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Power Quality Analysis in Power System with Non Linear Load

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Abstract

Increasing non-linear loads cause various undesirable effects and power quality problems. The use of power converters, electronic equipments and other non-linear loads are rapidly increasing in industry and also by consumers. These equipments draw non-linear currents from the AC mains as compare to traditional loads such as motors and resistive heating elements. This leads to the distortion of power system voltage and current & other problems. Here, the power quality with non linear load is studied and total harmonic distortion (THD) is calculated under this condition by using Fast Fourier Transform (FFT) method. In this paper the power quality is study with non-linear loads such as diode bridge rectifier and arc furnace with the help of IEEE 9 bus system by changing the load at various buses. Total harmonic distortions (THDs) observed in every case is record for power quality that is for harmonics present in the current and voltage at all the buses. The power quality analysis is studied under steady state only. Also various mitigation techniques for these harmonics such as various filters and various FACTS (flexible AC transmission system) devices are discussed for future scope.

Keywords: Non linear load, Linear load, Total Harmonic Distortion (THD), Fast Fourier Transform (FFT).

I. INTRODUCTION

Power quality is nowadays, a major topic in the electric-power generation, distribution, and user areas. The main objective of the electric utility is to deliver sinusoidal voltage at fairly constant magnitude throughout the system. But, this is not an easy task for any power system to provide the pure power without any harmonics or distortion to the consumer level continuously without any interruption as there are various non linear loads at the consumer level which produces the harmonics current in the power system. These currents result in distorted voltages and currents that can directly impact the system performance in different ways. As the number of harmonic producing loads has increased over the years, it has become increasingly necessary to address of harmonic- current producing loads (non-linear loads). To fully study the impact of these phenomena, there are two important concepts to bear in mind with regard to power system harmonics. The first is the nature on the system that produce harmonic currents and the second is the way in which harmonic currents flow and how the resulting harmonic voltages develop. The uses of nonlinear loads connected to electric power systems include static power converters, arc discharge devices, saturated magnetic devices, and, to a lesser degree, rotating machines. Static power converters of electric power are the largest nonlinear loads and are used in industry for a variety of purposes, such as electrochemical power supplies, adjustable speed drives, and uninterruptible power supplies. These devices are useful because they can convert ac to dc, dc to dc, dc to ac, and ac to ac. Nonlinear loads change the sinusoidal nature of the ac power current (and consequently the ac voltage drop), thereby resulting in the flow of harmonic currents in the ac power system that can cause interference with communication circuits and other types of equipment. When reactive power compensation, in the form of power factor improvement capacitors, is used with these nonlinear loads, resonant conditions can occur that may result in high levels of harmonic voltage and current distortion when the resonance condition occurs at a harmonic associated with nonlinear loads.

Harmonics is one of the major power quality problems in industrial and commercial power system. A harmonic of an electrical signal is defined as the content of signal whose frequency is an integral multiple of the fundamental frequency. IEEE Standard 519 Harmonics is defined as “a sinusoidal component of a periodic wave or quantity having a frequency that is an integer multiple of the fundamental frequency”. Harmonic analysis is the process of calculating the magnitudes and phases of the fundamental and higher order harmonics of the power system.

Fast Fourier Transform (FFT) calculation method determines the total harmonic distortion (THD) contained within a nonlinear current or voltage waveform. Total harmonic distortions can be related to either current harmonics or voltage harmonics, and it is defined as the ratio of total harmonics to the value at fundamental frequency times 100%.

Formula for total harmonic distortion (THD) in current and voltage is given as follows:-

$$THD_I = \frac{\sqrt{\sum_{k=2}^{n} I_k^2}}{I_1} * 100\% = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + ...I_n^2}}{I_1} * 100\%$$

$$THD_V = \frac{\sqrt{\sum_{k=2}^{n} V_k^2}}{V_1} * 100\% = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + ...V_n^2}}{V_1} * 100\%$$

Where,

I_n =RMS current of nth harmonic

V_n =RMS voltage of n^{th} harmonic

n = 1 at the fundamental frequency

If the fundamental frequency is n, then the harmonics have frequency n,2n,3n,4n,5n……Even harmonics are 2n,4n,6n,8n,10n…and odd harmonics are n,3n,5n,7n,9n,11n... Generally even harmonics get cancelled because of their symmetrical nature, but odd harmonics should be eliminated by some filtering or compensation techniques.

