

Power Quality Improvement of Distribution Network with Non- Linear Load Using Active Power Filter with Adaptive PI Controller

Mr.Chandrakat R.Shinde¹, Mr. Parag chourey²,

¹Mr.Chandrakat R. Shinde, Student, electrical engineering Department, Pdm.Dr.V.B.Kolte college of engineering, cshinde58@gmail.com

²Mr. Parag Chourey, Asst. Prof., Electrical engineering Department, Pdm.Dr.V.B.Kolte college of engineering, choureyparag@gmail.com

ABSTRACT

In recent year power system turn toward the smart grid and micro grid i.e. renewable energy sources are integrated with utility grid network and hence various power electronics devices and non linear loads are used which leads to power quality problem in power system. The main critical issue of power quality is harmonics present in power system. This paper introduce proposed filtering method which is belonging to Active power filtering and used adaptive control strategy as compared to traditional filtering method. Because of this proposed methodology harmonics component are suppressed near to non-linear loads the harmonic flow is limited to near the harmonic source, the power quality of the distribution network improved.

Keywords: fully tuned branch, inductively filtered converter transformer, harmonic, power quality.

1. INTRODUCTION

The term power quality is most important term in power system. As day to day non-linear loads are goes on increasing for residential and in industrial application, power quality of system in polluted with harmonics. Thus in order to eliminate harmonics components filtering is only option. For harmonics compensation Active power filter are often used in applications where low current harmonics are desirable. With the use of active power filter, it is possible to draw perfect sinusoidal currents and voltage from grid or renewable distributed power sources. Since active power filter effective solve the power quality problem of public network but cannot provide solution to power supply system connected to network, hence to overcome this problem and improved power quality proposed filtering method is introduce. The fully

tuned branch continuously analysis the change in harmonic components at load side. Fully tuned branch consisting of LC circuit and voltage source inverter, LC circuit is tuned with each harmonics order to be filtered and it's installed in

parallel with non-linear load. This circuit absorbs the harmonics and hence avoiding to flow in distribution network. Two different decoupled current control techniques using adaptive Proportional-integral type controller and hysteresis controller are implemented to force the current of the filter to track their reference value. On other side DC voltage of filter is regulated using Proportional-integral type controller.

2. SYSTEM DEVELOPMENT

The modeling and analysis have been carried out in the MATLAB/SIMULINK environment. Based on the analysis, possible solutions for this problem have been suggested, such as providing passive filters on the secondary wind-ings of the conver ter transformer, connecting a parallel capacitor on the dc side of the converter and R-C snubbers across the secondary windings. The suggested solutions have been compared to bring out the irrelative merits and demerits

2.1 P-Q Theory

The Generalized Theory of the Instantaneous Reactive Power in Three-Phase Circuits, also known as instantaneous power theory, or p-q theory. It is based on instantaneous values in three-phase power systems with or without neutral wire, and is

valid for steady-state or transitory operations, as well as for generic voltage and current waveforms. The p-q theory consists of an algebraic transformation (Clarke transformation) of the three-phase voltages and currents in the *a-b-c* coordinates to the *α-β-0* coordinates, followed by the calculation of the p-q theory instantaneous power components

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \begin{bmatrix} \frac{1}{\sqrt{3}} & 0 & 0 \\ 0 & \frac{2}{\sqrt{3}} & 0 \\ 0 & 0 & \frac{2}{\sqrt{3}} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & 1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

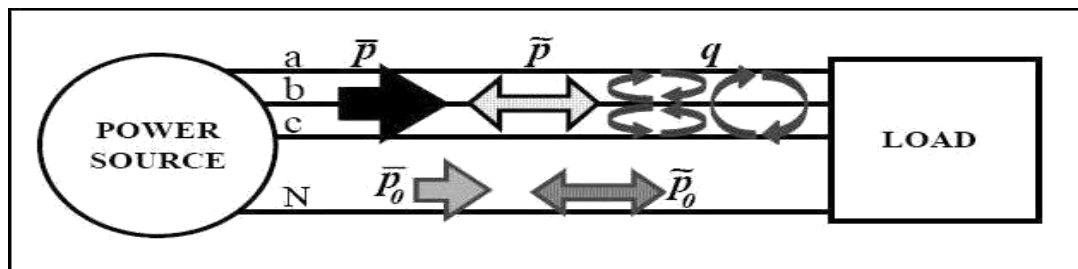


Fig.1-Power components of p-q theory in a-b-c coordinate

\bar{p}_0 =mean value of the instantaneous zero-sequence power–corresponds to the energy per time unity which is transferred from the power supply to the load through the zero-sequence components of voltage and current.

