Outcomes of Harmonics & Its Reduction Techniques: A Comprehensive Review

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Abstract- This paper describes that concept of harmonics in the power systems and explains the different methods to reduce the harmonics problems. In the power system due to use of highly nonlinear devices harmonics are generated and it reduce the performance of the power systems. Thus it is necessary to examine and evaluate the different harmonic problems in the power system and introduce the suitable solution techniques. This paper firstly examine the propagation of harmonic current and voltage in the power system network and appreciate their consequences on both utility system equipments and end user components. Throughout the examine of harmonic wave forms and idea about cancellation, effective methods have been introduced by the application of filter. Base on harmonic distortion the filter has been designed and added to the panels to degrade the harmonic distortion.

Keyword- Harmonic, Displacement Power Factor (DPF), Transformer Phase Shifting, Harmonic distortion

I. INTRODUCTION

In generally, when we consider the Power System at that time AC is introduce. In Power System, the voltage forcing that current through the load circuit is explain in term of frequency and amplitude. In Ac Power System Harmonic component is defined as a sinusoidal component of a alternate waveform that has a frequency equal to an integer multiple of the fundamental frequency of the system [1].

Total Harmonic distortion is the addition of all harmonic frequency current to fundamental when harmonic are the multiple fundamental frequency [2]. If we consider, Harmonics in voltage and current waveforms than be create as better sinusoidal components of frequencies multiple of fundamental frequency:

Fh = (h) * (fundamental frequency)

Where h is integer. So if we consider first harmonics of system will be cosine with the line frequency. Now we talk about the 3rd harmonics component is given by above equation for the system having 50 Hz frequency[3]

F3 = 3 * 50 = 150 Hz

Similarly for fifth and seventh harmonics equation are:

F5 = 5 * 50 = 250 Hz

F7 = 7 * 50 = 350 Hz

Power System harmonic analysis is to consider the effect of harmonic creating load on power system [3]. Harmonic analysis has been broadly used for planning of system, criteria development of operation, design of equipment, trouble shooting and so on. Harmonic current are current in modern electrical distribution system originate from non-linear load such as ASD (Adjustable Speed Drive), electronics lighting, computers and much of the telephonic component use in the modern offices. Waveform level in distribution networks, the application of capacitor banks used in plants for correction of power factor and increasing voltage profile by power utilizes onward distribution lines.

Cause of single phase electronic loads, Harmonics at all odd multiples of fundamental but the very dangerous of these are generally the triple harmonics that have frequencies multiples of the third harmonic: triple and well-balance, in the neutral on the secondary side of a delta-wye transformer and cause very high neutral currents drawn in secondary side. In conventional transformer triple harmonic are generated in primary winding causing excessive losses in the transformer.

Triple harmonic de not generate in three-phase load. As a result harmonic problem in Industrial by three-phase load will very often cause from current flowing at the 5th ,7th ,11th ,17th …. etc. order harmonic. The most leading cause of distortion and heating problem in the three-phase power distribution by 5th & 7th harmonic [4].

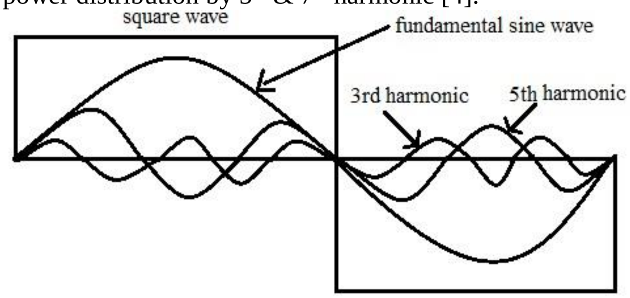

Figure 1. Relation between 3rd 5th and 7th harmonic

II. EFFECTS OF LOADS IN POWER SYSTEM

In the system Harmonics are basically introduce due to type of load. Power systems have basically two types of loads, first one is linear load and another one is Non-linear load. In up to 1980's, It has been seen that the load are of linear load type. The different type of load is given as non-linear load which has different waveform than the supply waveform the simple example is switch mode power supply (SMPS). In recent year all type of load is non-linear and they produce harmonic.