II. EFFECTS OF HARMONICS

When a nonlinear load draws distorted (non-sinusoidal) current from the supply, this distorted current passes through all of the impedance between the load and power source. The associated harmonic currents passing through the system impedance cause voltage drops for each harmonic frequency. The vector sum of all the individual voltage drops results in total voltage distortion, the magnitude of which depends on the system impedance, available system fault current levels and the levels of harmonic currents at each harmonic frequency.

- High fault current (stiff system)
  - Distribution system impedance and distortion is low
  - Harmonic current draw is high
- Low fault current (soft system)
  - Distribution system impedance and distortion is high
  - Harmonic current draw is low

Harmonics have deleterious effects on electrical equipment. These can be itemized as follows:

- Capacitor bank failure because of reactive power overload, resonance, and harmonic amplification.
- Excessive losses, heating, harmonic torques, and oscillations in induction and synchronous machines, which may give rise to torsional stresses.
- Increase in negative sequence current loading of synchronous generators, endangering the rotor circuit and windings.
- Generation of harmonic fluxes and increase in flux density in transformers, eddy current heating and consequent de-rating.
- Overvoltage and excessive currents in the power system, resulting from resonance.
- De-rating of cables due to additional eddy current heating and skin effect losses.
- Inductive interference with telecommunication circuits.
- Signal interference and relay malfunctions, particularly in solid state and microprocessor controlled systems.
- Interference with ripple control and power line carrier systems, causing misoperation of the systems, which accomplish remote switching, load control, and metering.
- Unstable operation of firing circuits based on zero voltage crossing detection and latching.
- Interference with large motor controllers and power plant excitation systems.

III. HARMONICS BECAUSE OF LINEAR LOAD

Fig.1 shows the IEEE 9 bus system for power quality analysis with three machine 9 bus system. As shown in the single line diagram there are three loads in the system which is at bus 5, bus 6 and at bus 8.

