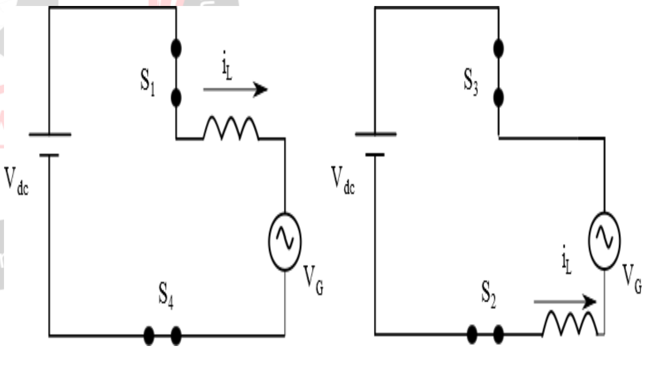


Fig.3.Fixed band hysteresis current control

In this fixed band hysteresis current control, there is wide variation in switching frequency which is undesirable. The high switching frequency component can be reduced by increasing the band width but it increases the current ripple.

III. PROPOSED HYSTERESIS CURRENT CONTROL METHOD

In proposed method, there is no physical band to limit the increasing or decreasing inductor current. In this method, constant frequency switching signals are produced for inverter switches. For making the constant switching frequency, constant time interval is set for two consecutive rises or falls of inductor current.



(a) **(b)**

Fig.4. Equivalent circuit (a) Turn ON (b) Turn OFF

Figure 4 shows the equivalent circuits of the inverter in which switches S_1 and $S_4$are in turn-ON and turn-OFF modes. The inductor current behavior can be expressed differently in positive half cycle and negative half cycle of reference current. In grid connected VSI the reference current is generated from the grid voltage V_G. For positive half cycle of the reference current, if S_1 and S_4 are ON and S_2 and S_3 are OFF, the inductor current behavior can be expressed by

$$\left(\frac{di_L}{dt}\right)_{rise} = \frac{V_{dc}-V_G}{L} \qquad (1)$$

if S_2 and S_3 are ON and S_1 and S_4 are OFF

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$$\left(\frac{di_L}{dt}\right)_{fall} = -\frac{V_{dc}+V_G}{L} \quad (2)$$

For negative half cycle of the reference current, if S_1 and S_4 are ON and S_2 and S_3 are OFF

$$\left(\frac{di_L}{dt}\right)_{rise} = \frac{V_{dc}+V_G}{L} \quad (3)$$

if S_2 and S_3 are ON and S_1 and S_4 are OFF

$$\left(\frac{di_L}{dt}\right)_{fall} = -\frac{V_{dc}-V_G}{L} \quad (4)$$

Where V_{dc} is the DC link voltage, L is the output inductance i_L is the inductor current and V_G is the instantaneous grid voltage,

$$V_G = \begin{cases} +V_G & \text{for + ve half cycle} \\ -V_G & \text{for − ve half cycle} \end{cases} \quad (5)$$

By evaluating the equations (1),(2),(3),(4) it can be seen that rising and falling slopes of inductor current is different in positive half cycle and negative half cycle of reference current. The time interval between consecutive high slope edges needs to be controlled in order to reduce the current ripple. Therefore in the positive half cycle, time interval between two consecutive falls are controlled and in the negative half cycle time interval between two consecutives rises are controlled.

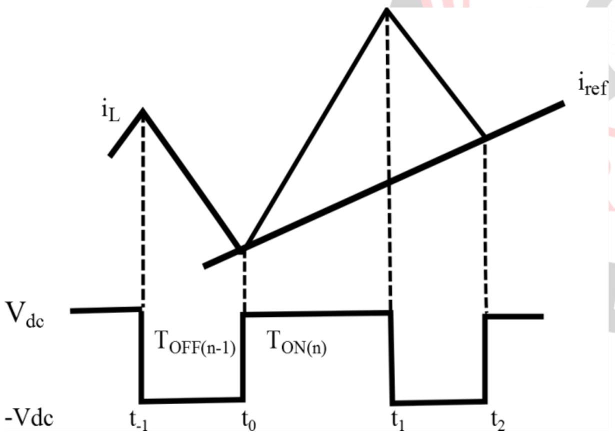

Fig.5 Positive half cycle of the reference current

In the positive half cycle of the reference current, consider the instant t_0 as shown in figure 5 where the output current i_L goes below the reference current i_{ref} the switches S_1 and S_4 are turned ON. When it goes above the reference, these switches will be turned off only if sum of the previous off period and present ON period is greater than switching period T_{sw}.

