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Reactive Power Improvement Using Adaptive Current Controller Method

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Abstract— Most of the pollution issues created in power systems are due to the non-linear characteristics and fast switching of power electronic equipment. Power quality issues are becoming stronger because sensitive equipment will be more sensitive for market competition reasons, equipment will continue polluting the system more and more due to cost increase caused by the built-in compensation and sometimes for the lack of enforced regulations. Efficiency and cost are considered today almost at the same level. In this paper the three-phase grid connected inverter has been investigated. The inverter's control strategy is based on the adaptive hysteresis current controller. Inverter connects the DG (distributed generation) source to the grid. The main advantages of this method are constant switching frequency, better current control, easy filter design and less THD (total harmonic distortion). Since a constant and ripple free dc bus voltage is not ensured at the output of alternate energy sources, the main aim of the proposed algorithm is to make the output of the inverter immune to the fluctuations in the dc input voltage This inverter can be used to connect the medium and small-scale wind turbines and solar cells to the grid and compensate local load reactive power. Reactive power compensating improves SUF (system usage factor). The simulation results confirm that switching frequency is constant and THD of injected current is low

.Keywords— Adaptive hysteresis current controller, distributed generation system, grid connected inverter, system usage factor, total harmonic distortion.

INTRODUCTION

In modern electrical distribution systems there has been a sudden increase of single phase and three-phase non-linear loads. These non-linear loads employ solid state power conversion and draw non-sinusoidal currents from AC mains and cause harmonics and reactive power burden, and excessive neutral currents that result in pollution of power systems. They also result in lower efficiency and interference to nearby communication networks and other equipments. In these Distributed energy offers solutions to many of the nation's most pressing energy and electric power problems, including blackouts and brownouts, energy security concerns, power quality issues, tighter emissions standards, transmission bottlenecks, and the desire for greater control over energy costs. Most of DG's (Distributed Generation) power generation is depending on environment conditions. For example in photovoltaic systems at nights or in cloudy days power generation is stopped and in wind power generation systems, power generation depends on wind speed. So the SUF (System Usage Factor) is low. In for increasing SUF, system not only injects power to the grid but also can compensate load reactive power. Because DG sources have discontinuous power generation characteristics, dc-link voltage has many variations. Therefore for increasing power quality and achieving the constant switching frequency, adaptive hysteresis band current control is used. A dead beat adaptive hysteresis current control has been implemented in real time for voltage source inverters. In the present paper, the adaptive hysteresis band current controller proposed in for electrical machine drives and in for shunt active filter has been applied to grid connected inverter. In the proposed method the output active power and reactive power compensation (RPC) of the local load are realized simultaneously. When DG source power generation is not enough for injection to grid, the RPC feature of inverter base DG can still be used to improve the utilization factor of the system. So in some cases (photovoltaic systems) SUF increases from 20% to 100%. This work presents the MATLAB code simulation of three phase system, comparative study of HCC and AHCC and implementation of a fully digital controller for shunt active power filter (APF).The controller uses a PI-regulator and a Hysteresis current controller. The result obtained from the MATLAB/SIMULINK environment will be validated with experimental

II . THREE PHASE GRID CONNECTED INVERTER:

Most of the active power filter topologies use voltage source Inverters, which have a voltage source at the dc bus, usually a capacitor, as an energy storage device. This topology, shown in Figure 1.1, converts a dc voltage into an ac voltage by appropriately gating the power semiconductor switches (IGBT). Three-phase inverters are widely used in industrial applications such as motor drives, standby power supplies and uninterruptible supplies. However in three-phase grid connected inverter the output of the inverter is connected to the grid. The inverter includes six IGBT switches connected in the form of a bridge configuration [7], [8]. The three-phase grid connected inverter topology is shown in Fig.1. It contains of a dc voltage source (Vdc), six power switches (SI-S6), a (L) filter, two capacitors (C) and utility grid (Vgrid). In inverter-based DG, the produced voltage from inverter must be higher than the Vgrid, in order to assure power flow to the grid.

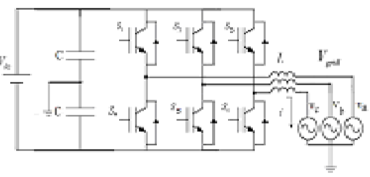


Figure 1.Three Phase grid Connected Inverter

III. CURRENT CONTROL TECHNIQUES:

Decoupled current control method has been used. The goals are 1) injection of active power to grid and 2) compensation of local load reactive power [2]. The three phase local load currents, which are shown in Fig.2, already have been transformed to the synchronous reference frame (a-b-c to d-q-0). The coordinate transformation from three-phase local load currents (i_{La}, i_{Lb}, i_{Lc}) to the synchronous reference frame based local load currents (i_{Ld}, i_{Lq}, i_{L0}) is obtained as follows:

