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# Adaptive Modified Hysteresis Current Controlled Grid Connected Photovoltaic Inverter

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***Abstract*— Harmonics are the major power quality issues produced by the nonlinear loads. The harmonics injection will lead to generation of non sinusoidal grid current. This article intends to optimize Total Harmonic Distortion (THD) of the source current through adaptive controlled modified hysteresis current controller .which also acts as a shunt active filter (SAF). The proposed control scheme uses a combination of I cos Φ theory, which computes the reference compensation currents to be injected by SAF and Adaptive Hysteresis Band Current Controller (AHBC) determines the switching signals of the SAF. Use of Adaptive Hysteresis Band Current Controller instantaneous switching frequency is reduced,optimized and maintained nearly constant and THD is brought to the limits specified by the standards. Effectiveness of The proposed control strategy is analyzed .and checked for various source and load conditions with MATLAB/SIMULINK.**

***Keywords*— Adaptivecontrol, Modified Hysteresis Current controller, Total Harmonic Distortion, Switching losses, Switching frequency.***

## I. INTRODUCTION

Sun is the major source of energy to the entire universe. The recent fall in the cost of solar photo-voltaic (SPV) energy, and ever increasing prices of fossil fuels, has moved the worlds attention towards SPV energy systems. Conventionally two-stage grid interfaced SPV energy systems are used, in which the first stage performs MPPT (maximum power point tracking) and the second stage is used to feed extracted energy into the grid. These two stage systems suffer from drawback of two power converters of full rating. Several configurations of grid interfaced PV farms are proposed in [1]. In grid-connected photo-voltaic systems, three-phase current controlled voltage-source inverters (VSIs) are often employed for power conversion, grid synchronization and control optimization [3], [4]. In addition, synchronization to grid by Phase Locked Loop (PLL). Phase Locked Loop (PLL) will tracks the measured phase voltages Ua, Ub and Uc. under balanced and unbalanced voltage conditions Proper operation is ensured by PLL. fluctuation at the dc-bus capacitor Voltage was used to calculate extra power loss in inverter .using a Proportional–Integral–differential(PID)controller Corresponding phase current amplitude calculated and it was multiplied with PLL output .This output current was added to reference compensation current in each phase. The loss in shunt active power filter is thus taken care of by three phase source and dc bus capacitor voltage becomes a self supporting one. In modified hysteresis controller only 2 switches are controlled at high frequency at any instant of time [5]. This will reduces the switching losses to one third of that of conventional hysteresis controller. Even though using the modified hysteresis controller it is insufficient to maintain current THD within the specified limits. To overcome this drawback, pulses are modified with adaptive control mechanism . Main advantage of the adaptive control is sought out Problem of variable switching frequency. The total harmonic distortion (THD) of the grid current is limited to 5%, as recommended in the IEEE 1547 standards [2].

## I. SYSTEM CONFIGURATION AND ANALYSIS

The configuration of a PV fed adaptive hysteresis current controlled grid connected inverter is shown in Fig. 2. It mainly includes a pv array as a dc power source,DC-DC converter including MPPT algorithms, a voltage source inverter (VSI), an output RL filter, local loads, and the utility grid.

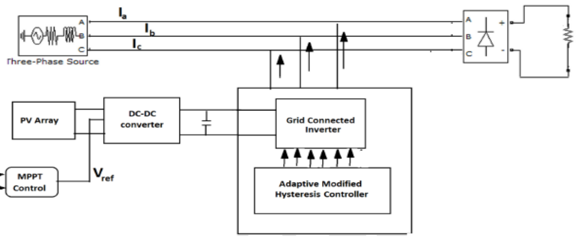

Fig. 1. Configuration of Shunt Active Power Filter

In this paper current controlled Voltage source inverter based three phase grid connected inverter with control circuit is discussed . It also acts as a shunt active power filter(SAP) and is connected in parallel with the harmonic producing loads at the Point Of Common Coupling (PCC).Shunt active power filter will generates a current which is equal and opposite to that of harmonic current drawn by the load and injects it at the point of common coupling and making the source current purely sinusoidal. the characteristics of harmonic compensation decides Filtering algorithms used for the calculation of load current harmonics. Voltage Source Inverter (VSI) and interfacing inductor together producing the Current waveform for cancelling harmonics. smoothing and isolation of high frequency componentsis achieved by the use of a inductor. Desired current waveform of the source is obtained by controlling the switches of the inverter .