$$T_{OFF(n-1)}+T_{ON(n)} \geq T_{sw} \quad (6)$$

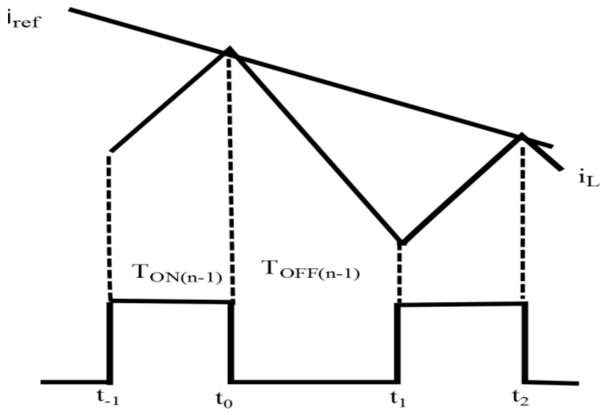

Fig.6 Negative half cycle of the reference current

Similarly in the negative half cycle as shown in figure 6 when the output current goes above the reference, switches S1 and S4 turned off .When it goes below the reference, these switches will be turned on only if sum of the previous ON period and present OFF period is greater than switching period T_{sw}.

$$T_{ON(n-1)}+T_{OFF(n)} \geq T_{sw} \quad (7)$$

Equations (6) and (7) ensure the constant switching frequency in the positive and negative half cycles of the reference voltage. Still some variations appear in the output voltage with respect to the reference voltage and it is more visible in the zero crossing. This can be overcome by modifying the reference voltage by adding and subtracting an offset value from positive and negative half cycles of the reference voltage respectively.

IV. SIMULATION RESULT

Simulations have been carried out by using Matlab-simulink software to compare the performance of the proposed method with the conventional method. A single-phase full-bridge inverter was employed with the following parameters: an output inductance of *L* =5mH and a filter capacitor of *C* =1.25μF. The switching transistors in the inverter circuit were modeled by MOSFET. The inverter was connected to the DC voltage source V_{dc} = 100V. Unity sine was set as reference current and hysteresis band is fixed at 0.2A.

Simulation result of conventional method is shown in figure 7. Here the inverter output current follows the reference current, but the problem is that it has variable switching frequency.

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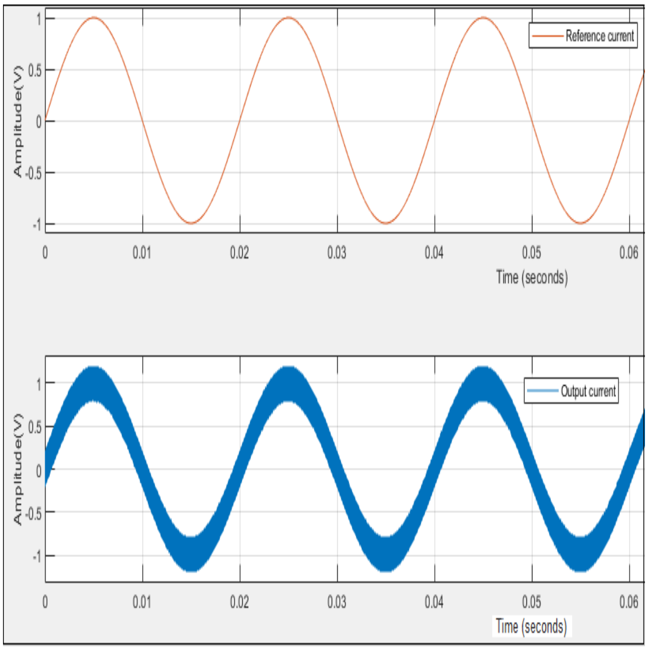

Fig.7 Reference and output current curve of conventional Hysteresis current control method

Then the proposed hysteresis current control method is simulated. Inverter parameters are same as the conventional method. In this method a constant time period is maintained between two consecutive falls in positive half cycle and between two consecutive rises of the inverter output current. Simulation result of this method is shown in figure 8. This method produces output current, it follows reference current very well. FFT analysis is performed and THD (Total Harmonic Distortion) factors of both methods are shown in figure 9 and 10. The THD value of Proposed Hysteresis current controller is less compared to the conventional current controller.