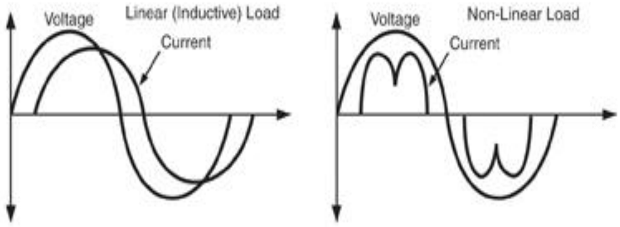

Figure 2. Linear Load and Non-Linear Load waveform

Table 1.1 Comparisons of Linear Load and Non-Linear Load

Linear Load	Non-Linear Load
Ohm's law applicable	Ohm's law is not applicable
$\text{Crest Factor} = \frac{1\ \text{Peak}}{1\ \text{RMS}}$ Is value √2=1.41	Crest Factor is 3 to 4
$\text{Power Factor} = \frac{\text{Watts}}{V \times I} = cos\emptyset$	$\text{Power Factor} = \frac{\text{Watts}}{V \times I} \neq cos\Phi$ =Displacement factor *Distortion factor
Load current does not contain harmonics	Load current contain all odd harmonics
It could be inductive or capacitive	It can't be classified. It's load leading or lagging
It's equipment with resistive, inductive or capacitive	Usually, it's equipment with diode and capacitor
Linear load mains zero neutral current if 1 Ph. Loads are equally balance on 3Ph.	Non-linear load mains neutral current could be 2.7 times line current 1 Ph. Loads are equally balance on 3Ph.
May not demand high inrush current while starting	In generally approx. very high inrush current (1 normal times to 20 times) is drawn while starting.

Linear load are those voltage and current signal come after one another vary nearly, such as the voltage drop that create across a constant resistance, which change as a direct function of the current that passes through it.

Linear Load:

Table 1.2 Example of Linear load

Resistive Element	Inductive Element	Capacitive Element
•Electric heaters • Incandescent lighting	• Induction Generators (wind mills) •Induction motors • Current limiting reactors	• Insulated cables •Power factor correction capacitor banks •Underground cables • Capacitors used in harmonic filters

This cosine is better known as Ohm's law and states that the current pass through a resistance deliver by a changing voltage source is equal to the cosine between the voltage and resistance, as describe by:

I = V/ R

From this equation, voltage and current waveform is linear in electrical circuit. Therefore, no distortion if we consider the source is clean open circuit voltage. Circuit of the power system is linear load thus make it easy calculate voltage waveform and current waveform. Even the amount of heat generated by resistive, linear load using heating elements can easily be calculate because they are promotional to square of the current.

Other linear loads, such as driving fans of electrical motors, pump of water, pump of oil, cranes, elevators, etc. not supplied power similar as power conventional devices such as ASD or any other inversion of current will absorb magnetic core losses learn on iron and copper physical characteristics. Voltage and current deformation may be generated on secondary part, cause that can be reached for instance when component is operated above rated values.

Voltage and current including inductor make voltage lead current and circuit that accommodate power factor capacitor also make current lead voltage. Therefore in both statement, the two waveforms will another. As a result, no waveform distortion will take place.

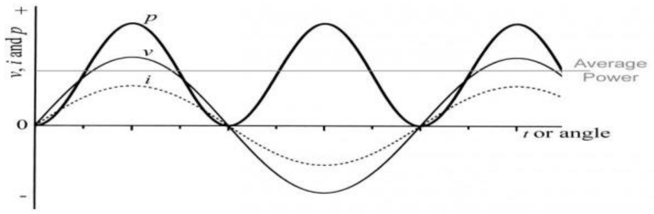

Figure 3. Relation among voltage, current, and power in a purely resistive circuit

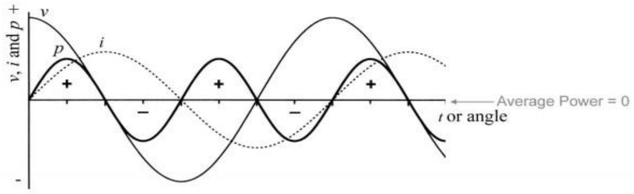

Figure 4. Current *I lags the voltage V (inductive circuit)*

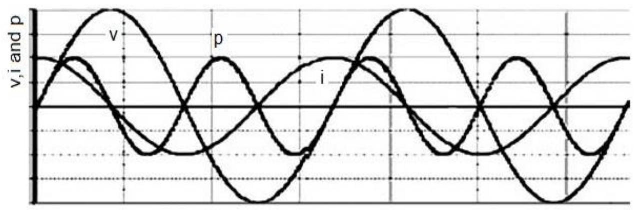

Figure 5. Current *I leads the voltage V (capacitive circuit)*

In the different type of linear load such as Resistive, Inductive and Capacitive load show the above fig. it is clear that there are no harmonic distortion in the voltage and current waveform.

