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Introspection into Domestic & Industrial Harmonic Analysis

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ABSTRACT

This paper presents the survey and introduction of a harmonic reduction module for domestic consumers as well as a study on the harmonic analysis in the industrial sector. As the non-linear loads are increasing day by day such a system should be able to reduce problems associated with nonlinear loads in power grid. In this paper we focus on studying harmonic contents injected by various loads available at domestic consumer end. It is also intended to give an overview of power system harmonics in the industrial sectors and study the basic methods used to reduce the problems caused by it

Keywords: Harmonics, measurement, filter, voltage, current

I. INTRODUCTION

Power Quality is a major concern for both the power supplier and end users. Harmonics is one of the factors which determine power quality. It affects not only the power system but also cause huge economics losses. Harmonics are produced by mainly nonlinear loads. The harmonics causes huge impact on the equipment connected in the power grid. Though it is more prominent in the industrial sector, it will be an upcoming issue in the domestic sector as well.

In the present scenario, the applications of the nonlinear loads in the industrial plants grow rapidly and the percentage of these loads has increased up to 50% of the total plant load. As a result, the effects of harmonics within the electrical system and their impact on the electric utility and neighbouring plants should be examined to avoid equipment damage and plant shutdowns. As such, developments in harmonic analysis are termed as a topic of great interest and research for the coming generations.

In the state of Kerala, domestic consumers amount to 80% (almost 75 lakh) of the total electricity consumers. As of now, there is no regulation for domestic sector that mandates harmonic reduction in our state, though such a regulation exists in the industrial sector. For a consumer, a distorted power system will affect the equipment that is being used. Harmonic distortion may cause them to overheat and reduces their lifetime. In turn there will an increase in the electricity bills and economic losses to the customer.

Therefore it should be mandatory that there exists a regulation scheme for domestic consumers as well in states such as Kerala where the industrial plants and sector are not abundant. This ensures that there is no electrical pollution transfer among domestic consumers.

II. HARMONICS AND ITS SIGNIFICANCE

Harmonics are steady-state distortions in current and voltage waves and they repeat every cycle. Harmonic voltages and currents in an electric power system are a result of non-linear electric loads. Power system problems related to harmonics are rare but it is possible for a number of undesirable effects to occur.

Now this has many effects which includes following:

1. Overloading of Neutrals
2. Effects on Transformers

3. Nuisance Tripping of Circuit Breakers
4. Capacitor banks
5. Skin Effect
6. Effect on Induction Motors
7. Harmonic Problems Affecting the Supply

A. Sources of Harmonics

In the industrial sector, the major devices that lead to the presence of harmonics are:

1) Saturable Magnetic equipment:
   i. Rotating machines when operating in abnormal or overloaded conditions.
   ii. Ballasts of various lamps such as mercury vapour, fluorescent etc.
   iii. Transformer harmonic due to over-excitation
   iv. Generator harmonics due to the non-sinusoidal flux distribution of flux in the air gap

2) Power Electronic Devices:
   i. SMPS
   ii. HVDC
   iii. VFD
   iv. Static VAR compensators
   v. UPS
   vi. FACTS

Harmonic analysis becomes critical in an industrial plant when:

a. The role of non-linear loads exceeds 25% of the industrial
b. Harmonic distortion becomes fairly strong and questions the plant efficiency
c. There is a need for plant expansion which results in further addition of harmonics causing loads.

B. IEEE 519-1992 HARMONIC LIMITS

The primary limits for a single consumer is the amount of harmonic current that they can inject into the power grid. These limits are based upon the size of the consumer relative to the size of the supply. Larger consumers are restricted more than smaller consumers. As we know the relative size of the load with respect to the source is defined as the short circuit ratio (SCR), at the point of common coupling (PCC). Now the consumer's size is defined by the total fundamental frequency current in the load that is I_L, which includes all linear and nonlinear loads, while the size of the supply system is defined by the level of short-circuit current, Isc, at the PCC. These two currents are the parameters used to make SCR: A high value means that the load is relatively small and that current limits will not be so strict.

a. Harmonic current distortion limits

Harmonic current distortion limits are introduced in the IEEE 519-1992. A summary of these current harmonic limits is shown in Table I. Setting limits for the current harmonic levels protects the utility company and the other utility consumers connected on the same feeder where:

I_{SC}: maximum short circuit current at PCC
I_1 or I_L: maximum demand load current (fundamental frequency component) at PCC

It should be noted that all the power generation equipment are limited to these values of current distortion, regardless of the actual I_{SC}/I_L ratio. The ratio I_{SC}/I_L is the ratio of the short circuit current available at the (PCC) to the maximum fundamental load current. It is recommended that the load current (I_L) be calculated over any (15) or (30) min period and then averaged over the next (12) month period.

b. Harmonic voltage distortion limits

The IEEE 519-1992 defines the allowable voltage harmonic limits at the PCC. Table II summarizes the limits for the voltage systems.

