To Optimize the Reduction of THD of Line Interactive UPS System with SRF Controller in Three Phase Four Wire System

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***Abstract* - This paper presents modified SRF Three phase three wires shunt active power line conditioner system, for three wire and four wire systems in which three single phase loads are fed. In power system Poor power quality sources are raised from two categories: (i) Non-linear loads, electrical components and equipments (ii) Subsystems of transmission and distribution systems Quality degradation of electric power mainly occurs due to power line disturbances such as impulses, notches, voltage sags / swell, voltage and current unbalance, interruption and harmonic distortions. The electric power quality has become an important part of the distribution power system. Harmonics are the primary cause for the poor power quality of the distribution system. To improve the power quality both input currents and output voltages are simultaneously controlled to be in phase with respect the input voltages. Therefore, an effective power factor correction is carried out. Operation of a three-phase phase-locked loop (PLL) structure, used in the line interactive UPS implementation, is presented. The control algorithm using SRF method and modified SRF method active power flow through the UPS system are described and analytically studied. Design procedures, digital simulations and experimental results are presented in order to verify the good performance of the proposed three-phase line interactive UPS system..**

***Keywords*: Modified SRF; Active Filter; UPS; THD.**

I. INTRODUCTION

Modified SRF based Active Power Filter (APF)) is designed and implemented for power quality improvements in terms of current harmonics and reactive power compensation. The widespread use of nonlinear loads in industrial, commercial and domestic facilities cause harmonic problems. A harmonic induce malfunctions in sensitive equipment, overvoltage by resonance, increase heat in the conductors, harmonic voltage drop across the network impedance and affects other customer loads connected at the Point of Common Coupling (PCC). Active power line conditioner is implemented for compensating the harmonics and reactive-power simultaneously in the distribution system. The performance of the active power line conditioner depends on the design and characteristics of the controller. The objective of this research is to find a suitable control strategy for reference current extraction as well as PWM VSI current controller. Proposed sinusoidal extraction controller and modified synchronous reference frame theory methods are utilized for extracting reference current.

II.DESCRIPTION OF THE LINE INTERACTIVE UPS TOPOLOGY

The topology of the line interactive UPS system is shown in Fig. 1. Two pulse width modulation (PWM) converters, coupled to a common dc bus, are used to perform the series active filter and the parallel active filter functions. Capacitors and a battery bank are placed in the dc bus and a static switch 'sw' is used to provide the disconnection between the UPS system and the power supply when an occasional interruption of the incoming power occurs. The center-tap of the dc-bus is connected to the utility neutral.