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \\ i_{L0} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin(\omega) & \sin(\omega-(2\pi/3)) & \sin(\omega-(2\pi/3)) \\ \cos(\omega) & \cos(\omega-(2\pi/3)) & \cos(\omega+(2\pi/3)) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \times \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (1)$$

PLL (Phase Locked Loop) unit detects angle of grid phase a voltage. This angle has been used in transformations. A low pass filter is used to extract the dc component of iLq . This dc value is used as iq ref for inverter q axis reference current in synchronous reference frame. Therefore inverter base DG compensates local reactive power. In synchronous reference frame, id ref (d axis reference

current) controls active power injection. This reference current could be generated with MPPT (Maximum Power
Point Tracking)unit or other controllers with notification of DG source.

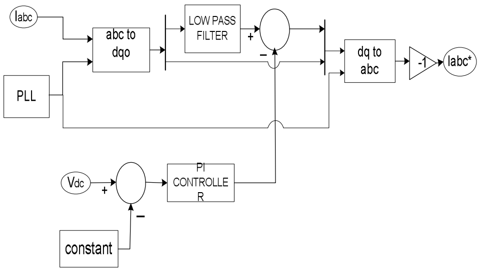


Figure 2. Synchronous d-q-0 reference frame based compensation

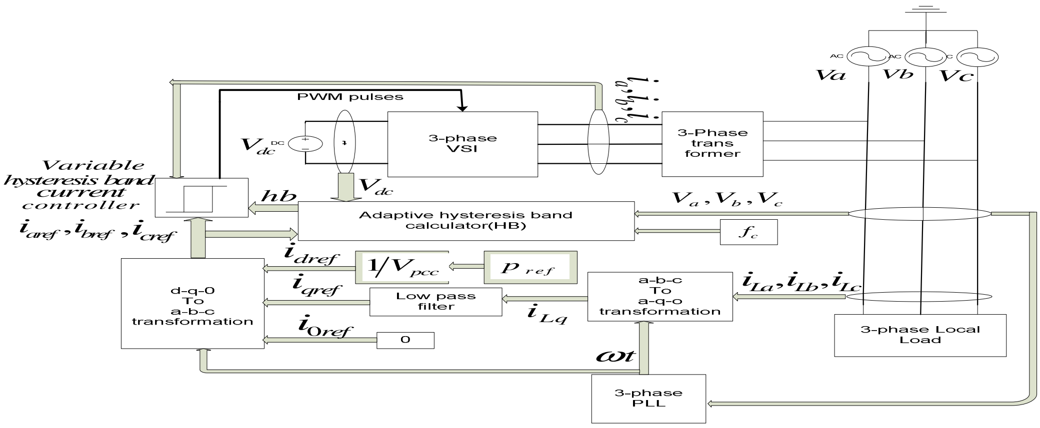


Figure 3. Diagram of overall control system

$$\begin{bmatrix} i_{aref} \\ i_{bref} \\ i_{cref} \end{bmatrix} = \begin{bmatrix} \sin(\omega) & \cos(\omega) & 1 \\ \sin(\omega-(2\pi/3)) & \cos(\omega+2\pi/3) & 1 \\ \sin(\omega+(2\pi/3)) & \cos(\omega+2\pi/3) & 1 \end{bmatrix} \times \begin{bmatrix} i_{dref} \\ i_{qref} \\ i_0 \end{bmatrix} \quad (2)$$

Three-phase reference currents have been sent to the adaptive hysteresis band current controller for current control of VSI (Voltage Source Inverter).

IV. THE ADAPATIVE HYSTERESIS BAND CURRENT CONTROLLER:

The hysteresis band current control technique has proven to be most suitable for current controlled voltage source inverters. The hysteresis band current control is characterized by simplicity implementation, inherent-peak current limiting capability, unconditioned stability, very fast response, robust against system parameters changing and good accuracy [5],[9].
However, the basic hysteresis technique exhibits also several undesirable features; such as vary switching frequency that causes acoustic noise and difficulty in designing input filters [3]. The conventional hysteresis band current control scheme used for the control of grid connected inverter line current is shown in Fig. 2, composed of a hysteresis around the reference line current. By notice equation 3 the reference line current of the grid connected inverter is referred to as iref , measured line current of the grid connected inverter is referred to as i and difference between i and iref is

referred to as δ . The hysteresis band current controller assigns the switching pattern of grid connected inverter .