### A. *Shunt Active Filter Using I Cos Φ Algorithm*

The control strategy employed for Reference current generation is I Cos Φ algorithm. Which computes the reference compensation currents to be injected by the active filter (AF). the accuracy and response time of the filter depends on the The choice of the control algorithm . The calculation steps should be minimal to make the control circuit compact. The SAF is expected to provide compensation for the harmonic and unbalanced source load conditions. This will ensures that a balanced current will be drawn from the three phase source which will be purely sinusoidal and in phase with the three phase voltage source. So the three phase mains is required to supply only the active portion of the load current (i.e, I cos Φ, where “I” is the amplitude of the fundamental load current and cos Φ is the displacement power factor of the load). So the proposed algorithm is named as “IcosΦ” algorithm. It is capable of providing 1) harmonic 2) unbalance source load compensation in conjunction with achieving unity power factor at the source side.

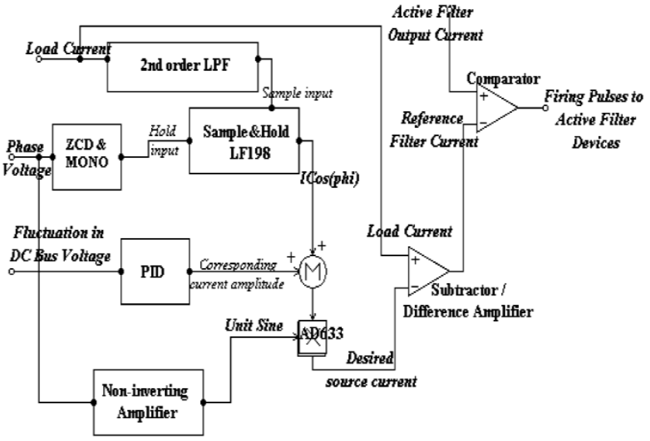

Fig. 2. Realization of I Cos Φ algorithm

In IcosΦ algorithm, only the real part of the fundamental component of the load current has to be supply by the source. Remaining parts of load current such as reactive and harmonics parts are to be supplied by the active filter. In a balanced source load condition ,the instantaneous source voltages can be represented by:

$$V_a = V_m \sin(\omega t) .............(1)$$

$$V_b = V_m \sin(\omega t - 120) ......(2)$$

$$V_c = V_m \sin(\omega t + 120) .......(3)$$

Where ,

a, b, c = phases a, b, c, respectively

$V_m$ = peak value of the instantaneous voltage

The load current contains fundamental and harmonic components When balanced three phase supply feeds a non-linear reactive load.

$$i_{La} = \sum_{h=1}^{\infty} I_{La,h} \sin(h\omega t - \phi_{ha}) ................(4)$$

$$i_{Lb} = \sum_{h=1}^{\infty} I_{Lb,h} \sin(h\omega t - 120 - \phi_{hb}) .........(5)$$

$$i_{Lc} = \sum_{h=1}^{\infty} I_{Lc,h} \sin(h\omega t + 120 - \phi_{hc}) ...........(6)$$

where,

a, b, c = phases a, b, c, respectively

iL = instantaneous load current in phases a, b,c

IL, h = peak value of hth harmonic component of load current

$\phi_h$ = phase angle of the hth harmonic component with respect to voltage

while passing through a biquad low pass filter the fundamental component of the load current get separated pass filter. During the filtering operation output of fundamental component is delayed by 90

$$i_{Lfa} = I_{La,1} \sin(\omega t - \phi_{1a} - 90) ............(7)$$

$$i_{Lfb} = I_{Lb,1} \sin(\omega t - \phi_{1b} - 120 - 90) ....(8)$$

$$i_{Lfc} = I_{Lc,1} \sin(\omega t - \phi_{1c} + 120 - 90) .....(9)$$

The real part of the fundamental component of load current is estimated as follows:

At the time of negative zero crossing of the input voltage of any one phase, say a phase , instantaneous value of fundamental component of load current is the peak value of real component of the fundamental load current. Similarly, instantaneous values of fundamental components of phase b and c [5] motor drive. At every cycle the real part of fundamental component of load current is updated .The magnitude of the desired source current *Is*(*ref* ) is equal to the magnitude of real part of the fundamental component of load current .i.e., for phase a it can be Re (*ILa*) . The magnitude of the desired source current can be expressed as the average of the real components of the fundamental load currents in the three phases.

i.e,

$$\left|I_{s(ref)}\right| = \frac{\left|R_e(I_{La})\right| + \left|R_e(I_{Lb})\right| + \left|R_e(I_{Lc})\right|}{3}$$

$$= \frac{\left|I_{La}\right| \cos\phi_a + \left|I_{Lb}\right| \cos\phi_b + \left|I_{Lc}\right| \cos\phi_c}{3} .......(10)$$

The DC bus voltage fluctuations are sensed and given to a PID controller .The out put of PID controller is the current which has to meet the power loss in the inverter as well as the coupling inductor. The resultant current is added to the average value of *I s* (*ref* ) in equation (4.9) above. For generating unit amplitude sine waves(in phase with source voltages) The three phase source voltages are used as templates .

they are expressed as,

i.e,

$$U_a = 1\sin\omega t...............(11)$$

$$U_b = 1\sin(\omega t - 120).....(12)$$

$$U_C = 1\sin(\omega t + 120).....(13)$$

The reference source currents multiplied with the unit amplitude templates of the phase to ground source voltages in the three phases there by getting the desired (reference) source currents in the three phases .

$$i_{sa(ref)} = \left|I_{S(ref)}\right| * U_a = \left|I_{S(ref)}\right| \sin\omega t..............(14)$$

$$i_{sb(ref)} = \left|I_{S(ref)}\right| * U_b = \left|I_{S(ref)}\right| \sin(\omega t - 120)....(15)$$

$$i_{sc(ref)} = \left|I_{S(ref)}\right| * U_c = \left|I_{S(ref)}\right| \sin(\omega t + 120).....(16)$$

The difference between the actual load currents and the desired source currents is the compensation currents .which is to be to be injected by the shunt active filter are given below :

$$i_{a(comp)} = i_{La} - i_{Sa(ref)}........(17)$$

$$i_{b(comp)} = i_{Lb} - i_{Sb(ref)}........(18)$$

$$i_{c(comp)} = i_{Lc} - i_{Sc(ref)}.........(19)$$

*B. Modified hysteresis controller with adaptive band*

The main drawbacks of fixed hysteresis band method are variable switching frequency, harmonic content around the switching side band, irregularity of the modulation pulse position and heavy interference. These drawbacks will cause a high current ripples and acoustic noise. To overcome these undesirable effects, this work presents an adaptive modified hysteresis band control. This controller will adjusts the hysteresis bandwidth according to the reference compensator current variation, the switching frequency and THD of supply current.

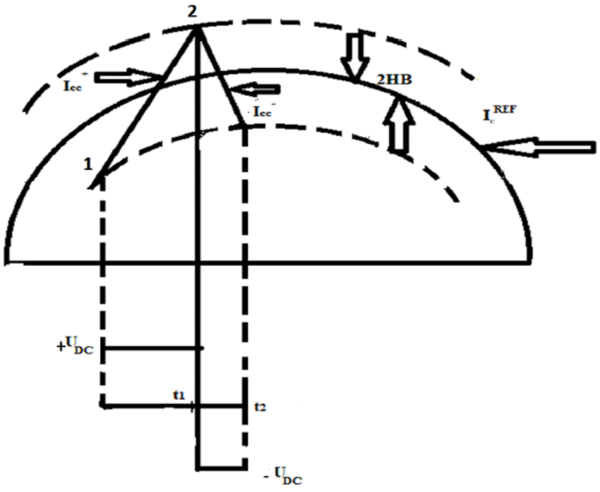

Fig.4.Concept of adaptive control

Figure. 4. shows the pulse width modulated current waves for phase c. When the source current icc- cross the lower hysteresis band at point 1, the switch of leg “c” is on.similarly in the case of lower switch When the source current icc+ cross the lower hysteresis band at point 2, the switch of leg “c” is on. During the switching intervals t1 and t2 The following equations can be written from the figure4.