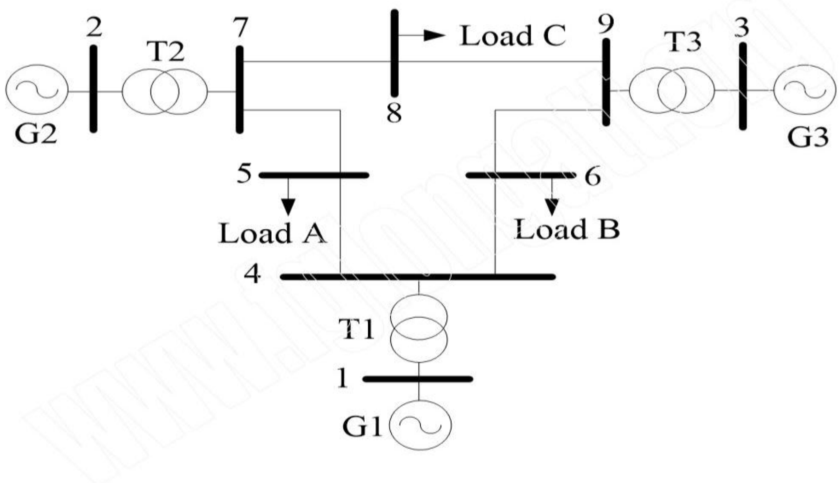

Fig.1. Single line diagram of IEEE 9 bus system

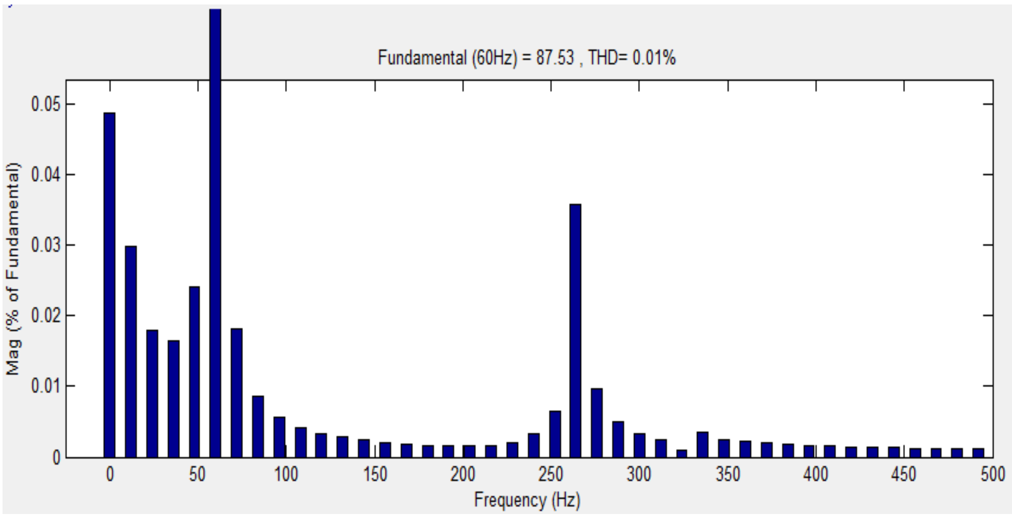

Fig.2. FFT analysis results with linear load

Figure 2 shows the FFT analysis result with linear load when connected to IEEE 9 bus system the total harmonic distortion becomes 0.01%. It shows that with the linear load the distortion present in the system is very less as current varies proportional to the voltage.

Here, in this case three phase series RLC load is considered as a linear load as in case of three phase series RLC load current varies linearly with the voltage. Here the THD is calculated at the voltage at bus 6. This results show that the total harmonic distortions present in the line voltage is very less means negligible in case of linear load.

IV. HARMONICS BECAUSE OF NON-LINEAR LOAD

Harmonics are one of the major power quality concerns. Harmonics cause distortions of the voltage and current waveforms, which have adverse effects on electrical equipment. Some examples of nonlinear loads are:

- Electric arc furnace
- Adjustable drive systems
- Rectifiers
- Switching mode power supplies
- Computers, copy machines, and television sets
- Static var compensators (SVCs)
- HVDC transmission
- Electric traction
- Wind and solar power generation
- Battery charging and fuel cells