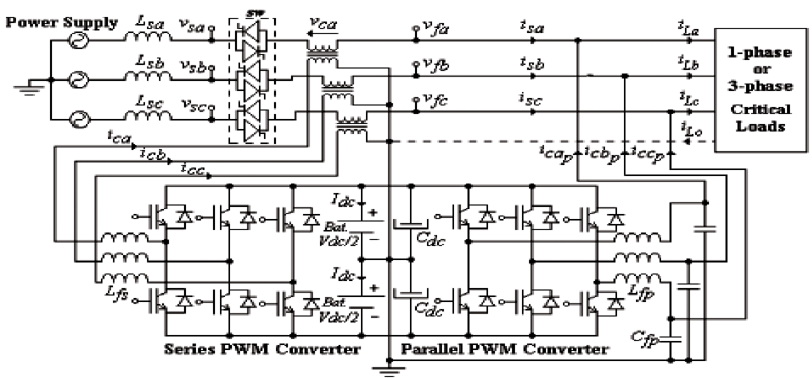


Figure 1. Line-Interactive UPS system topology

III. SYNCHRONOUS REFERENCE THEORY (SRF)

An SRF based controller is used to provide and to control the compensating reference currents (i_{ca} , i_{cb} , and i_{cc}) for the series PWM converter shown in Fig. 1. The block diagram of the control scheme for current compensation is shown in Fig. The three-phase load currents (i_{La} , i_{Lb} , i_{Lc}) are measured and transformed into a two phase stationary reference frame $(dq)^s$ quantities (id^s, iq^s) based on the transformation (1). Then, these quantities are transformed from a two phase stationary reference frame $(dq)^s$ into a two phase synchronous rotating $(dq)^e$ reference frame, based on the transformation. The unit vectors sin θ and cos θ are obtained from PLL system. The currents at the fundamental frequency Z (id^e and iq^e) are now dc values and all the harmonics, transformed into non-dc quantities, can be filtered using a low pass filter (LPF) as shown in Fig. Now, id_{dc}^e represents the fundamental active component of the load current and iq_{dc}^e represents the fundamental reactive component of the load current, both in dq axis.

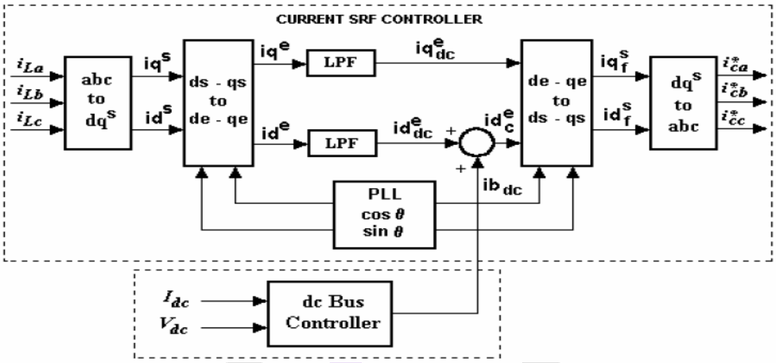


Fig: Block diagram of the current SRF-based controller.

An additional dc-bus controller is responsible for regulating the current I_{dc} and the voltage V_{dc}. Apart from the conventional active filter applications, in which only the dc-bus voltage is controlled, the UPS dc bus controller is able to control the dc-bus current for adequate charging of the battery bank. The dc-bus controller is also responsible to control the active power flow of the UPS system. Its output Ib_{dc} is added to the active current in the d axis I_{dc}^e and, thus, the amplitude of the reference currents can be controlled by I_c^e.

$$\begin{bmatrix} id^s \\ iq^s \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix}$$

$$\begin{bmatrix} id^e \\ iq^e \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} id^s \\ iq^s \end{bmatrix}$$

$$id_c^e = id_{dc}^e + ib_{dc}$$

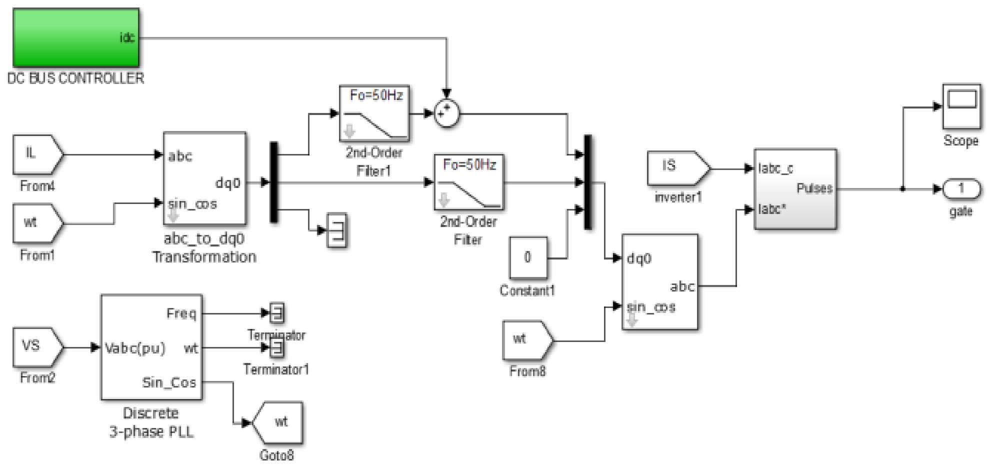
Now, the dc components of the synchronous reference frame I_{dc}^e and I_{dc}^e can be transformed into the stationary reference frame $(dq)_s$. The inverse transformation matrix from two-phase synchronous reference frame to two-phase stationary reference frame is given by (4). As only the fundamental active component reference needs to be obtained, (4) can be replaced by (5). The matrix that provides the linear transformation from two-phase system to three-phase stationary reference frame system is given by (6). Thereby, the dc component of the synchronous reference frame is transformed into the stationary reference frame I_{dc}^e and yields the fundamental components of the load currents (I_a^*, I_b^*, and I_c^*). Such reference currents are generated in software.