$$\frac{di_{cc^+}}{dt} = \frac{1}{L}(U_{dc} - U_S).....(20)$$

$$\frac{di_{cc^+}}{dt} = -\frac{1}{L}(U_{dc} + U_S......(21)$$

Consider the geometry of Figure. 4. equation can be can be written as,

$$\frac{di_{cc^+}}{dt} t_1 - \frac{di^{ref}{}_c}{dt} t_1 = 2HB........(22)$$

$$\frac{di_{cc^-}}{dt} t_2 - \frac{di^{ref}{}_c}{dt} t_2 = -2HB.......(23)$$

$$t_1 + t_2 = t_c = {}^{1}\!/_{f_c} ....................(24)$$

Adding Equation (24) and Equation (25) and substituting Equation (26) it can be written

$$t_1 \frac{di_{cc^+}}{dt} + t_2 \frac{di_{cc^-}}{dt} - \frac{1}{f_c} \frac{di^{ref}{}_c}{dt} = 0........(25)$$

Subtracting Equation (25) from Equation (24), we get

$$4HB = t_1 \frac{di_{cc^+}}{dt} - t_2 \frac{di_{cc^-}}{dt} - (t_1 - t_2)\frac{di^{ref}{}_c}{dt} \text{.........(26)}$$

Substituting Equation (23) in Equation (28) gives

$$4HB = (t_1 + t_2)\frac{di_{cc^+}}{dt} - (t_{1\_}t_2)\frac{di^{ref}{}_c}{dt} \text{..........(27)}$$

Substituting Equation (22) and Equation (23) in Equation (27) and getting equation (30)

$$t_1 - t_2 = \frac{1}{U_{dc} f_c}\left[\frac{U_s}{L} + m\right] \text{..........(28)}$$

Substituting Equation (22), Equation (23) and Equation (30) in Equation (28) gives equation (31)

$$HB = \frac{0.25U_{DC}}{f_c L}\left[1 - \frac{L^2}{U_{DC}{}^2}\left(\frac{U_s}{L} + m\right)^2\right] \text{.......(29)}$$

Where

fc = modulation frequency
m=dIrefc/dt is the slope of reference current wave.
UDC=capacitor voltage of voltage source inverter
L= Interface inductance
Us = voltage of respective phase.

In the proposed method the Hysteresis band is modulated at different points of fundamental frequency cycle and by the switching pattern of inverter is controlled. From Equation (11)it is clear that the hysteresis band is mainly depends on the system parameters. While substituting the switching frequency and there by getting the hysteresis band value. There by getting a nearly constant frequency.The main function of a Adaptive hysteresis band current controller changes the hysteresis band width according to reference current to optimize switching frequency of inverter and THD of supply current [15-17].

TABLE I
SYSTEM PARAMETERS

| PARAMETERS | Values |
|---|---|
| Source voltage | 415 V(L-L) |
| Dc Link Voltage | 680V |
| Bridge Rectifier | Three phase diode rectifier |
| Load | 1KW, 600VAR |
| Interfacing Inductance | 1.5mH |
| Ac-Side Resistance | 1 ohm |
| System Frequency | 50HZ |
| Dc-Bus Capacitance | 8000microfarad |

## II. SIMULATION RESULTS

The Simulation was carried out to demonstrate the effectiveness of proposed Adaptive modified hysteresis current controlled grid connected photovoltaic inverter to mitigate harmonics. The analysis mainly consists of a three phase voltage source and a three phase diode bridge rectifier with RL load. The shunt active power filter is connected to the system through an interfacing inductor L. The values of the circuit elements used in the simulation are given in Table I. The test work was simulated using MATLAB-SIMULINK.
consider the three cases :

1) Case I: Sinusoidal grid voltage and nonlinear local load.
2)Case II: **unbalanced** grid voltage and nonlinear local load.
3) Case III: Sinusoidal grid voltage and unbalanced nonlinear local load.

In Cases I ,II and III, the grid voltage is assumed to be a pure sinusoid. In three Cases, the distorted grid current is supplied with the 5th harmonic and 7th harmonic components.