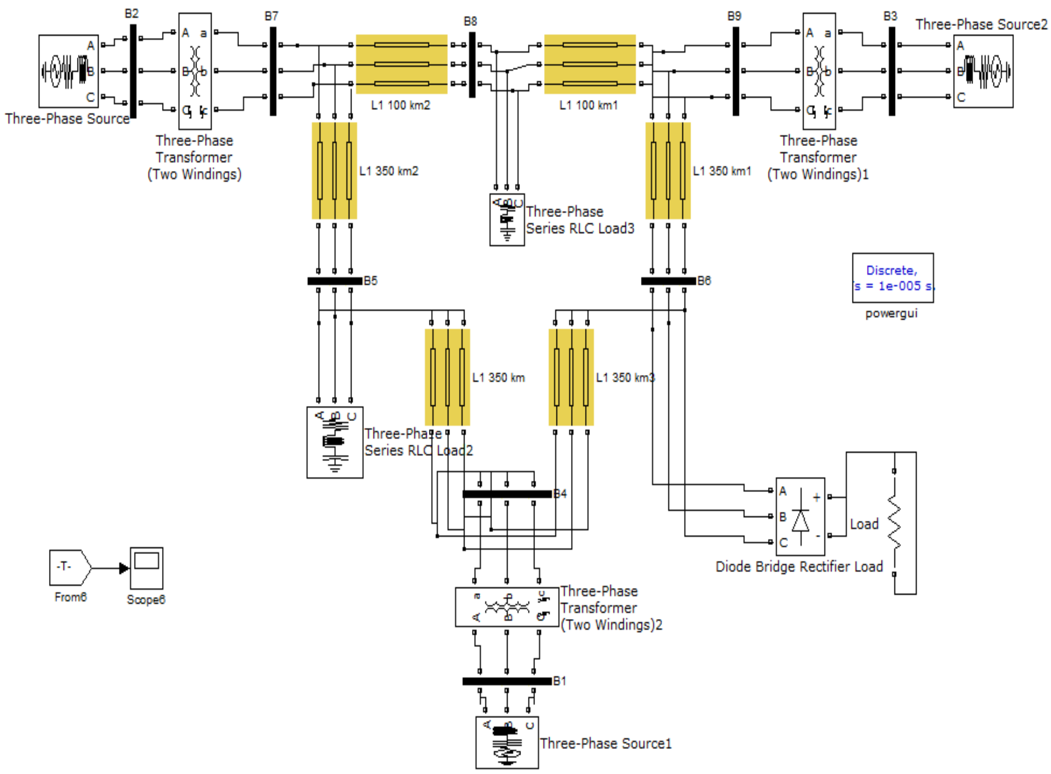

Fig.3 IEEE 9 bus system with non linear load

Fig.3 shows the IEEE 9 bus system with non linear load connected at bus 6. In this paper, study of power quality is done by the linear load diode bridge rectifier and electric arc furnace at steady state.

VOLTAGE-CURRENT (VI) Characteristics of Non linear loads:-

Voltage current characteristics with diode bridge rectifier and electric arc furnace are shown in the fig.4. and fig.5. which shows clearly that with non linear load, current does not follow the linear relationship with the voltage.

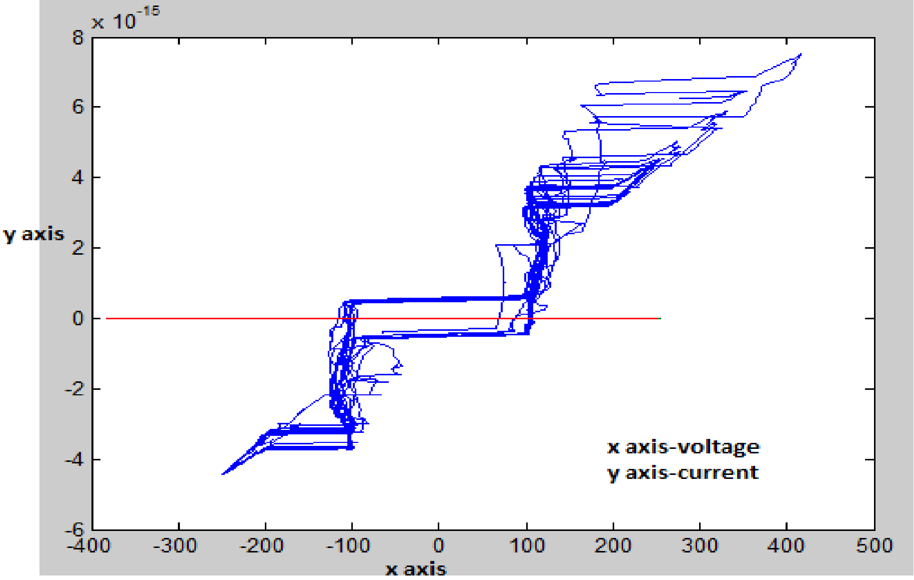

Fig.4.VI characteristics of diode bridge rectifier

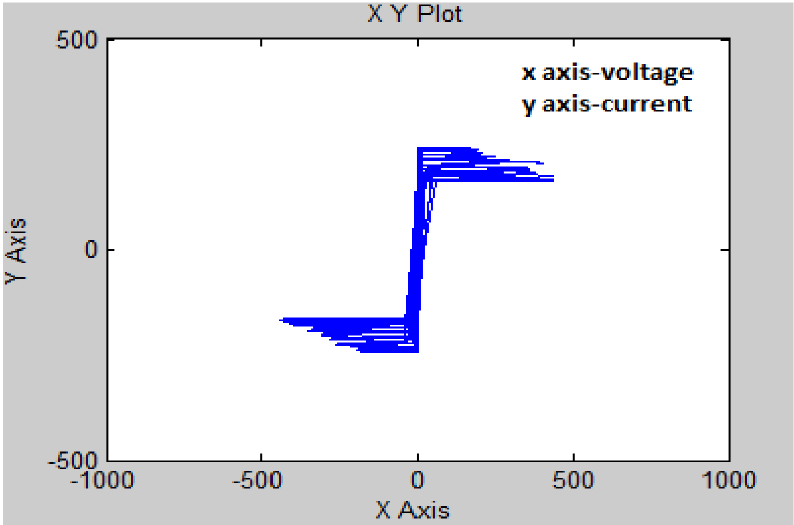

Fig.5.VI characteristics of electric arc furnace (EAF)