\tilde{p}_0 =alternated value of the instantaneous zero-sequence power– it means the energy per time unity that is exchanged between the power supply and the load through the zero-sequence components.

\bar{P} =mean value of the instantaneous real power–corresponds to the energy per time unity which is transferred from the power supply to the load, through the *a-b-c* coordinates, in a balanced way (it is the desired power component).

\tilde{P} =alternated value of the instantaneous real power. It is the energy per time unity that is exchanged between the power supply and the load, through the *a-b-c* coordinates.

q=instantaneous imaginary power–corresponds to the power that is exchanged between the phases of the load. This components does not imply any transference or exchange of energy between the power supply and the load

= The mean value of the instantaneous imaginary power and is equal to the conventional power

2.1.1 Converter Transformer:

The converter transformer is an integral part of HVDC system. High AC and DC voltages put specific requirement on dielectric insulation. Non sinusoidal current give rise to additional losses, which are to be considered. Winding adopts prolonged-delta wiring. To facilitate our discussion, the winding of *A_i - a_i, B_i - b_i, C_i - c_i* (*i*=1,2) is called a prolonged winding, and the winding of *a1-b1,b1-c1,c1-a1 ,a2-c2,b2-a2,c2-a2* is called common winding. (b) Shows the **transformer's voltage Phasor** diagram, which is used to discuss the phase-shifting of the new transformer. Fig. 2 shows the new converter transformer and the corresponding inductive filtering system, in which, (a) shows the wiring mode of the transformer, and its secondary[1]

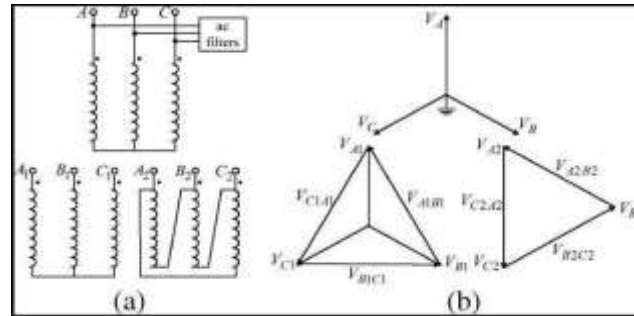


Fig.2.Traditional converter transformer with ac filter
(a) Wiring mode, (b) Voltage Phasor diagram

2.1.2 Inductively active power Filtering Mechanism:-

Usually a converter transformer is generally used in the rectifier/inverter system. Since there is no effective scheme on PQ improvement active on power-electronic side of the transformer, all of the harmonic and the reactive power components flow freely in the windings of transformer, which inevitably leads to a series of problems for the transformer, such as additional losses, temperature increase, vibration, noise& sometimes may lead to system failure. To overcome these problems, an inductive shunt active power filtering method was proposed [3] in recent years. This method can prevent harmonic and reactive power components from flowing in to the primary (grid) winding of the transformer, so it can effectively solve PQ problems of the power-supply system

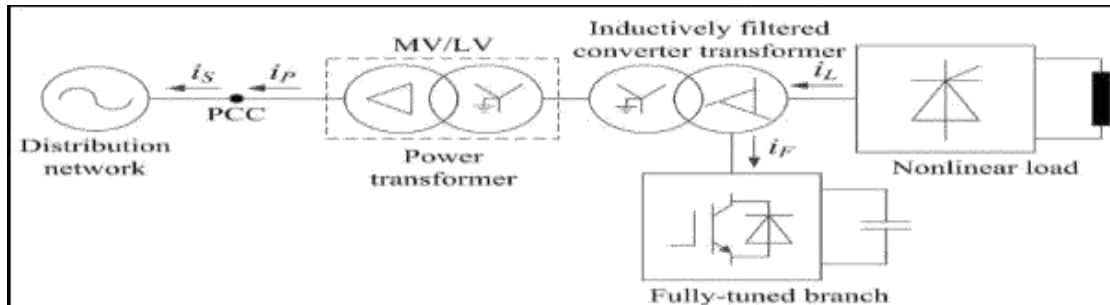


Fig.3 general mode of inductively active filter with converter transformer

In this figure, there is an inductively filtered converter transformer between the nonlinear load and the power transformer. This converter transformer has a special wiring scheme. Its secondary winding adopts extended delta wiring. Between the extended windings and the delta windings, there is a linking point connected to the fully tuned branch. The fully tuned branch is controlled by an inverter, and it can attract almost all of the harmonic components flowing into this branch. Under these conditions, the harmonic magnetic potential is balanced between the extended windings and the delta windings; thus, there are very few harmonic components in the primary winding of the converter transformer. In this way, the harmonic components are suppressed near the nonlinear load (harmonic source).[3]