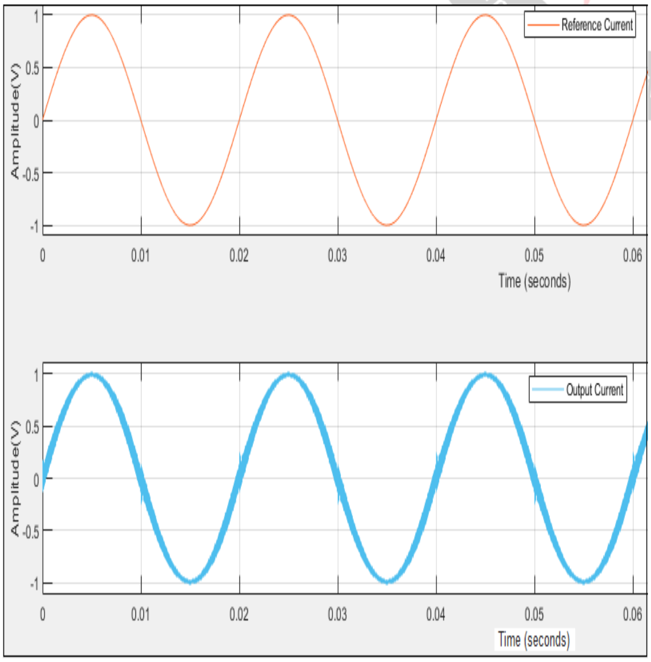

Fig.7 Reference and output current curve of Proposed Hysteresis current control method

