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Power Quality Improvement for Stable Operation in Renewable Hybrid Power System using Sapfwith Icosϕ Control Technique

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***Abstract** Nowadays Power quality is a extremely main issue. Switching actions of power electronics devices draws reactive power, which causes distortion in current waveform, resulting in harmonics which further leads to capacitor failure, resonance problem and power factor performance etc. Therefore the harmonics are eliminated and the reactive power is compensated in the power supply in the grid side. Passive filters were previously used for removal of harmonics, but due to large resonance problem and effect of source impendence on performance it was dropped.*

In the proposed model, VSI used as Shunt Active Power Filter is proposed to design as per work producing component of basic current of load (ICos□) for providing to eliminate distortion of a sinusoidal waveform by waveforms of different frequencies and power produced by non-work producing component reparation as requested by reactive load drawn non-sinusoidal current from sinusoidal supply. Control circuit of Voltage Source Inverter provided to improve quality of power is performed for various active functioning conditions under non-linear reactive loads.

MATLAB / Simulink simulation tool is used to obtain this result. The obtained outputs were within the suggested IEEE-519 standard i.e. less than 5% and also the system power factor is almost unity.

***Keywords** – Voltage Source Inverter (VSI), Non Linear Loads, Solid State Electronics Converters, Harmonics, ICosΦ Control Algorithm.*

I. INTRODUCTION

Now-a-days, the broad employ of nonlinear loads leads to a multiplicity of unpleasant event in the power system process. Quality of power is maintained by keeping desired level of voltage and current magnitudes, less distortion and free from interruptions. According to the solid state electronics converters prologue, distortion of current deviated from AC supply send to the system of power. Mostly distortion of a sinusoidal waveform by waveforms of different frequencies is produced at load side, howbeit harmonics are going in the direction of source side creating the non sinusoidal source. If sinusoidal and non-sinusoidal waveforms are superimposed, heavy injure happens in system of power.

II. PROPOSED METHODOLOGY

Tuned passive power filters are extremely effectual to eliminate the definite components of distortion of a sinusoidal waveform by waveforms of different frequencies howbeit these had some limitations like fixed reparation, resonance and very large size. To conquer these limitations active power filters are used which are fundamentally VSI or CSI so as to supply the essential reparation voltages and currents.

A SAPF produces spectrum of current harmonics which is contrary in phase with the current harmonics, it sees at the load end. Therefore harmonic and reactive currents are annulled at the supply end and the result is undistorted sinusoidal balanced currents.

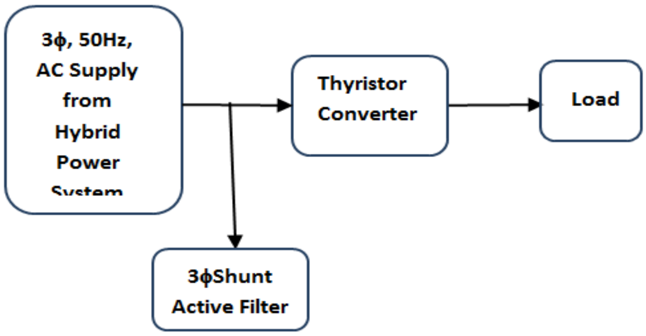

Fig.1: Block Diagram of Proposed Model

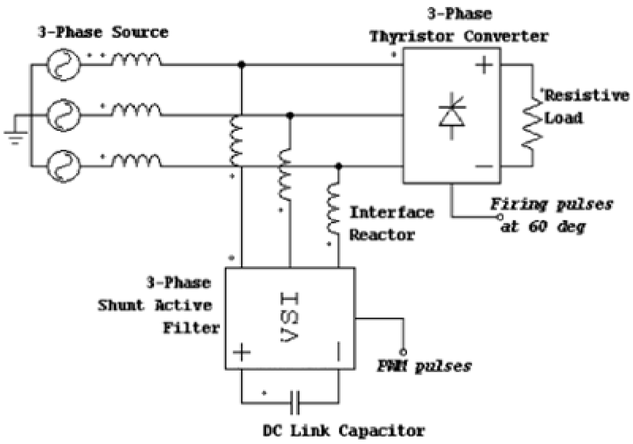

Fig.2: Circuit Diagram of Proposed Model

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III. PROPOSED ICOS CONTROL ALGORITHM

The ICosϕ control algorithm is to provide harmonic, reactive power and unbalance reparation in a 3Φ system with balanced/unbalanced source and load conditions. It employs the smallest possible number of computational steps and is simple to practically implement in the system conditions like twist out of shaped and irregular alternating current source providing non-linear equipoised loads. The highly non-linear and reactive current drawn from the grid when it is providing a non-linear load such as diode bridge rectifier, thyristor converter, and alternating current voltage controller based loads. The aim of the algorithm is to limit total harmonic distortion in terms of percentage in the grid current within the limits given by IEEE standard to accomplish UPF at the grid end.