For example switching logic for phase A written as follows

$$\delta = i - i_{ref} \quad (3)$$

If $\delta > HB$ upper switch is OFF and lower switch is ON $(s_4 = 1, s_1 = 0)$ (4)

If $\delta < -HB$ upper switch is ON and lower switch is OFF $(s_4 = 0, s_1 = 1)$ (5)

The switching logic for phases B and C is similarly, using corresponding reference and measured currents and hysteresis bandwidth (h).
The switching frequency of the hysteresis band current control method is described above depends on how fast the current changes from the upper limit of the hysteresis band to the lower limit of the hysteresis band, or vice versa. The rate of change of the line currents vary the switching frequency, therefore the switching frequency does not remain constant throughout the switching operation, but varies along with the current waveform. Furthermore, the line inductance value of the grid connected inverter and the dc link voltage are the main parameters determining the rate of change of grid connected inverter line currents.

The bandwidth of the hysteresis current controller determines the allowable current shaping error. By changing the bandwidth the user can control the average switching frequency of the grid connected inverter and evaluate the performance for different values of hysteresis bandwidth. In principle, increasing the inverter operating frequency helps to get a better current waveform. However, there are device limitations and increasing the switching frequency causes increased switching losses, and EMI related problems. The range of switching frequencies used is based on a compromise between these factors.

However, the current control with a fixed hysteresis band 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 [2]. Fig.4 shows the PWM current and voltage waveforms for phase a. The currents ia tends to cross the lower hysteresis band at point 1, where S1 is switched on. The linearly rising current (ia +) then touches the upper band at point 2, where is S4 switched on. The following equations can be written in the respective switching intervals t1 and t2 from Fig.4.

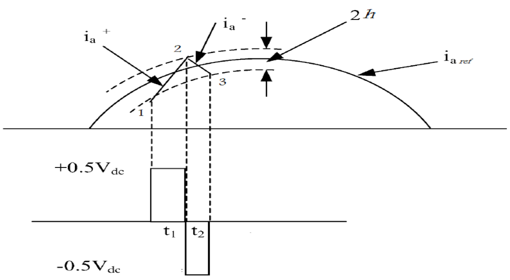


Fig.4. Current and voltage waves with hysteresis band current control

Formula:

$$di_a^+ = \frac{1}{L}(0.5V_{DC} - V_a) \quad (6)$$

$$di_a^- = -\frac{1}{L}(0.5V_{DC} + V_a) \quad (7)$$

From the geometry of Fig. 4 can be written,

$$\frac{di_a^+}{dt}t_1 - \frac{di_{aref}}{dt}t_1 = 2HB \quad (8)$$

$$\frac{di_a^-}{dt}t_2 - \frac{di_{aref}}{dt}t_2 = -2HB \quad (9)$$

$$t_1 + t_2 = T_c = \frac{1}{f_c} \quad (10)$$

where t1 and t2 are the respective switching intervals, and fc is the switching frequency. Adding (8) and (9) and substituting (10) in the resulting equation, it can be written as

$$\frac{di_a^+}{dt}t_1 + \frac{di_a^-}{dt}t_2 - \frac{1}{f_c}\frac{di_{aref}}{dt} = 0 \quad (11)$$

Subtracting (9) from (8), we get

$$\frac{di_a^+}{dt}t_1 - \frac{di_a^-}{dt}t_2 - (t_1 - t_2)\frac{di_{aref}}{dt} = 4HB \quad (12)$$

Substituting (7) in (12), gives

$$(t_1 + t_2)\frac{di_a^+}{dt} - (t_1 - t_2)\frac{di_{aref}}{dt} = 4HB \quad (13)$$

Substituting (5) in (9), and simplifying

$$(t_1 - t_2) = \frac{d_{iaref}/dt}{f_c\left(di_a^+/dt\right)} \quad (14)$$

Substituting (13) in (13), given

$$HB = \frac{0.125V_{DC}}{f_c L}\left[1 - \frac{4L^2}{V_{DC}^2}\left(\frac{V_a}{L} + m\right)^2\right] \quad (15)$$

Where fc is modulation frequency, m = diaref /dt is the slope of command current wave.Hysteresis band (h) can be modulated at different points of fundamental frequency cycle to control the switching pattern of the inverter. For symmetrical operation of all three phases, it is expected that the hysteresis bandwidth (h) profiles h_a, h_b and h_c will be same, but have different phases

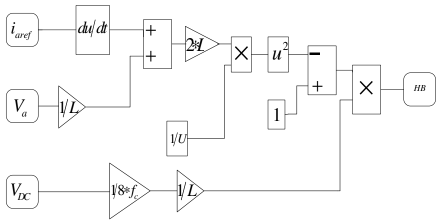


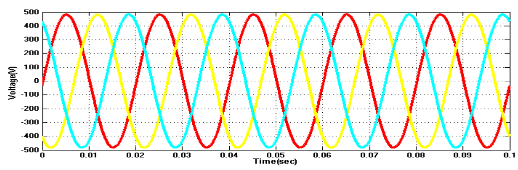
Figure.5. The adaptive hysteresis band width calculation block diagram

V. SIMULATION RESULTS:

In this section of proposed technique of adaptive hysteresis current controller with three- phase grid connect inverter is simulated by Matlab\Simulink software. In this simulation following parameters are shown table 1.

table 1.