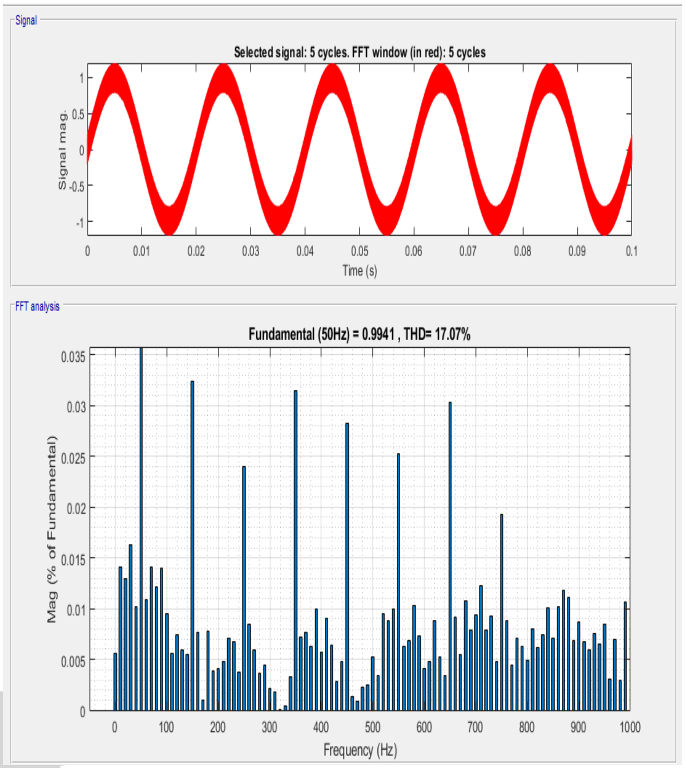

Fig.8 THD Diagram of Conventional hysteresis current control method

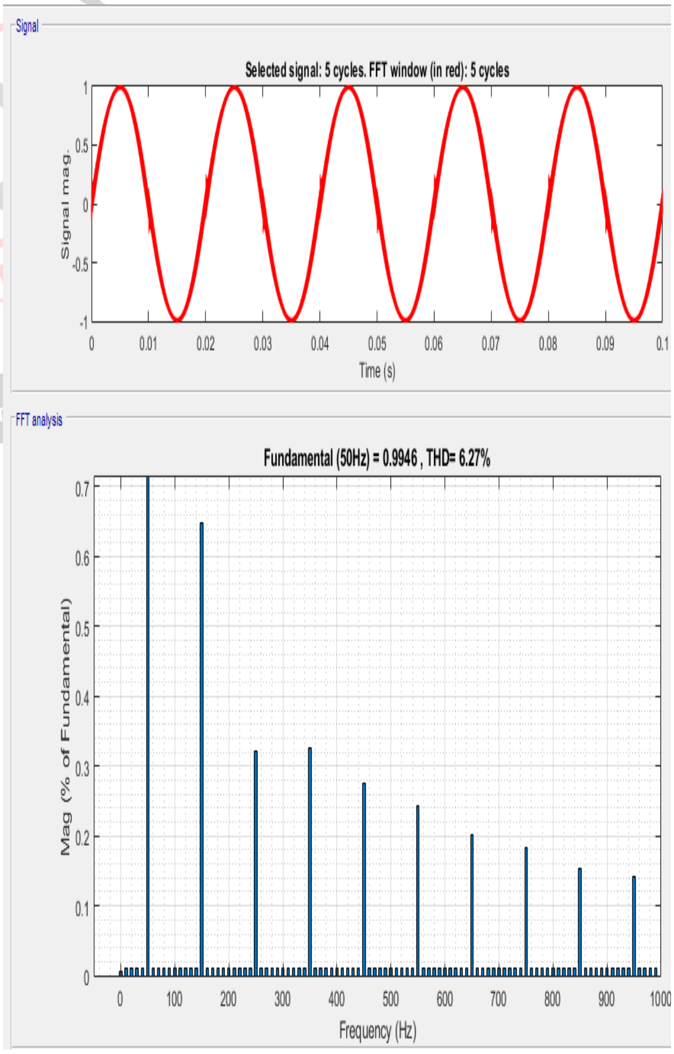

Fig.8 THD Diagram of Proposed hysteresis current control method

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V. Experiment Results

The proposed hysteresis current control method is implemented and tested on single phase inverter with the following parameters, dc input voltage V_{dc} is 12V, filter inductance L is 3mH and load resistor $R_L$is10ohm 10 watt resistor. A 50H_z sinewave generated by using FPGA is used as reference current. The inverter output current is sensed by using a current sensor ACS722. The reference current and inverter output current is compared by using comparator. Output of the comparator has a lot of switching which causes switching losses. Therefore the comparator output is given to FPGA. The FPGA applies the proposed switching logic to the comparator output for making the constant switching frequency. The desired switching frequency is set as 20KH_z.The experimental result shown in figure show that resulting inverter output current follows the reference current very well.

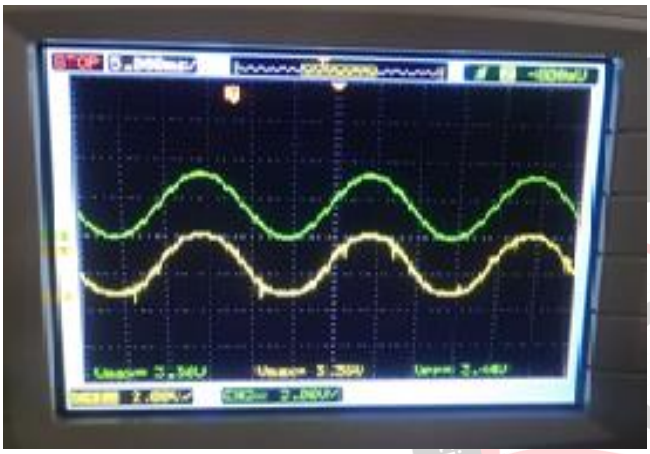

Fig.9. Reference current and output current

VI. Conclusion

A new constant switching frequency hysteresis current control method for single phase inverter has been proposed. The conventional HCC has severe drawback which is variable switching frequency. Therefore to avoid the difficulty of conventional method, a new method is proposed. In this method the inverter output current is first compared with the reference current, if there is any change that is corrected by controlling the switches of the inverter. To maintain a constant frequency for this inverter switching signal, a switching logic is implemented. That logic is successfully simulated by using Matlab Simulink and FPGA. Matlab simulation result shows the comparison of conventional method and proposed method. Then it is implemented in hardware by using single phase inverter, current sensor and comparator IC. Proposed switching logic works very well to maintain the constant frequency and reduce the switching losses.

VII. Future Scope

The switching logic used in this proposed control method still produces some variations in inverter output current. It can further be improved by using more advanced logic and noises in it can be avoided by using accurate current sensors.

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