2.1.3 Mathematical Modeling

According to the theory of multiwinding transformers and combining the equivalent circuit model shown in Fig.5, the voltage equations at the fundamental and the harmonic frequencies can be obtained as follows

$$\begin{cases} V_{Aah} - k^{-1}_{12}V_{Ag h} = -k_{12}I_{Ag h}Z_{h21} - k_{32}I_{abh}Z_{2h} \\ V_{Aah} - k^{-1}_{32}V_{abh} = -k_{32}I_{abh}Z_{h23} - k_{12}I_{Ag h}Z_{2h} \\ V_{Bbh} - k^{-1}_{12}V_{Bg h} = -k_{12}I_{Bg h}Z_{h21} - k_{32}I_{bch}Z_{2h} \\ V_{Bbh} - k^{-1}_{32}V_{bch} = -k_{32}I_{bch}Z_{h23} - k_{12}I_{Bg h}Z_{2h} \\ V_{Cch} - k^{-1}_{12}V_{Cg h} = -k_{12}I_{Cg h}Z_{h21} - k_{32}I_{cah}Z_{2h} \\ V_{Cch} - k^{-1}_{32}V_{cah} = -k_{32}I_{cah}Z_{h23} - k_{12}I_{Cg h}Z_{2h} \end{cases}$$

Where and can be obtained by the short-circuit test, and is calculated based on and (here the superscript means the impedance value is reduced into the side of the secondary extended winding) that is to say h

$$h = h_+ h_- h$$

According to the principle of transformer magnetic potential balance and ignoring very few exciting currents, the current equations at the fundamental and the harmonic frequencies can be obtained as follows:

$$\begin{cases} I_{Abh} + k_{12}I_{Ag} + k_{22}I_{abh} = 0 \\ I_{Bbh} + k_{12}I_{Bg} + k_{22}I_{bch} = 0 \\ I_{Cch} + k_{12}I_{Cg} + k_{22}I_{cch} = 0 \end{cases}$$

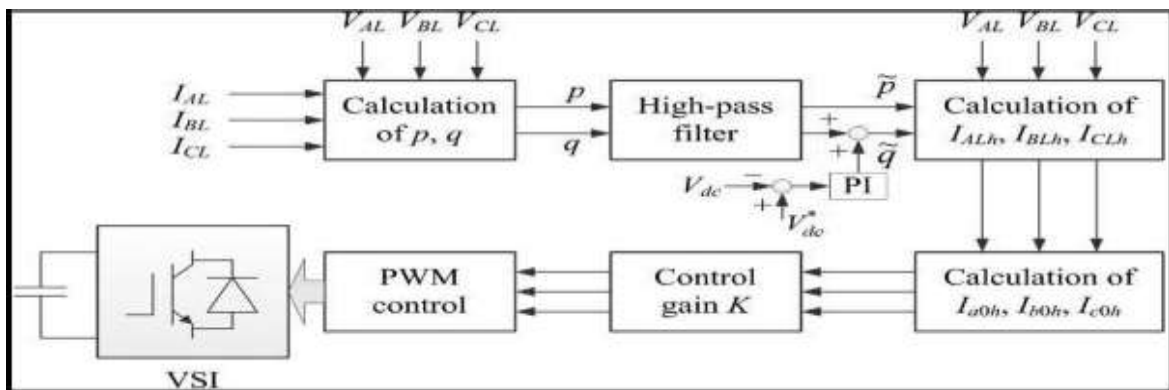
According to **Kirchhoff's current law** (KCL), the following equations can be obtained to illustrate the relationship between the load-side current and the winding current, between the winding current and the fully tuned branch current, respectively, that is

$$\begin{cases} I_{Aah} = I_{ALh} \\ I_{Aah} = I_{abh} + I_{aah} - I_{cah} \\ I_{Bbh} = I_{BLh} \\ I_{Bbh} = I_{bch} + I_{bbh} - I_{abh} \\ I_{Cch} = I_{CLh} \\ I_{Cch} = I_{cah} + I_{cch} - I_{bch} \\ I_{abh} + I_{bch} + I_{cah} = 0 \\ I_{aah} + I_{bbh} + I_{cch} = 0 \end{cases}$$