$$\begin{bmatrix} id_f^s \\ iq_f^s \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} id_{dc}^e \\ iq_{dc}^e \end{bmatrix}$$

$$\begin{bmatrix} id_f^s \\ iq_f^s \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} id_{dc}^e \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} id_f^s \\ iq_f^s \end{bmatrix}$$

Above method implemented in MATLAB as follows



IV. PROPOSED MODIFIED SRF

The block diagram of modified-SRF structure is shown in Fig. a The modified SRF method consist of simplified unit vector generation for vector orientation, dc link capacitor voltage regulator and stationary-rotating synchronous frames to extract the reference current.

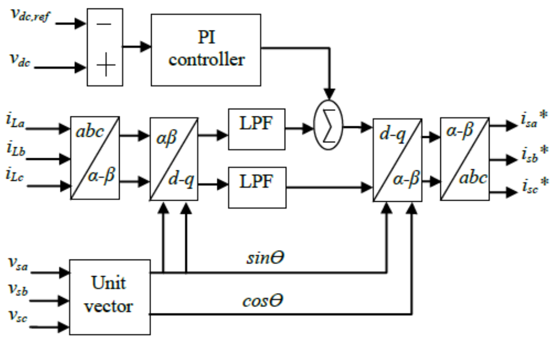


Fig. a. Block diagram of the modified - SRF method

V. INSTANTANEOUS CURRENT COMPONENT (ID-IQ) THEORY

The Modified Synchronous Frame method is called the instantaneous current component (id-iq) method. This is similar to the SRF frame method. The transformation angle is now obtained with the voltages of the ac network. The major difference is that, due to voltage harmonics and imbalance, the speed of the reference frame is no longer constant. It varies instantaneously depending of the waveform of the three phase voltage system. In this method the compensating currents are obtained from the instantaneous active and reactive current components and of the nonlinear load. In the same way, the mains voltages V(a,b,c) and the polluted currents I_{LABC} in α-β components must be calculated as given by (2), where C is Clarke Transformation Matrix. However, the load current components are derived from a synchronous reference frame based on the Park transformation, where represents the instantaneous voltage vector angle (3).

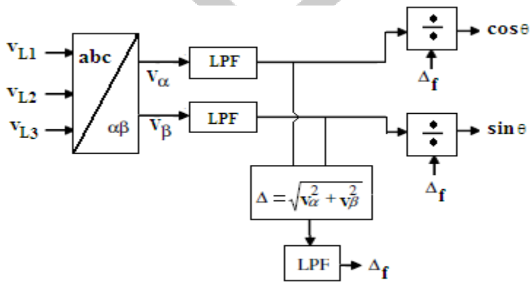


Fig. Principal of modified (id-iq) method

$$\begin{bmatrix} il_\alpha \\ il_\beta \end{bmatrix} = [C] \begin{bmatrix} I_{la} \\ I_{lb} \\ I_{lc} \end{bmatrix}$$

$$\begin{bmatrix} il_d \\ il_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} il_\alpha \\ il_\beta \end{bmatrix} ,\theta = \tan^{-1}\frac{v_\beta}{v_\alpha}$$