Non-Linear Load:

Table 1.3:- Example of Non-Linear Load

Power Electronics	ARC devices
• Battery chargers • Inverters • Power converters • Variable frequency drives • Power supplies • UPS	• Welding machines • Fluorescent lighting • ARC furnaces

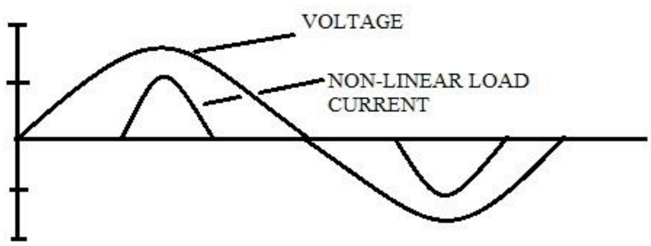

Figure 6. Non-Linear Load waveform

Non-Linear load which the current waveform does not correspond the applied voltage waveform due to many of resonance. For example, the use of electronic switches handling load current only during of piece of power frequency period. Therefore, we cannot apply Ohm's law to the non-linear load. Among the most accepted non-linear load in power system are all types of rectifying devices to power converter, source of power, UPS, and electrical arc furnace and fluorescent lamp.

III. CAUSES OF HARMONIC IN POWER SYSTEM

The supply voltage is sinusoidal, even the characteristic behavior of non-linear load is that they draw distorted current waveform. Most electrical component only generate odd harmonics [5][6]. For each devices, changes due to the consumption of the active power, background voltage distortion and varies in the source impedance due to the current distortion.

In general most common types of causes in single and three phases are non-linear load for residential and industrial uses are given bellow:

A. Loads of Single Phase

In the power system, component of electronics devices supplied from the low voltage, at different DC voltage level for electronic component rectifier is used to convert ac power to dc power for internal use. Such as equipment's made of:

- Computer, CD/DVD player, recorder
- Digital microwave ovens, Printers
- Electronics lighting, ASD (Adjustable Speed Drive)

B. Loads of Three-Phase

High power application three phase rectifiers are used. In basically rectifiers are controlled or non-controlled and subsist of in the majority cases of a capacitor for the lower power application. Smoothing of inductor and capacitor larger rectifiers are used. Mostly in industrial application and in the power system three phase group is used. Some equipment's are:

- SVC's
- Arc furnaces, Large UPS's, Adjustable Speed Drive

C. Harmonics created by Transformer

In the transformer core saturated condition can either following two cases:

1. When transformer operating above rated power
2. When transformer operating above rated voltage

In the power system harmonics are also bulkily produce by transformer. Structure of transformer is generally to make optimum use of magnetic core materials, resulting in maximum magnetic flux density in its steady state. Causes of saturation with such maximum operating magnetic flux design when the core materials may be subjected to a large magnetic flux density. As a result converter transformer core is saturation; the magnetizing current has all the odd harmonics. However delta winding of transformer is used to absorb the triplen harmonics.

D. Harmonics created by Rotating Machine

In practical and economical design of electrical machines are also main harmonic generated in power system. In rotating machine magneto motive force (mmf) generating a torque components of different frequencies, when mmf induced by positive and negative sequence harmonics combine with the nominal frequency. In rotating machine space harmonics are created by imperfection of the distribution of windings. Another source of the harmonics produce in power system is magnetic saturation in these machines.

E. Harmonics generated by Power Converter

The most extensive source of harmonics in distribution systems are the increasing use of the power conditioners in which parameters like voltage and frequency are changed to adapt to specific industrial and commercial process has made power converters. Ac into DC power electronic switching helps the task to rectify 50 Hz or 60 Hz converters can be classified into the following categories:

- Large Power Converters - It is used in metal industry and also used in high voltage DC (HVDC) transmission systems.
- .Medium Size Power Converters - It is used in speed control of motor manufacturing industry and in the railway industry.
- Small Size Power Converters - It is used in entertaining device of residential, including radio, TV sets and Personal Computer. Another example is Battery Chargers.