Where Z_{Ech} , Z_{Fbh} and Z_{Fch} are controlled by the VSI. Above Equations construct the mathematical model for the inductively active power filtered transformer and the FT branch. Based on this model, it is easy to investigate the operating characteristics and the special proposed filtering characteristics.[1]

3. CONTROL STRATEGIES

Unlike the existing traditional active power filter method, in the inductively active power filter method, the control object of the fully tuned branch includes the following parts:



3.1 Calculation of p and q

Based on the detected three-phase voltage (V_{AL} , V_{BL} , and V_{CL}) and current (I_{AL} , I_{BL} , and I_{CL}) at the load side, the instantaneous real and reactive power based on α and β quantities are obtained by using the p-q theory. Generally, the phase voltage at the ac valve side of the converter bridge represents nonsinusoidal; thus, it is difficult to accurately transform the three-phase voltage into the α and β quantities. To overcome this problem, we can measure the voltage at the primary (grid) side of the converter transformer and indirectly obtain the voltage at the load side by using the potential transformer (PT) with the same wiring to the converter transformer, or consider the phase-shift factor of the

converter transformer and indirectly calculate the valve-side voltage by using the grid-side voltage.

3.2 PWM Controller

To control the shunt active filter a PWM logic controller is developed. The difference between the injected current and the reference current determine the modulation wave of the reference voltage. This voltage is compared with two carrying triangular identical waves shifted one from other by a half period of chopping and generate switching pulses

3.3 Calculation of Harmonic Components of the Load-Side Current:

The harmonic components of the load-side current are extracted by p, q, and the load-side voltage (VAL, VBL, and VCL). Besides, the dc voltage of the VSI is controlled by a proportional integral (PI) controller. The output of the PI controller is an additional component to the filtered reactive power at the q-axis.

3.4 Calculation of Harmonic Components Attracted to the FT Branch:

Due to the constraints among the harmonic currents in the secondary extended and delta winding, the harmonic components attracted to the FT branch, that is, the I_{a0h} , I_{b0h} , and I_{c0h} are not shown in fig of control for FT branch from the load side directly.

3.5 Control Gain K:

The calculated currents I_{a0h} , I_{b0h} and I_{c0h} are multiplied by K to generate the current reference for the pulse-width modulation (PWM) of the VSI. The reference is compared with the output of the ac current of the VSI, which is used to produce the PWM waves for the independent current control of the VSI.

3.6 Phase Locked Loop (PLL)

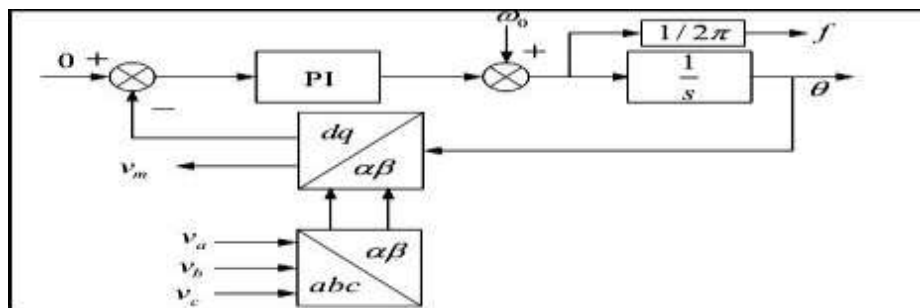


Fig.7. Block diagram of SF-PLL

The basic function of the PLL is a feedback system with a PI-regulator tracking the phase angle. Input is the three phases of the grid voltage and output from the PLL is the phase angle of one of the three phases. In the power supply substation there will be one inverter leg for each of the three phases. There are two alternatives, either assuming the grid voltages are in balance and track only one of the phases and then shift with 120 degree for each of the other two phases or having three PLL system one for each phase. The main advantage of this method is best suitable for harmonic compensation with sinusoidal and non-sinusoidal source voltage. The Fig.7. shows the Block diagram of synchronous frame phase locked loop.