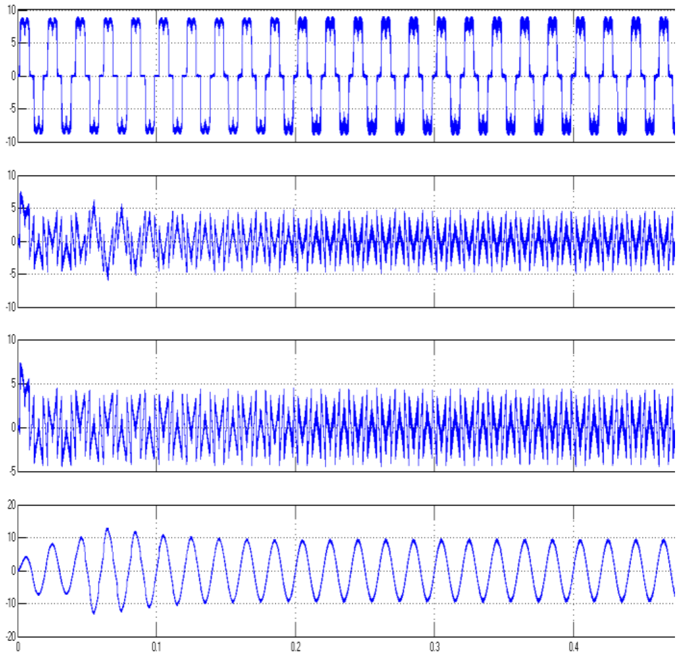

Fig.5.load current, filter current, reference current &Compensated source current

In Figure.5.Load current, reference current and filter current , compensated source current are shown .In Figure. 6shows the response of a shunt active power filter under unbalanced source voltage conditions. The unbalanced source voltage conditions is obtained by giving phases Voltages of 230 Volts, 300Volts, 160 volts for phases a, b and c respectively. From the graph the shunt active power filter works well under the unbalanced source voltage condition and also getting a purely sinusoidal source current. In Figure.7shows the response of a shunt active power filter under unbalance in load currents conditions. The unbalance in load currents is obtained by connecting a single phase diode rectifier feeding a R-L load between phases a and c. From the graph the shunt active power filter works well under the unbalance in load currents and also getting a purely sinusoidal source current. In Figure.8.Load current, reference current and filter current , compensated source current for a three phase system are shown . From figure 9 Good DC bus voltage stabilization was achieved and the voltage is maintained at 680 volts.

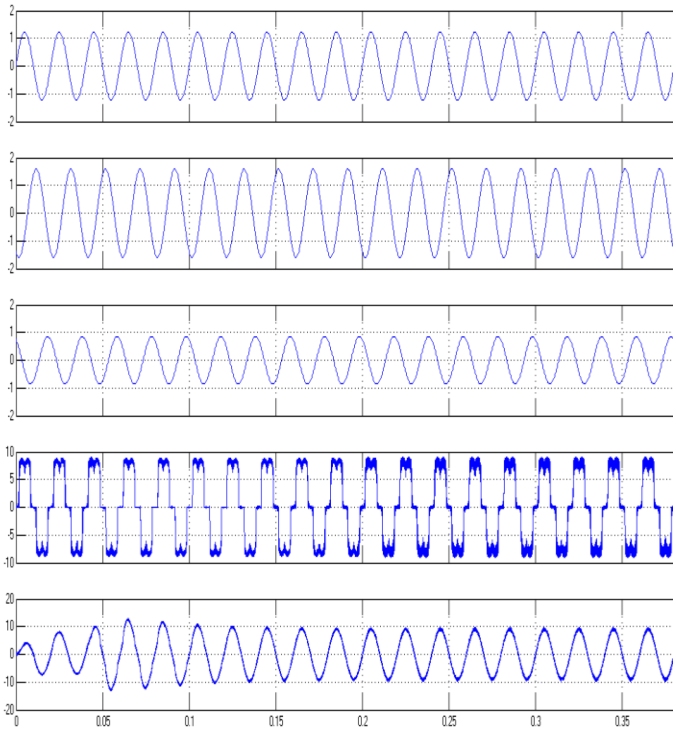

Fig.6.The effectiveness of the proposed shunt active power filter under unbalanced source voltage conditions (voltage imbalance in phases b and c).