1. Electrical Arc Furnaces

Generate substantial amounts of harmonics distortion when the melting process in industrial electric furnaces use. Consider of fundamental frequency harmonics generate from a combination of the delay I the disturbance of the electric arc along with it highly nonlinear voltage-current character.

IV. OUTCOMES OF HARMONIC IN POWER SYSTEM

After causes of harmonics are clearly identified, their effects on power system and different network can be studies.

1.*OUTCOME OF POWER FACTOR*

In Power distribution system, power factor is a scope of the efficiency of utilization. If we consider a powering system of linear load, the power factor is called displacement power factor (DPF). Recent year, many electrical systems have harmonic currents on their lines. Sources of harmonic by non-linear and current sources are the apparent power to exceed the active and reactive powers by a substantial amount. In non-linear load apparent power can be calculated using the equation

$$KVA = \sqrt{(Q^2 + P^2 + \mathrm{DVA}^2)}$$

Where Q and P are the reactive and active power correlating to the basic component and where DVA is the distorted voltage ampere that corresponds to the other components.

Increases the current of harmonics the apparent power that must be delivered, therefore lowering power factor. In this case, the arrangement of power factor is called distortion power factor. True power factor (TPF) is a sum of cosine of both displacement angle and distortion in a power system consider linear and non-linear loads, if harmonic current under the displacement power factor.

2.*OUTCOME OF PARALLEL AND SERIES CIRCUITS*

In power systems resonances at some harmonic frequencies can occur, such as the resonance between capacitor and different components. The dangerously increase the loss of system devices by harmonic resonances cause over voltage and excessive currents that can damage them. Caused of the large current by harmonic resonances, for situation, can flow into power factor correction capacitor banks and damage their dielectric materials. System components can over voltage; insulation materials life is reduce and often lead to their destruction.

3.*OUTCOME OF ROTATING MACHINES*

In the Power system harmonics are produce losses in rotating machines. These losses arise in their stator winding, circuits of rotor, and stator and rotor cores. Basically, the effects mainly are created by low order harmonics with large magnitudes. Harmonic currents in stator and rotor end winding generate the additional losses due to leakage fields set up. More harmonic contents in induction machine can reduce their output torque at rated speed and effects of these machines are vibrating.

4.*OUTCOME OF RIPPLE CONTROL SYSTEMS*

Operate street lighting circuits and to decrease loads during maximum hours of a day at that time ripple control system is used. The harmonic distortion of ripple control system can cause the malfunction of a relay switch used to protect the lighting circuit if the distortion is significant. If a ripple relay switch is basically a voltage operated device that has high voltage impedance. Operation of the relay switch base on voltage harmonics, the relay switch is disclosure circuit and different between reference frequency and frequencies of distorting harmonics.

5.*OUTCOME OF PROTECTIVE RELAYS*

Since harmonic change the wave forms of voltage and current, it can distort the starting characteristics principal and design. Protection instruments have different features However, protective relay operate base on power system states. Modern relays that rely on sampled data therefore, be prone to error when harmonic is present. Their protective functions are generally developed base on fundamental current and voltage and any harmonics in fault wave forms are either filter out or neglected. In other words, harmonics are not appropriate into account in relay protection settings. As the result, the attendance of harmonics in power system can base on considerable measurement errors in the protective relay.

6.*OUTCOME OF CONSUMER EQIPMENTS*

Consider consumer loads, power system harmonics also affect the operation such as TV (television) set, mercury arc lightings and fluorescent lightings and converter equipment. Effect of harmonics it changes in television picture size and brightness. In fluorescent and mercury lightings they also introduce the resonances between the capacitances and inductances. In terrible case, the more harmonics distortion in power system can source of the malfunction of the data processing system in computers.

V. SOLUTION METHODS FOR HARMONIC ANALYSIS

Various methods are available for harmonic reduction to meet the standard regulation limits. Irregular harmonics reduction standard exists for the buses inside plant; the proper technology is that meet the required of client. The following are some discus more popular methods to reduce harmonics.