Total Harmonic Distortion (THD) analysis for non linear load:-

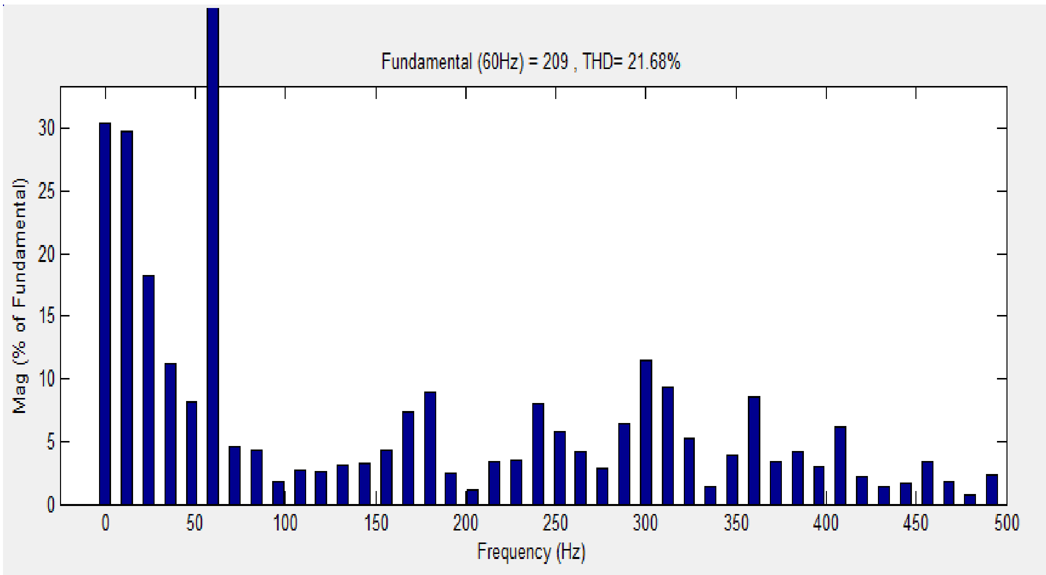

Fig.6. FFT analysis results with diode bridge rectifier

FFT analysis results with diode bridge rectifier and electric arc furnace is shown in the fig.6.and fig.7.

Here, the study of harmonics with non linear load is done when the load is connected in the IEEE 9 bus system. The diode bridge rectifier as non linear load is connected at the bus 6and after that FFT analysis is done for power quality analysis. The result with the diode bridge rectifier is shown in the form of FFT analysis in fig.4. It is found that with the diode bridge rectifier which is non linear load total harmonic distortion founds to be more i.e. 21.68%. DC components present in the voltage are 30.36%. Hence from the fig.4 it is clear that the numbers of harmonic present in the system are more and the power quality gets reduced because of diode bridge rectifier.

As we know all the industries demands more power from the generating companies or from other utility as every industry have to supply various load at its terminal. In many industries electric arc furnace causes more power quality problems. It produces non linear current in the supply system because of that the power quality of the whole electrical system gets reduced. Hence, the problem with power quality because of electric arc furnace is studied and the total harmonic distortion (THD) is observed with the help of FFT analysis.