In ICosϕ algorithm, the grid current at desired level is taking into consideration to be the product of ICosϕ magnitude and unit amplitude sinusoidal in phase with the grid voltage. The grid is needed to provide only the active part of the load current and the expectation of shunt active power filter is to supply reparation for the harmonic and reactive part of 3Φ load current and also for any lack of balance in 3Φ load currents. Hence, from the grid only balanced currents will be taken which will be purely sinusoidal and in phase with grid vSoltages.

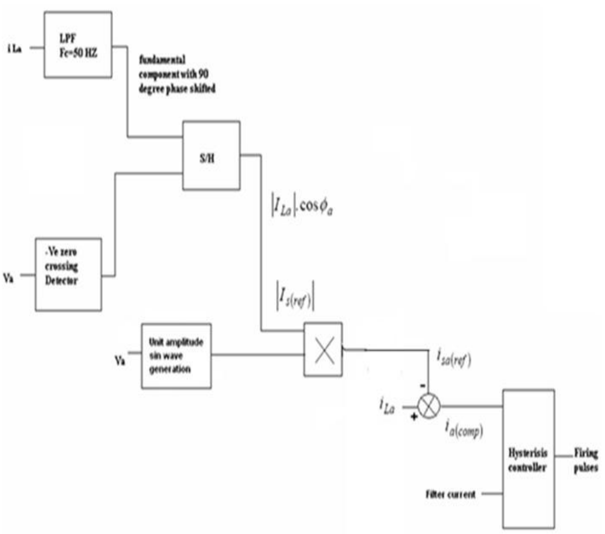

Fig.3: Block Diagram of Proposed ICos□ Control Algorithm

IV. PROPOSED ICOSϕ CONTROL ALGORITHM WITH MATHEMATICAL MODELLING

The expectation of shunt active power filter is to supply reparation for harmonics, reactive part of 3Φ load current and any lack of balance in 3Φload currents. These make sure that from the grid only balanced currents will be taken which will be purely sinusoidal and in phase with grid voltage. Therefore the main is needed to provide the real part of load current. In ICosϕ algorithm, the main current at desired level is taking into consideration to be the product of ICosϕ magnitude and unit amplitude sinusoidal in phase with main voltage.

For a balanced source, the 3Φ instant voltages can be specified as

$$v_a = V_m \sin \omega t$$
$$v_b = V_m \sin(\omega t - 120°)$$
$$v_c = V_m \sin(\omega t + 120°) \quad ---- \quad (1)$$

For example, one of the phases of the load takes a lower current that the other two phases, the unbalanced 3Φ reactive harmonic load currents can be specified as

$$i_{La} = I_{La1}.\sin(\omega t - \phi_a) + \sum_{n=2}^{\infty} I_{Lan}.\sin(n\omega t - \phi_{an})$$
$$= R_e.(i_{La1}) + I_m.(i_{La1}) + \text{harmonic components}$$
$$i_{Lb} = I_{Lb1}.\sin(\omega t - 120 - \phi_b) + \sum_{n=2}^{\infty} I_{Lbn}.\sin(n(\omega t - 120 - \phi bn$$
$$= R_e.(i_{Lb1}) + I_m.(i_{Lb1}) + \text{harmonic components}$$
$$i_{Lc} = I_{Lc1}.\sin(\omega t + 120 - \phi_c) + \sum_{n=2}^{\infty} I_{Lcn}.\sin(n(\omega t + 120 - \phi cn$$
$$= R_e.(i_{Lc1}) + I_m.(i_{Lc1}) + \text{harmonic components} \quad ------(2)$$

Where

ϕ_a, ϕ_b, ϕ_c = phase angles of fundamental currents in a, b and c phases;

$\phi_{an}, \phi_{bn}, \phi_{cn}$ = phase angles of n^{th} harmonic currents in a, b and c phases;

$I_{La1}, I_{Lb1}, I_{Lc1}$ = three phase fundamental current amplitudes;

$I_{Lan}, I_{Lbn}, I_{Lcn}$ = three phase n^{th} harmonic current amplitudes.