4. SIMULATION RESULTS AND DISCUSSION

In order to validate the theoretical analysis and indicate the filtering performance of the distribution network supply system using the proposed filtering method, both the simulation and the experimental studies on a practical. The simulation model is as shown in fig.8 In the experimental study one part involves the test on the inductive filtering performance, which issued to verify the filtering effect on the public network, and the other part involves the test on the harmonic magnetic flux suppression, which is used to represent the effect of inductive filtering on the rectifier transformer the filtering performance tests as follows

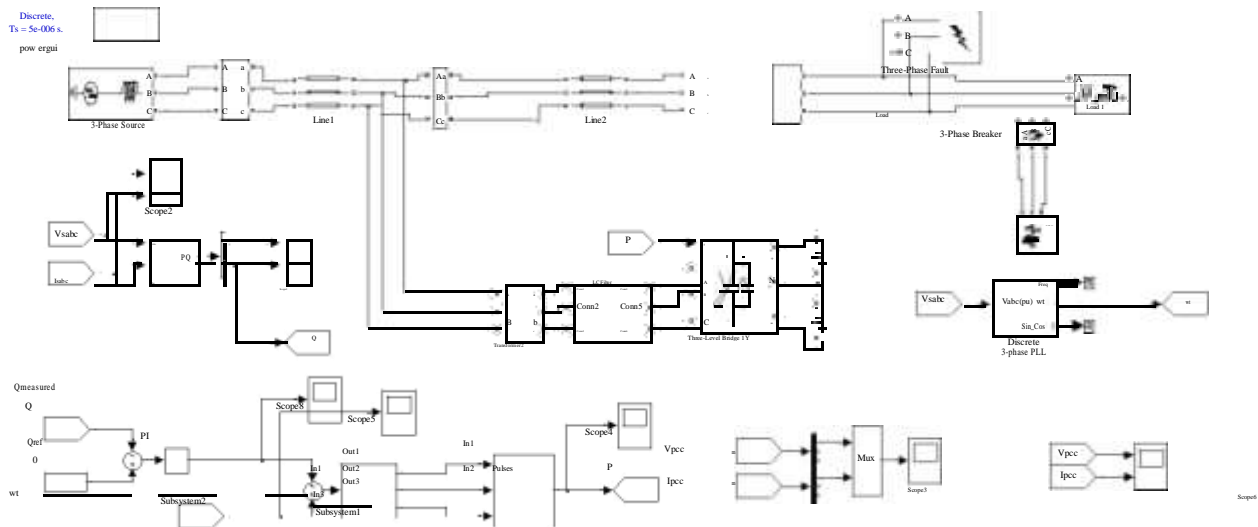


Fig.8.Circuit model for the proposed inductively active power filtering method

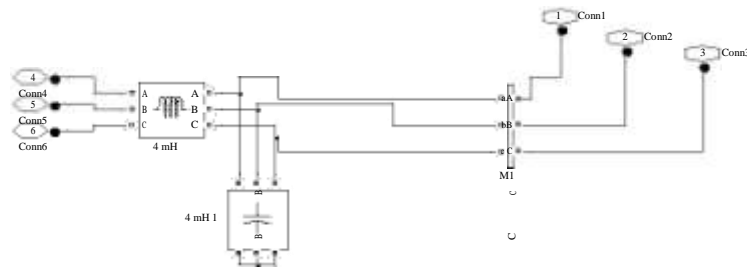


Fig.9.Filter Configuration

In the experimental study one part involves the test on the inductive filtering performance, which issued to verify the filtering effect on the public network, and the other part involves the test on the harmonic magnetic flux suppression, which is used to represent the effect of inductive filtering on the rectifier transformer the filtering performance tests as follows. Comparison between traditional method and IAF Method:-The simulation model is as shown in figure.8.It has the connected with VSC and control circuit has the pulse width modulation