Parameter	Value
Vdc	200V
Switching frequency	12HZ
Pref	2KW
Grid Voltage (L-L)	440V
Grid current	6.5A
Grid Frequency	50HZ
L	2 mH
C	2100uF



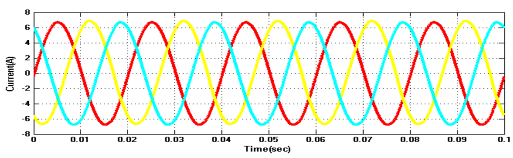


Figure 6.simulation for voltage(up) and current (down)

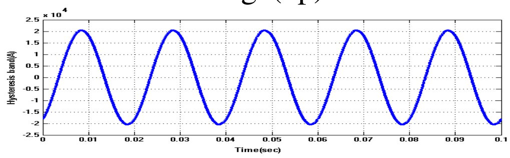


Figure 7.Simulated Adaptive Hysteresis Band(A)

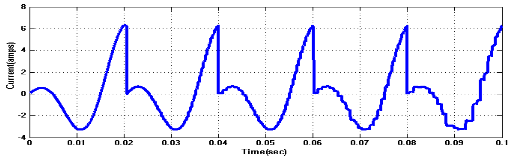


Figure 8.Output Waveform of Reference Current

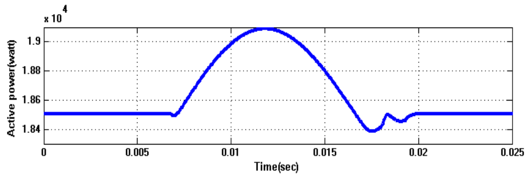


Figure 9. Active power variation during load variation time

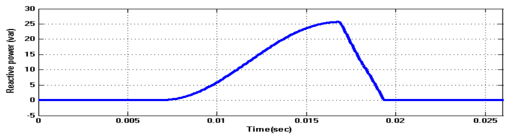


Figure10. Reactive power variation during load variation time

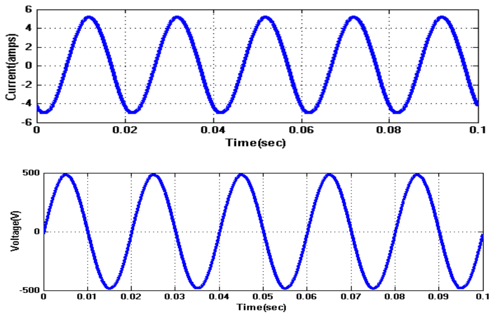
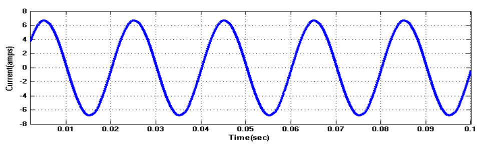


Figure11. current(up) and voltage(down) compensation during phase A (Inductive load)



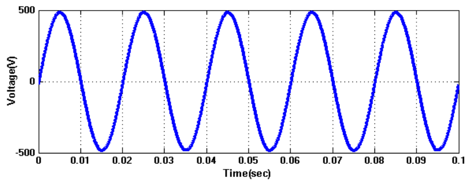


Figure12. current(up) and voltage(down) compensation during phase A (Capacitive load)

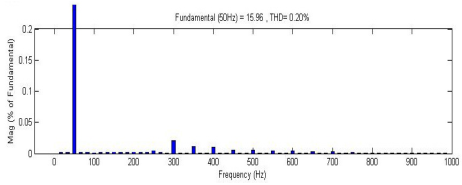


Figure13 THD analysis of ph A

Finally, the current harmonic spectrum for proposed method after t=0.007sec are shown in Fig.12. THD (Total Harmonic Distortion) is 0.22% which is less than THD of conventional method. THD of conventional method after t=0.007sec is 1.01%. So power quality increases by applying proposed method.

VI.CONCULSION

This paper presents an adaptive hysteresis band current control PWM technique for DG source grid connected inverters. The hysteresis Band width can be calculated as a function of system parameters. One of these parameters is dc link voltage that generates by DG source. Therefore, the power quality of the system increased and the constant switching frequency achieved by applying proposed method. Since most of DG sources have discontinuous power generation characteristics, reactive power compensating improves SUF (system usage factor) from nearly 20% (in photovoltaic systems) to 100%. This paper demonstrates the validity of the proposed adaptive hysteresis band current controller for grid connected inverter. Experimental verification of the proposed scheme is being performed and test results will be reported in future papers.

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