The active component magnitude of the fundamental load current in each phase is given by

$$|R_e(I_{La1})| = |I_{La}| Cos\ \phi_a$$
$$|R_e(I_{Lb1})| = |I_{Lb}| \text{ Cos } \phi_b$$
$$|R_e(I_{Lc1})| = |I_{Lc}| \text{ Cos } \phi_c \ ------- \ (3)$$

To make sure, sinusoidal balanced currents with unity power factor is being taken from the system source, the magnitude of wanted source currents can be expressed as the magnitudes of average active components with load currents at fundamental frequency in the three phases

$$|I_{s(ref)}| = \frac{|Re(I_{La1})| + |Re(I_{Lb1})| + |Re(I_{Lc1})|}{3}$$
$$= \frac{|I_{La}|.\cos\phi_a + |I_{Lb}|.\cos\phi_b + |I_{Lc}|.\cos\phi_c}{3} \ ---------- \ (4)$$

U_a, U_b and U_c are the phase - ground voltage of source for 3Φ in unit amplitude respectively.

$$U_a = 1.\sin\omega t$$
$$U_b = 1.\sin(\omega t - 120°)$$
$$U_c = 1.\sin(\omega t + 120°) \quad ------ \quad (5)$$

Therefore, the reference currents of source for 3Φ expressed as

$i_{sa(ref)} = |I_{s(ref)}| \times U_a = |I_{s(ref)}|.\sin\omega t$ $i_{sb(ref)} = |I_{s(ref)}| \times U_b = |I_{s(ref)}|.\sin(\omega t - 120)$

$i_{sc(ref)} = |I_{s(ref)}| \times U_c = |I_{s(ref)}|.\sin(\omega t + 120)$ ------- (6)

By that, the desired currents reparation of VSI for each phase found from difference in actual current of load and desired current of source.

$i_{a(comp)} = i_{La} - i_{sa(ref)}$
$i_{b(comp)} = i_{Lb} - i_{sb(ref)}$
$i_{c(comp)} = i_{Lc} - i_{sc(ref)}$ ----- (7)

Equation (7) can be expanded as

$i_{a(comp} = [R_e.(i_{La1}) + I_m.(i_{La1})$ + harmonic components] - [$|I_{s(ref)}|.\sin\omega t$]
$i_{b(comp)} = [R_e.(i_{Lb1}) + I_m.(i_{Lb1})$ + harmonic components] - [$|I_{s(ref)}|.\sin(\omega t - 120)$]
$i_{c(comp)} = [R_e.(i_{Lc1}) + I_m.(i_{Lc1})$ + harmonic components] - [$|I_{s(ref)}|.\sin(\omega t + 120)$]

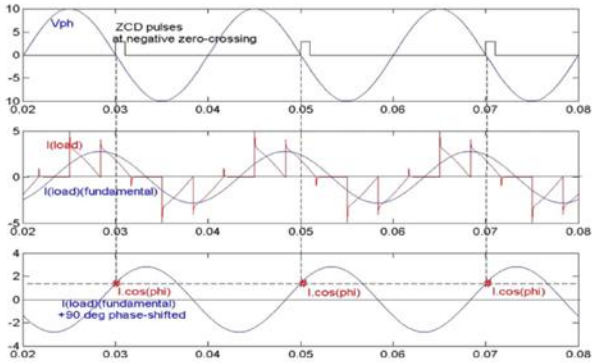

Fig.4: Illustration of the ICos? Algorithm

If the load currents of three phases are in balanced condition, then the desired currents reparation is basically being the addition of wattless components in each phase.