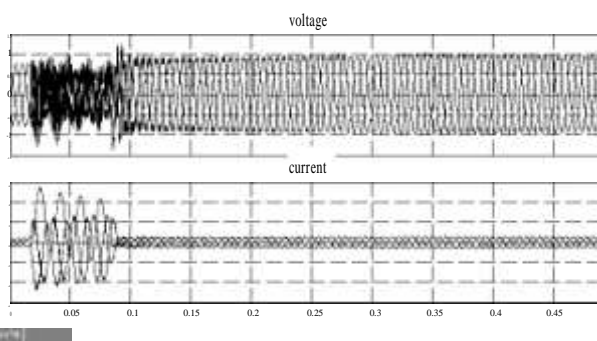


Fig.10.voltage and current with the traditional filtering

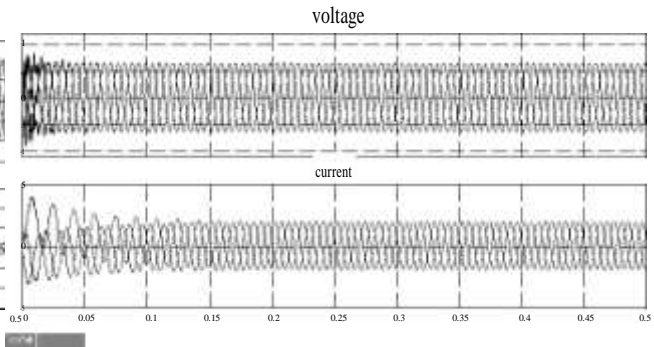


Fig.11.voltage and current with proposed filtering

Fig.10 shows the traditional filtering methods at the load side. When the proposed filtering method is used in the power system. The voltage and current waveforms are as shown in fig.11. We can obviously see that the inductive filtering

method has the better filtering performance than the traditional passive power filtering method. The inductive filtering method can greatly reduce the harmonic content in the grid winding of the converter transformer; however, the traditional passive filtering method cannot get the good filtering performance. From Fig.12 it is seen that the inductive converter transformer filters the harmonic current components caused by then on linear load. This is evident by the reduction of source current THD from 4% to nearly 1.72%.

The THD is the most common indicator to determine the quality of AC waveforms. Using the Fast Fourier Transform (FFT), the harmonic spectrum of the source current under different compensation conditions is presented. Then, the THD comparison is carried out for the simulation results and from the spectra plot, it can be seen that the source current Contains large amount of harmonic current components. (According to IEEE-519 standards the THD limits on the magnitude of harmonic current frequencies should be within 5%)

Frequency (Hz)	THD (%)	Phase (°)
0 Hz (DC)	2.87%	30.0°
3 Hz	4.29%	45.9°
6 Hz	2.74%	26.5°
9 Hz	1.88%	16.2°
12 Hz	1.84%	16.3°
15 Hz	1.25%	10.3°
18 Hz	1.10%	4.0°
21 Hz	0.72%	25.3°
24 Hz	0.70%	11.3°
27 Hz	0.61%	8.3°
30 Hz	0.49%	12.3°
33 Hz	0.44%	6.0°
36 Hz	0.32%	5.4°
39 Hz	0.18%	170.3°
42 Hz	0.66%	0.1°
45 Hz	0.39%	-4.0°
48 Hz	0.16%	-51.7°
51 Hz	1.23%	16.4°

Fig.12. THD load list.

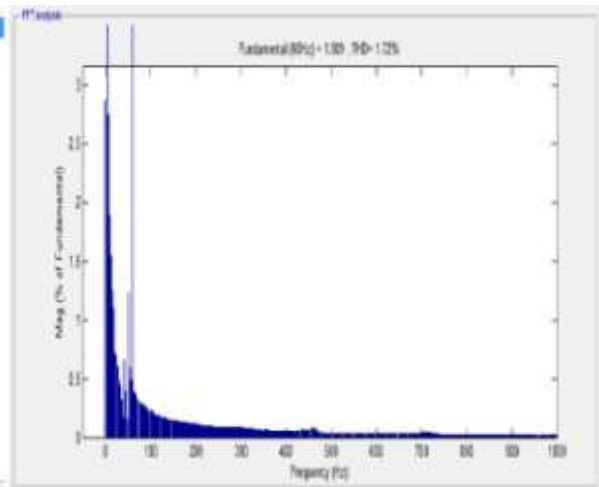


Fig.13 Harmonic spectrum

5. CONCLUSION.

In this paper, Because of this proposed methodology harmonics component are suppressed near to non-linear loads the harmonic flow is limited to near the harmonic source, the power quality of the distribution network improved. using proposed method of Filtering it is possible to improve the power quality of distribution network (public grid) and also the power-supply system (power consumer side) connected with the non-linear loads. The new power filtering method is introduced with the FT branch design, used to create the balance of harmonic magnetic potential in the windings of converter transformer. With the improved THD, it is possible to make the current in grid winding purely sinusoidal using proposed inductively shunt active power filtered method and which more beneficial in upcoming new trend of power system like smart-grid or micro-grid

6. REFERENCES

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