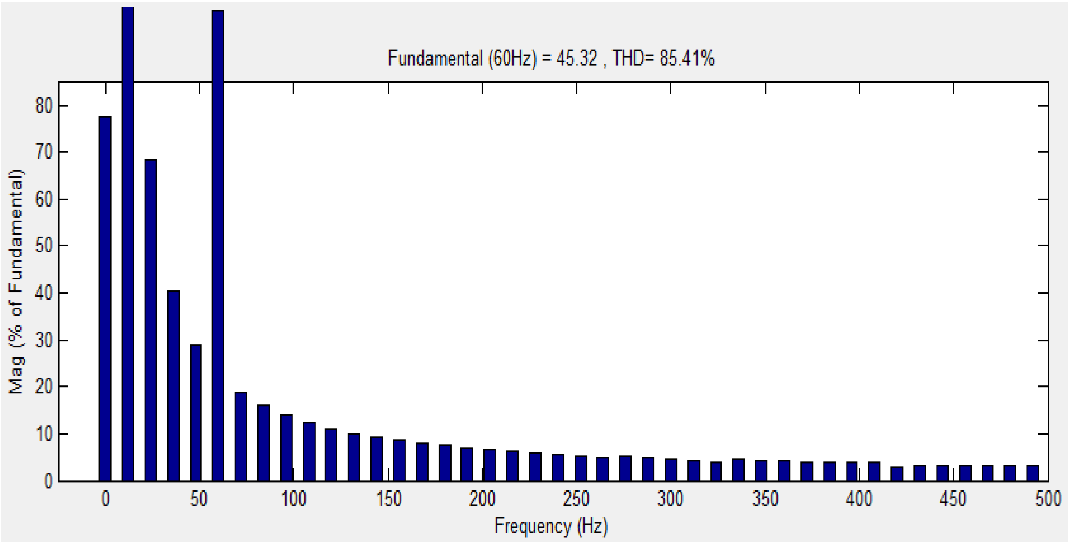

Fig.7. FFT analysis results with electric arc furnace

Arc furnace is connected at the bus 6 and above results Obtain as shown in fig.5. From the above FFT graph it is clear that the total harmonic distortion (THD) gets increased because of the arc furnace. THD measured is 85.41% in this case and the DC component present in the voltage is 73.33%. Which shows that because of the electric arc furnace total harmonic distortions in the system voltage gets increased.

TABLE I: INDIVIDUAL HARMONIC DISTORTION (IHD) FOR DIODE BRIDGE RECTIFIER AT BUS 6:

Harmonics	Frequency in Hz	Voltage IHD in %
DC component	0	30.66
Fundamental	60	100
2nd Harmonic	120	2.64
3rd Harmonic	180	8.88
4th Harmonic	240	8.07
5th Harmonic	300	11.49
6th Harmonic	360	8.51
7th Harmonic	420	2.15
8th Harmonic	480	0.77

TABLE II: INDIVIDUAL HARMONIC DISTORTION (IHD) FOR ELECTRIC ARC FURNACE AT BUS 6:

Harmonics	Frequency in Hz	Voltage IHD in %
DC component	0	73.33
Fundamental	60	100
2^{nd} Harmonic	120	11.13
3^{rd} Harmonic	180	7.45
4^{th} Harmonic	240	5.64
5^{th} Harmonic	300	4.61
6^{th} Harmonic	360	4.08
7^{th} Harmonic	420	2.99
8^{th} Harmonic	480	3.14

TABLE III: TOTAL HARMONIC DISTORTION OF VARIOUS LOADS AT BUS 6:

LOAD	THD (%)
1) Linear Load	0.01
2) Diode Bridge Rectifier	21.68
3) Electric Arc Furnace	85.41

From the above table 3 of total harmonic distortion in case of linear load are negligible but in case of non linear load diode bridge rectifier and electric arc furnace are observed to be 21.68 % and 85.41%. This shows that in case of electric arc furnace power quality gets reduced to very large extent.

V. FUTURE SCOPE

Harmonic Mitigation Techniques:-

Several different solutions are proposed for harmonic mitigation. The right choice is always dependent on a variety of factors, such as the activity sector, the applicable standards, and power levels. Several solutions are relative to Variable Speed Drives, as this type of electrical equipment represents a large part of the installed power in industrial installations and the most significant power harmonic current generators.

A. AC-Line or DC-link Chokes for Drives

They are commonly used up to about 500kW unit power or 1,000kW total drives power. Depending on the transformer size and cabling, the resulting THD will be ~5%, which is usually well accepted in industrial networks.