$i_{a(comp)} = [I_m.(i_{La1})$ + harmonic components]
$i_{b(comp)} = [I_m.(i_{Lb1})$ + harmonic components]
$i_{c(comp)} = [I_m.(i_{Lc1})$ + harmonic components]
------ (9)

The ICosϕ magnitude is the wattful part of load current at fundamental frequency. It is take out as phase current amplitude at fundamental frequency shifted by +90° at negative going zero crossing of phase voltage as seen in fig.4. A 2nd order low pass filter have 50 Hz as well as cut off cycle per second is provided to take out theload current at fundamental frequency for an intrinsic +90°phase shift. Here the LPF worked as a zero crossing detector (ZCD) employs to find out the negative going zero crossing of the corresponding phase voltage. The fundamental phase voltage component takes out by low pass filter before it sends to ZCD for making it resistant to any incoming voltage distortion.

The ZCD with 5% tolerance made for taken care of any oscillations on the zero crossing. The phase shifted fundamental current as a "sample" input and the output pulse of ZCD as a "hold" input goes to the "sample and hold" circuit whose output is the magnitude of ICosϕ. Then the mean of number of these values in 3Φ is calculated by summing amplifier having a gain of 1/3. From the given portion of control circuit or one of the 3Φ, it obviously describes how the desired reparation currents are produced using op-amp based control circuit.

The 3Φ mains voltages used as a template for producing unit amplitude of sine waves in phase with voltages of mains. Suppose the voltages of mains are out of shape, the mains voltages fundamental components are taken out with the help of second order low pass filter and utilized as a template.

A fluctuation in voltage of dc bus capacitor of SAPF is helped to compute the extra power loss in invertor and inter-phase transformer. The corresponding amplitude of phase current is computed with the help of proportional integral and derivative (PID) controller as follows and added to the real part of the load current at fundamental frequency in each phase.

Assumption 1:

Let V_{La}, V_{Lb} and V_{Lc} be the 3Φ balanced sinusoidal voltages at the point of common coupling (PCC)

Assumption 2:

Assume that V^*_{DC} is the reference dc link voltage. V_{DC} is the measured actual dc link voltage. Energy lost due to capacitor while the voltage discharging is given by

$$\Delta E = \frac{1}{2} C_{DC} (V^{*2}_{DC} - V_{DC}^2)$$

By keeping constant V_{DC}, the energy drawn by the SAPF from the ac mains must be equal to ΔE. ie, P× $T=\Delta E$,where P = active power drawn from the ac mains =3/2 VLm.ICm, where V_{Lm}= magnitude of instantaneous phase voltage, V_La, V_{Lb}or $V_{Lc}$and I_{Cm}= active current component magnitude, I_{Ca},I_{Cb}or I_{Cc} (corresponding to losses).

Therefore,

$$I_{Cm} = \frac{C_{DC}(V*_{DC}2 - V_{DC}2)}{3.V_{Lm}.T} = \frac{C_{DC}(V*_{DC}2 - V_{DC}2)\omega}{6.\pi.V_{Lm}} \quad - - - - (10)$$

Where T=2.π/ω and ω is the frequency of sampling.

In each phase, the component corresponding to losses is summed with the allusion compensation current magnitude. This makes sure that the SAPF losses are carefully taken by 3Φ source and DC bus voltage of SAPF is a capable of supporting oneself without outside help. After that the allusion compensation currents for the SAPF are calculated since the dissimilarity betwixt actual load and desired mains currents for 3Φ.

V. PROPOSED HARMONICS ALLEVIATION TECHNIQUES

Harmonic removal strategies are used to enhance the power device performance through a few goals.

- System PF improvement & reactive power compensation
- THD limit maintained in current harmonic distortion.

Therefore, several strategies are used for harmonic removal from electricity device. Several used devices are:

- Induction Reactor
- Isolation transformers
- K-Factor
- PST
- Current harmonic filters are provided to decrease harmonics in current wave inside energy tools.

Major classifications of harmonics filters are:

- Passive Power filters
- Active Power filters
- Hybrid Power filters

In the proposed model, active power filter is selected and employed for the alleviation of harmonics.

A. Active Power Filter

An active power filter produce compensating current signal by unceasingly observing the current of load by means of the assist of few set of rules including ICosϕ concept, p-q concept, d-q concept, D.S.P based algorithm and many others. The compensating current generated which is employed to produce the pulse of switching & series of switching of IGBT inverter by assist the hysteresis control or some different kinds of current control. Afterwards the inverter produces necessary current harmonic for the load via charging & discharging of direct current link capacitor & sent to device via coupling transformer having a phase difference to make amends the wattless power of mains of alternating current.