A. HARMONIC REDUCTION USING TRANSFOREMER PHASE SHIFTING

One of the prime way to reduce harmonics is to used a method known as “Phase Shifting”. The concept of phase shifting include separating the electrical supply into different outputs; each output being phase shifted with the other outputs and suitable angle for the harmonics to be reduced. The main concept of displace the harmonic currents in order to bring them to 180 degree phase shift so that they cancel each other.

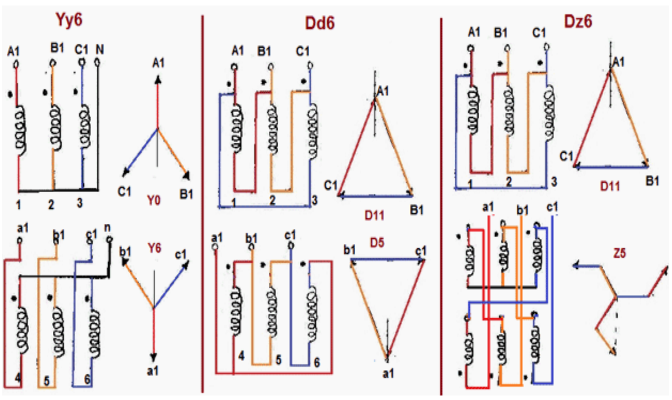

Figure 7. Transformer-phase-shift-180

B. HARMONIC REDUCTION USING CAPACITOR-SWITCHED FILTER

Another type of filter method is capacitor-switched has become generally available in massive form during the past few years. Built in standard active filters the switched capacitor is approximate overcome some of the problems, while attaching some interesting new abilities. Capacitor switched filter require additional capacitors or inductors and their cutoff frequencies are set to a typical accuracy of ±0.2% by external clock frequency. This permit steady, repeatable filter designs using economical crystal-controller oscillator or filters whose cutoff frequencies are accessible over a wide range simply by changing the clock frequency. Capacitor switched filter can also work with low sensitivity to temperature changes.

C. HARMONIC REDUCTION USING PASSIVE FILTER

Passive filter is simply filter that uses no amplifying elements such as transistor, operational amplifiers and etc. passive filters are made up of passive elements: resistors, capacitors and inductors with amplifying elements. Passive filter need no power supplies because they have no active element. Science passive filter are not limited by the bandwidth restriction of op-amps, they can be hold by active devices. When compared with circuit using active gain elements than passive filters also crate some noise.

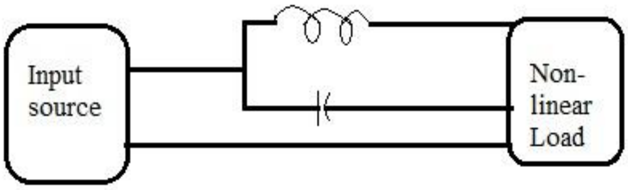

Figure 8. Basic structure of Passive filter

D. HARMONIC REDUCTION USING ACTIVE FILTER

Amplifying elements are used in active filter, generally op-amps with resistors and capacitors in their feedback loops, to synthesize the better filter characteristics. Active filter can work with high input impedance, low output impedance, and virtually any arbitrary gain. Active filters are also basically easier to design than passive filters. In active filters most important feature is that they have not work with inductors so that reducing the problem associated with those components.

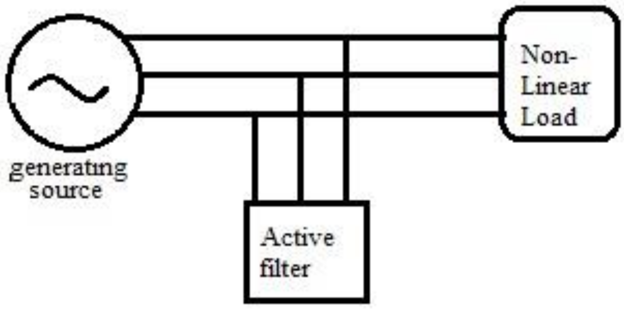

Figure 9. Basic Structure of Active filter

VI. CONCLUSION

The system elements and equipments have a very large effect on the performance by harmonic level. It is essential to study of harmonic examination for the distortion system for appreciating system operation and upgrade. The nonlinear loads are expected increase up to 70% during next decade. Understanding electrical system difficulties will help in applying appropriate solutions. It is necessary to make attention while studying harmonic problems in any power system. It is very necessary to consider types of loads, power factor characteristics, harmonic generating characteristics and frequency response.

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