Under balanced and sinusoidal mains voltage conditions angle θ is a uniformly increasing function of time. This transformation angle is sensitive to voltage harmonics and unbalance; therefore dθ/dt may not be constant over a mains period. With transformation (2) and (3) the direct voltage component is

$$V_d^2 = V_\alpha^2 + V_\beta^2$$

And the quadrature voltage component is always null, Vq = 0, so due to geometric relations "(3)," becomes,

$$\begin{bmatrix} il_d \\ il_q \end{bmatrix} = \frac{1}{\sqrt{V_\alpha{}^2 + V_\beta{}^2}} \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} il_\alpha \\ il_\beta \end{bmatrix}$$

Reference current extraction

The instantaneous three-phase load currents $i_{La,} i_{Lb}$ & i_{Lc} are transformed into the stationary coordinate currents $i_\alpha - i_\beta$ by using Clarke transformation equation

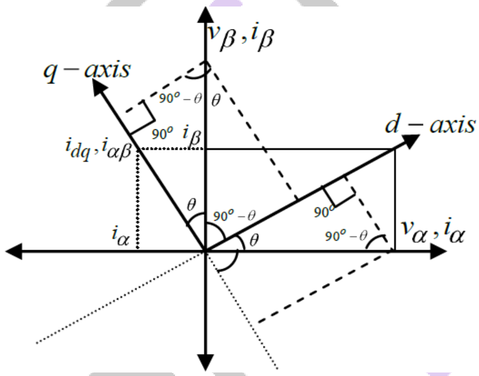


Fig. Voltage and current components in stationary and rotating d-q frame

Fig. shows the current components in stationary and rotating synchronous reference frames. The α − β components of the current quantities are transformed to the rotating synchronous d-q reference frame by park equations

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix}$$

The d-q transformed output signals depend on the load current and the performance of the unit vector generation. The i_d i_q harmonic currents are passed through the LPF to eliminate the higher order ripples. The LPF passes the active current of fundamental frequency component id * and reactive power component iq * required by the load. The algorithm is further developed to calculate the desired reference current signals; hence, the d-q rotating frame is converted back into stationary α − β frame.

$$\begin{bmatrix} i_\alpha{}^* \\ i_\beta{}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_d{}^* \\ i_q{}^* \end{bmatrix}$$

The inverse transformation from d q rotating frame into a b c stationary frame is achieved by the following equation

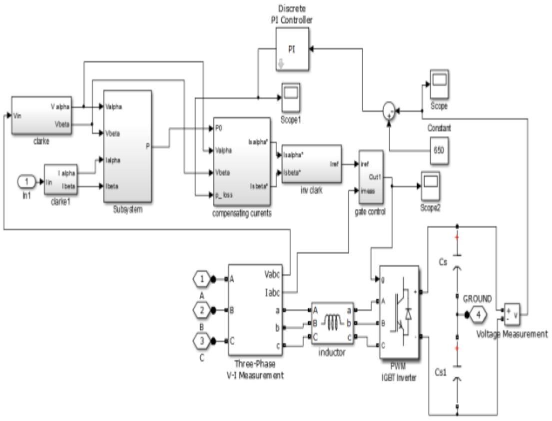
$$\begin{bmatrix} i_{sa}{}^* \\ i_{sb}{}^* \\ i_{sc}{}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_\alpha{}^* \\ i_\beta{}^* \end{bmatrix}$$

The extracted reference currents are compared with actual currents and generate switching pulses to drive the voltage source inverter by using PWM current controller.

Remark:

The conventional SRF controller requires PLL circuit for vector orientation. But the design of a high performance PLL circuit is difficult and this drawback is rectified by the proposed modified SRF method. It uses a simple unit vector for vector orientation and stationery frame transformation for high performance control strategy. The modified SRF provides better performance than conventional method in terms of dc voltage regulation, harmonic current elimination and reactive power compensation.