Active power filters are classified into two:

- Series Active Power Filter
- Shunt Active Power Filter

Shunt active power filter is proposed and used in the proposed model for the alleviation of harmonics.

VI. HYSTERESIS CURRENT CONTROLLER

This method have been provided to correct the switching signals for MOSFET inverter by examine the similarities and differences between the current error signal and given hysteresis band. The summer output ie., error signal which is sent to hysteresis band comparator and compared with the hysteresis band, then the output of comparator is fed to AF for producing the required compensating current that go after the waveform of allusion current.

Hysteresis band comparator techniques are employed for its superb forceful movement but this cannot be done if different kinds of comparator are used. The hysteresis band consists of two limits that are top and bottom limit hysteresis band.

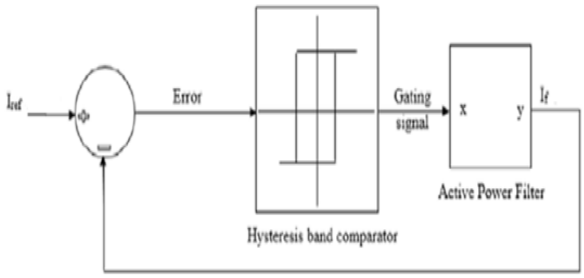

Fig.5: Control Logic of Hysteresis Current Controller

While the current tendency to go beyond the top limit band, the inverter top switch is switched off and bottom switch is switched on, therefore the current trails back in a second time to the hysteresis band. So, current be positioned inside the hysteresis band and compensating current go after the current allusion.

VII. PROPOSED SIMULATION MODEL

The proposed simulation model with ICosϕ Control Algorithm for current hysteresis is shown in fig.6. For done in an instant real and wattless power control of SAPF, the real and wattless power is calculated for current and voltage of the inverter and the allusion current is created which is proportional to low pass filter with disturbance in order to get disturbed power for compensation. This disturbed power is converted into current which is compared with actual value in order to create PWM for the inverter. This difference in the A phase current generates PWM which is the first leg of the inverter and similar way for B and C phase will be generated in the second and third legs of the inverter. This compensating current will produce a sinusoidal power wave at the source side. Thus, the overall circuit acts as SAPF.