B. Multi-pulse arrangement

This solution includes a dedicated transformer directly supplied from the MV network. Standard is the use of a 3-winding transformer providing a 12-pulse supply for one or multiple rectifiers or drives. This limits the power harmonic emission considerably and usually no further mitigation is necessary. Besides, multi-pulse solutions are the most efficient in terms of power losses. This is usually used for drives above 400 kW, but could also be reasonable for smaller power ratings.

C. Active Front End (AFE)

An Active Front End is a sophisticated electronic circuit connected on the supply side of a Variable Speed Drive. This is the best performing solution concerning harmonic mitigation, limiting the THD below 5%. All the applicable standard requirements can be met. No detailed system evaluation is necessary, making this solution the easiest to implement.

D. Passive Filter

A passive filter consists of reactors and capacitors set up in a resonant circuit configuration, tuned to the frequency of the power harmonic order to be eliminated. A system may be composed of a number of filters to eliminate several harmonic orders.

E. Active Filter

Active filters are special equipments that use power electronic converters to compensate for current and/or voltage harmonics originated by non-linear loads, or to avoid that harmonic voltages might be applied to sensitive loads.

F. Hybrid Filter

A hybrid filter is a combination of a passive filter and an active filter in a single unit. Among them, tuned filter is used to reduce harmonics in line current of nonlinear. It is necessary to consider between reliability and economic.

H. FACTS Devices

A flexible alternating current transmission system (FACTS) is a system composed of static equipment used for the AC transmission of electrical energy. It is meant to enhance controllability and increase power transfer capability of the network. It is generally a power electronics-based system.

Types of compensation:-

Shunt compensation:-

In shunt compensation, power system is connected in shunt (parallel) with the FACTS. It works as a controllable current source.

Shunt compensation are of two types:

1) Shunt capacitive compensation

2) Shunt inductive compensation

Examples of shunt compensation:-

- Static synchronous compensator (STATCOM);

Previously was known as a static condenser (STATCON).

- Static Var Compensator (SVC).

Series compensation:-

Series compensation is a well established technology that is primarily used to reduce transfer reactance, most notably in bulk transmission corridors. The result is a significant increase in the transient and voltage stability in transmission systems.

Examples of series compensation are:-

- Static synchronous series compensator(SSSC)
- Thyristor-controlled series capacitor (TCSC
- Thyristor-controlled series reactor (TCSR)
- Thyristor-switched series capacitor (TSSC)
- Thyristor-switched series reactor (TSSR)

VI. CONCLUSIONS

From the above results it can be concluded that power quality in the power system gets reduced only because of the no linear load. Electric arc furnace which is the mostly use non linear load in many industries cause more harmonics and hence power quality gets reduce because of electric arc furnace. Hence, there is a need to improve the power quality which gets reduced because of the electric arc furnace in the industries.

REFERENCES

[1] Mustafa Şeker, Arif Memmedov, “Investigation of Voltage Quality in Electric Arc Furnace with Matlab/Simulink ”, International Journal of Engineering and Technical Research (IJETR) ISSN: 2321-0869, Volume-2, Issue-11, November 2014, pp 274-284

[2] Rafael Collantes-Bellido, Tomas Gomez, “Identification and modelling of a Three Phase Arc Furnace for Voltage Disturbance Simulation.”, IEEE Transactions on Power Delivery, Vol. 12, No. 4, October 1997, pp 1812-1817

[3] Prakash Chittora, Alka Singh, Madhusudan Singh, “Modeling and Analysis of Power Quality Problems in Electric Arc Furnace”, IEEE INDICON 2015 1570188809

[4] K. R. Padiyar, “FACTS controllers in power transmission and distribution”, new age international publishers,pp 173-177

[5] Prabha Kundur,“Power System Stability And Control”, TATA McGRAW-HILL EDITION, pp 335

[6] Wakileh, George J “Power systems harmonics: fundamentals, analysis, and filter design.” Springer, Berlin ; New York, 2001

[7] Mehjabeen A. Khan, Akeed A. Pavel, M. Rezwan Khan and M. A. Choudhury, “Design of a single phase rectifier with switching on AC side for high power factor and low total harmonic distortion”, IEEE Region 5 Technical Conference, April 20-21, Fayetteville, AR, 2007