Modified SRF implemented in MATLAB as shown in figure.



IV. EXPERIMENTAL RESULTS

Result and comparison between conventional SRF and modified SRF

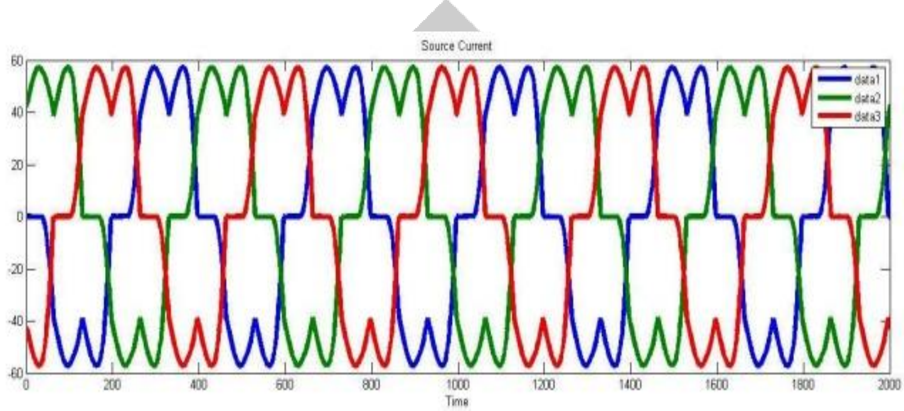


Fig: Source Current without compensation

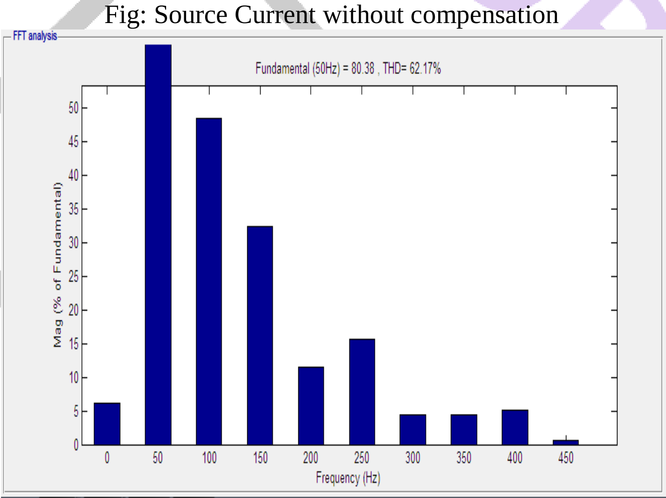


Fig. FFT analysis of IS1

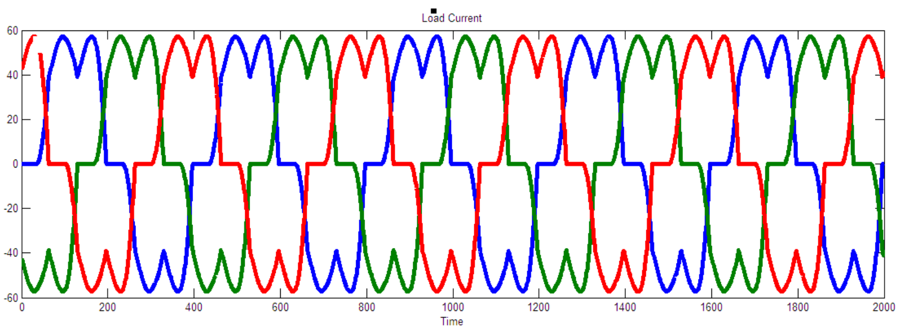
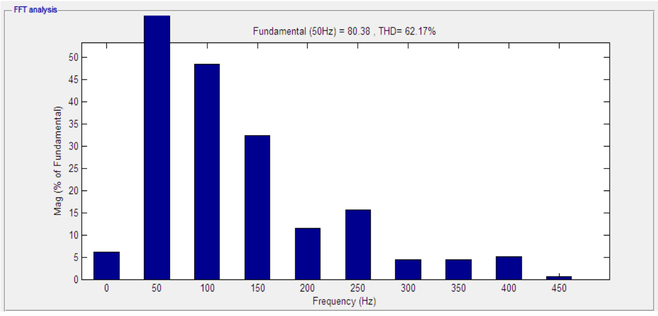