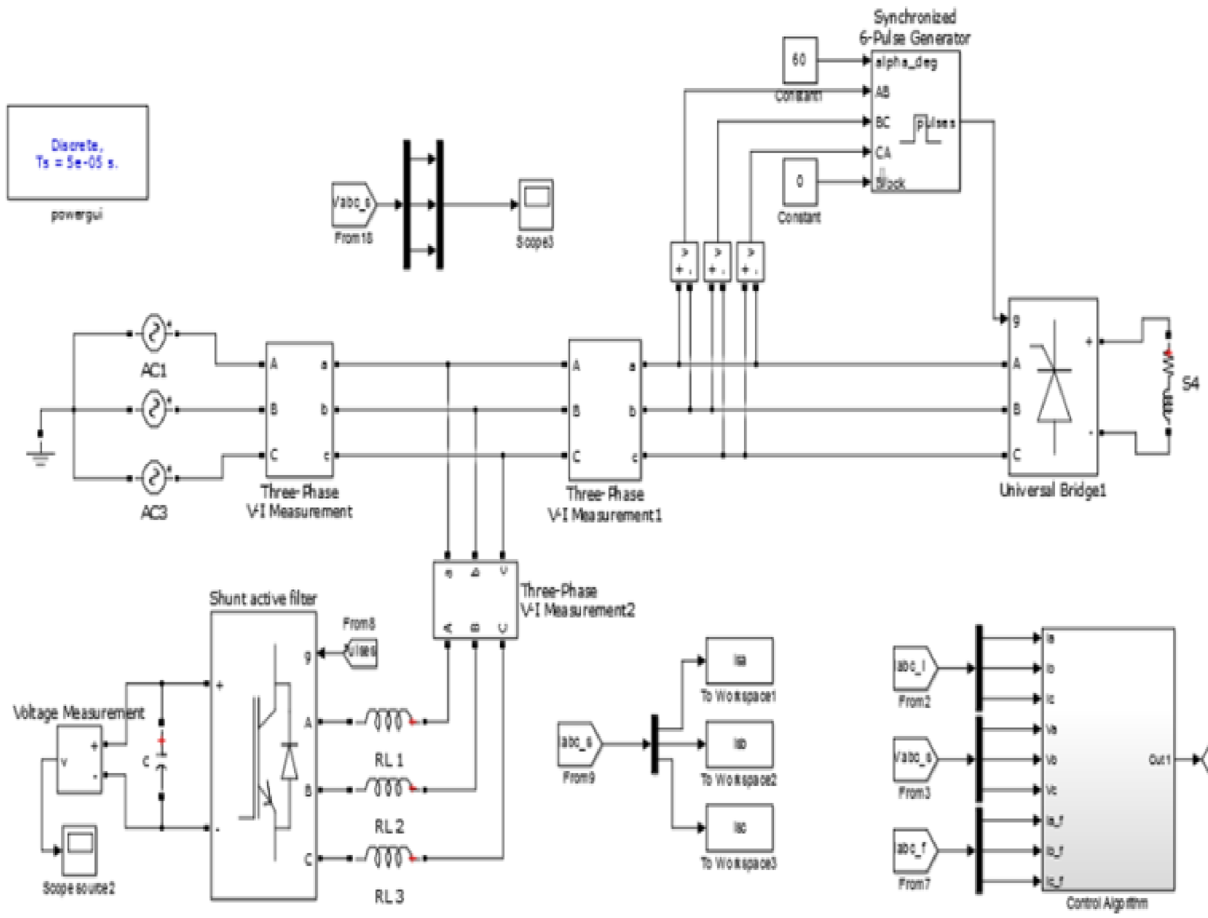

Fig.6: Proposed Simulation Model with ICos Control Algorithm

VIII. SIMULATION RESULTS

The source and the load voltage is observed to be undisturbed while the current during the non-linear load operation had a dead bit which introduced higher THD in the current waveform.

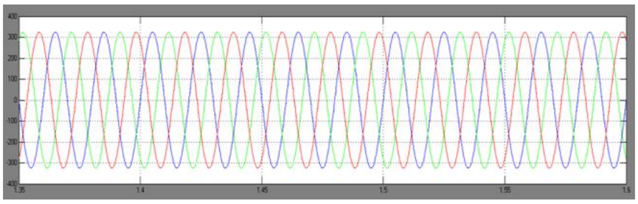

Fig.7: Waveform of 3? Voltage at grid side

In the source side, waveform of the curent is imitating as that of the load side but after the compensation the current wave in the source side has improved and it is near to sinusoidal wave thus reducing the THD to a level which is accepted by international standards as shown in the figures(7 - 9)

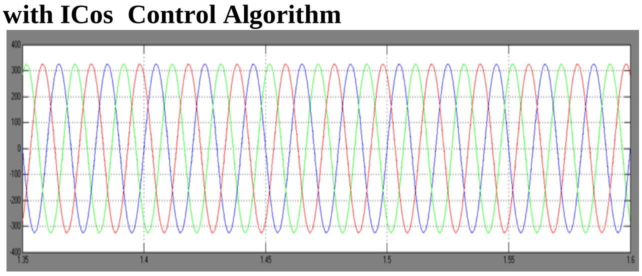

Fig.8: Load voltage waveform at grid side

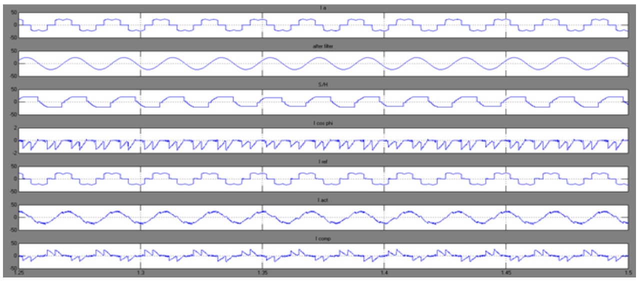

Fig.9: Load current waveform at grid side

The simulation is carried out using MATLAB PWM techniques like hysteresis controller using ICos Control Algorithm where the THD came down to as less as 1% is in compliance with IEEE 519 standards as shown in figures 10 and 12.