(b)

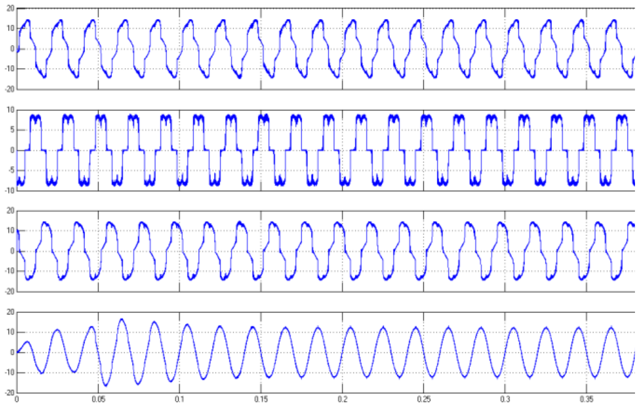

Fig.7.The effectiveness of the proposed shunt active power filter under unbalanced load conditions (current imbalance in phases a

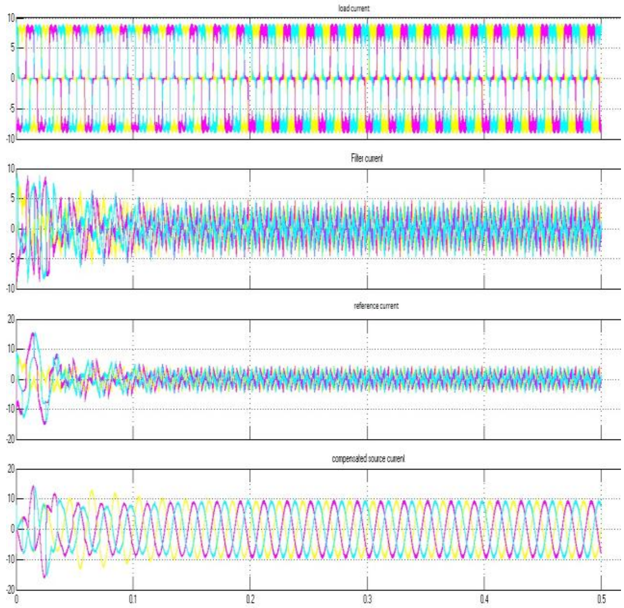

Fig.8.load current, filter current, reference current &Compensated source current for a three phase system

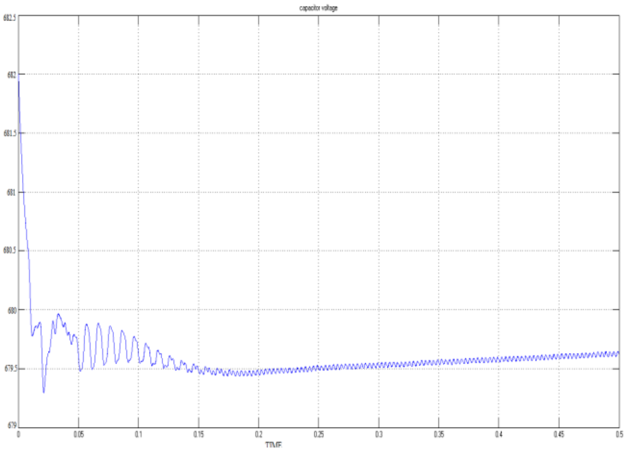

Figure. 9. DC bus Capacitor Voltage

## III CONCLUSION

This paper proposes an Adaptive modified hysteresis current controlled grid connected photovoltaic inverter for eliminate the effects of nonlinear local loads. which uses an Adaptive modified hysteresis current controller combined with the use of I cos Φ theory for computes the reference compensation currents to be injected by SAF . In which the switching losses are reduced to one third and also making a constant switching frequency . thereby overcoming the disadvantage of conventional and modified hysteresis controller ( variable switching frequency).By employing the Adaptive modified hysteresis current controlled grid connected photovoltaic inverter supply current THD is brought within the 5% limits as specified by the power quality standards .Here in the proposed system THD is reduced to 3.03%. Good DC bus voltage stabilization was achieved and the voltage is maintained at 680 volts. Adaptive modified hysteresis current controlled grid connected photovoltaic inverter works well under unbalanced source and load conditions also.

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