Fig: Load Current without compensation



FFT analysis of IL1

Conventional SRF based active filter.

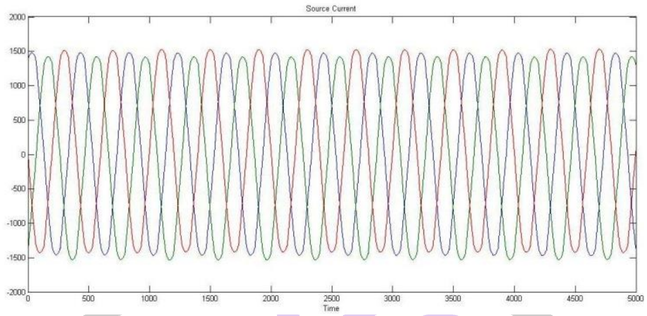


Fig: Source Current with compensation

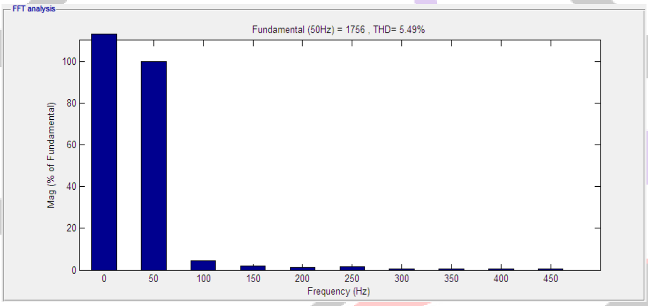


Fig. FFT analysis of source current

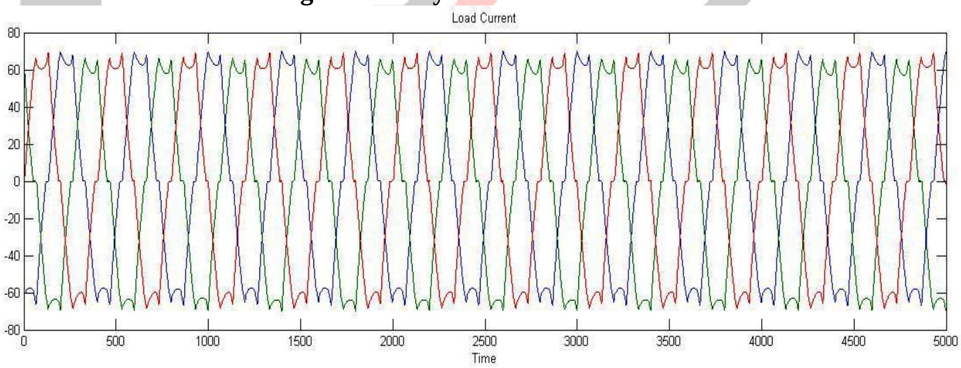


Fig: Load Current with compensation