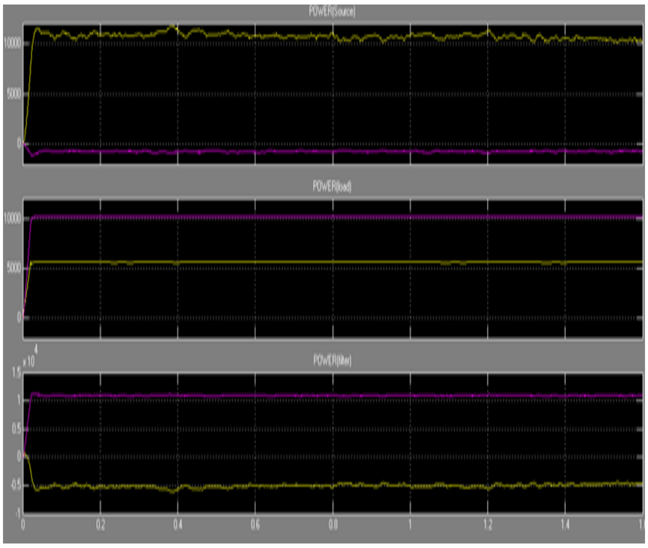

Fig.10: Real and Reactive Power at grid and load side

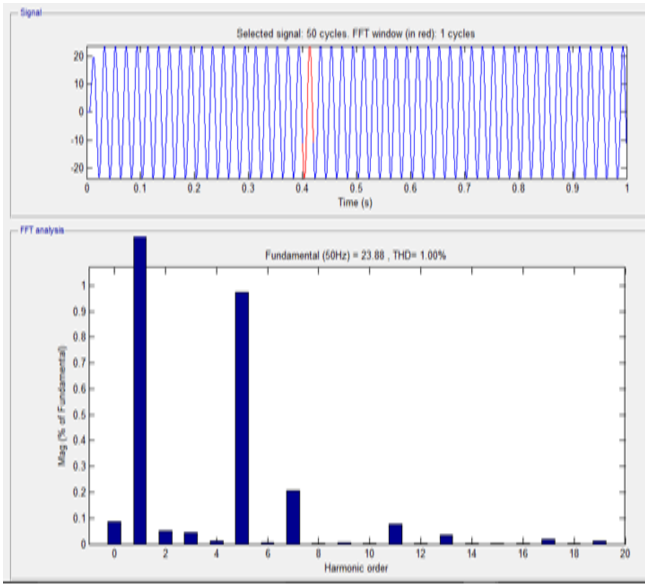

Fig.11: Current THD FFT Analysis

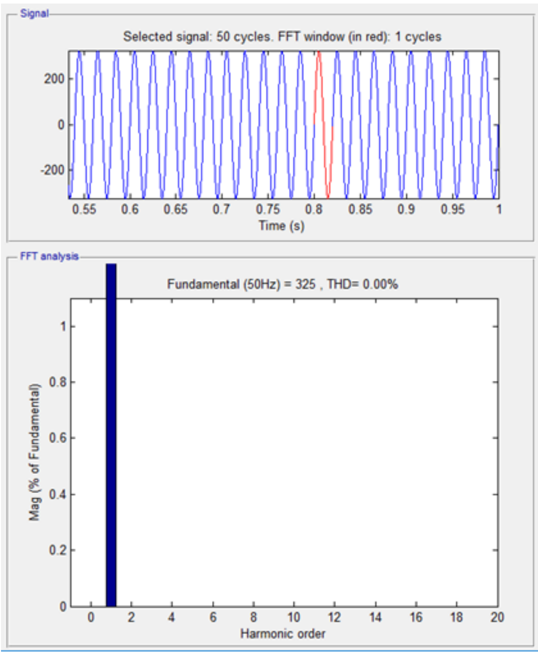

Fig.12: Voltage THD FFT Analysis

IX. CONCLUSION

The proposed ICos? algorithm is used in 3? SAPF for providing to eliminate the distortion of a sinusoidal waveform by waveforms of different frequencies and wattless power reparation as required by reactive load drawn non-sinusoidal current from sinusoidal supply. Simulation is investigated by MATLAB/ Simulink for reactive power and THD. The THD in the proposed system with SAPF is less compared to power system without SAPF. The reactive power compensation is observed while compensation has occurred in the power system, so that it is needed for the source to provide only the actual power required by the load.

X. FUTURE SCOPE

Project can be extended by generating by generating the compensating signal using fuzzy logic and neuro fuzzy compensation. The THD can be improved by using both shunt and series compensation so that the power quality can be improved.

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