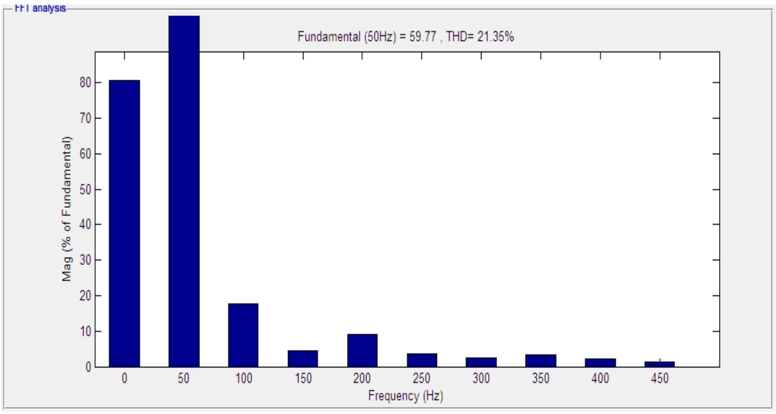


Fig. FFT analysis of Load current

Modified Conventional SRF based active filter

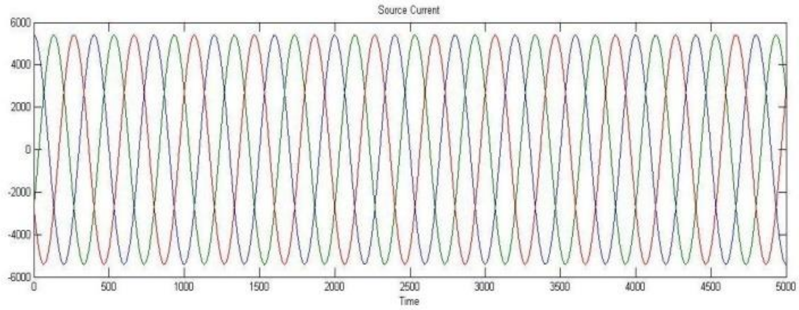
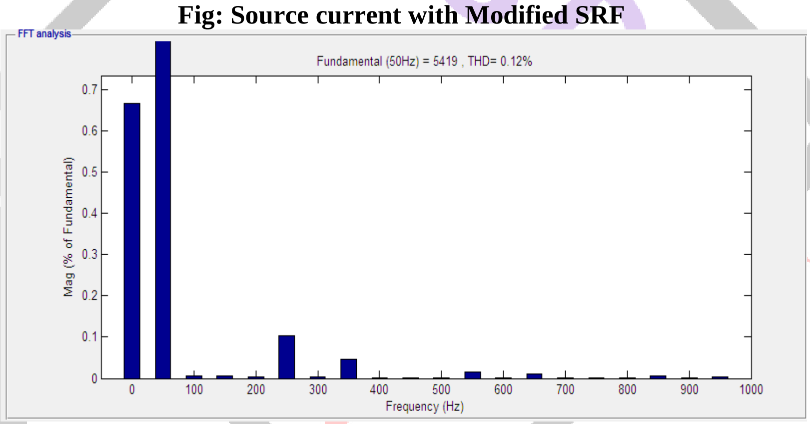


Fig: Source current with Modified SRF



FFT analysis of Source current with Modified SRF

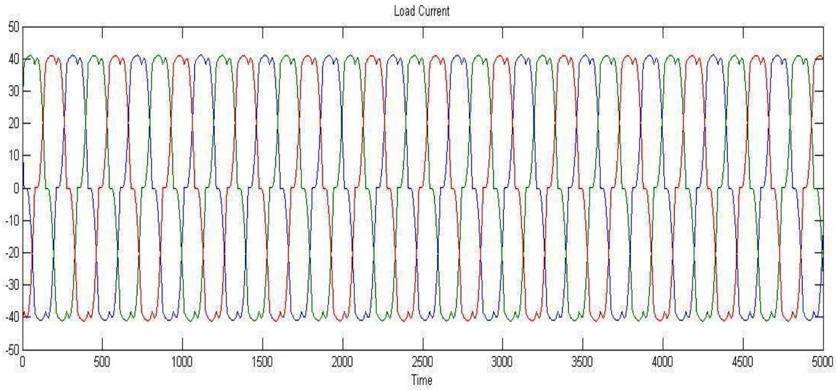
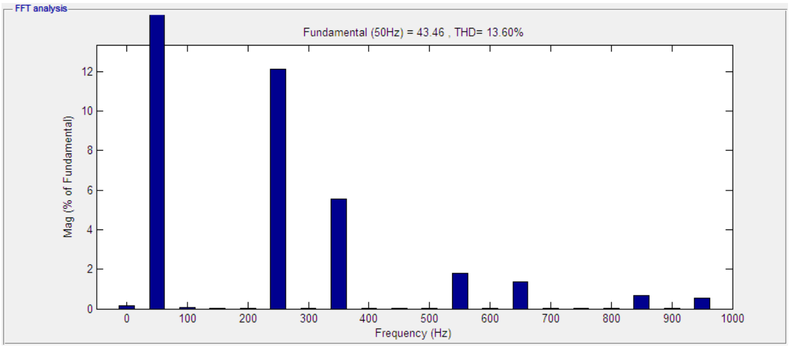


Fig: Load current with Modified SRF

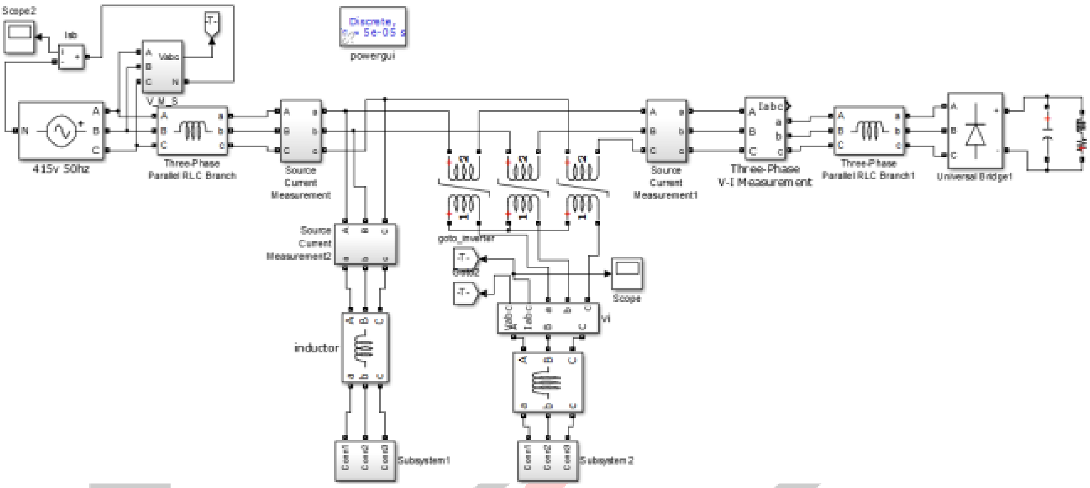


FFT analysis of load current with Modified SRF

Table THD measurements

Rectifier RL Load	Without Compensation	With Compensation	
		Conversational SRF	Modified SRF
	62.17%	5.49%	0.12%

Simulation with conventional SRF Technique



SIMULATION WITH CONVENTIONAL MODIFIED SRF TECHNIQUE

6 CONCLUSIONS

A three-phase line-interactive UPS system topology with active series parallel power line conditioning capabilities has been implemented and tested for four-wire systems. With SRF-based controller implementation, balanced and almost sinusoidal input currents with low THD were obtained. The levels of both fundamental and harmonic contents of the utility neutral current have been reduced considerably. The output voltages are balanced and almost sinusoidal with low THD.

The main advantage of the presented line interactive UPS topology, when compared to the on-line topology, which uses two cascaded PWM power converters working at full power rating, is the smaller power rating handled by both series and parallel converters during the standby mode, increasing the efficiency of the UPS. The high series impedance and the low parallel impedance can protect the load against mains transients.

It has been demonstrated that the experimentally obtained results agree with good approximation with the theoretically predicted results.

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