It is important to highlight that the limits should be used as system design values for normal operation conditions (lasting more than one hour). For shorter operation periods, during start-ups or unusual transient conditions, these harmonic limits may be allowed to exceed by 50%.

TABLE I

I_{SC}/I_L	**<11**	**11 <17**	**17 <23**	**23 <35**	**35**	**TDD**
<20	4	2	1.5	.6	.3	5
20<50	7	3.5	2.5	1	.5	8
50<100	10	4.5	4	1.5	.7	12
100<1000	12	5.5	5	2	1	15
>1000	15	7	6	2.5	1.4	20

Harmonic current limits for nonlinear loads at PCC with other loads for V120-6900 volts

Maximum odd harmonics currents distortion in % of fundamental harmonics order. The second set of criteria established by IEEE 519 is for voltage distortion limits. This governs the amount of voltage distortion that is acceptable in the utility supply voltage at the PCC with a consumer.

TABLE II

Bus voltage at PCC	**Individual voltage Distortion (%)**	**Total voltage Distrotion THD (%)**
Below 69kv	3	5
69kv to 137.9kv	1.5	2.5
138kv and above	1	1.5

C. Domestic loads

There are many electrical appliances which introduce harmonics in the system Electrical appliances used by domestic consumer take a major portion of harmonic injecting loads in the power system. Following is the table of experimental result which shows the harmonic contents at no load as well as during loads for most common appliances in our home. The values given in the table was obtained for a particular type of load as load changes values may change, however it gives you a rough approximation.

Given below are some data collected from the basic domestic loads used in our home such as electrical appliances such computer, lamps, oven etc.

1) Microwave Oven

At no load operation

Voltage THD	Current THD	Harmonics
3.2	32.5	3th 5th 7th

At load (4 pancakes)

Voltage THD	Current THD	Harmonics
3.2	33.3	3th 5th 7th

2) Induction heat plate(1600w)

Load operation (steel kettle with water)

Voltage THD	Current THD	Harmonics
2.6	6.2	5th

Stand-by operation

Voltage THD	Current THD	Harmonics
2.6	17.7	3,5,7,9,13,15,17,19,21,23

3) Personal computer(dell)

Idle mode

Voltage THD	Current THD	Harmonics
3.4	91.5	**3**,5,7,9,13,15,17,19,21,23

4) Laptop(Lenovo)

Charging mode

Voltage THD	Current THD	Harmonics
3.5	124.1	**3,5**,7,9,13,15,17,19,21,23

Operating mode

Voltage THD	Current THD	Harmonics
3.5	129.7	**3,5**,7,9,13,15,17,19,21,23

5) Laser printer

Idle mode

Voltage THD	Current THD	Harmonics
4.8	89.8	3,5,7,9,13,

Printing mode

Voltage THD	Current THD	Harmonics
4.8	4.1	5

6) Air-condition device

Standby mode

Voltage THD	Current THD	Harmonics
-	22.1	3,5,7,9,13

7) Compact fluorescent lamps

On load (3 CFLs of 15W and 20W connected in parallel)

Voltage THD	Current THD	Harmonics
-	94.1	3,5,7,9

III. MEASUREMENT AND MITIGATION

A. Measurement Devices:

Selection of a measurement device:
Only digital analysers, with correspondence on present technology, give sufficiently correct measurements for the harmonic levels of an electric network.
Other measurement devices were used in the past.

1) Oscilloscopes

For observation purposes:
A general indication of the distortion of a signal may be obtained by viewing the current or the voltage on an oscilloscope. When the wave form is not sinusoidal, the signal is distorted by harmonics. The voltage and current peaks can be displayed. Note that using an oscilloscope; it is not possible to precisely quantify the harmonic components.

2) Analogue Spectral Analysers

Implementing old technology, these devices are made up of a pass band filter combined with an rms voltmeter. These devices, now outdated, produce mediocre results and do not provide any information on displacement.

3) Digital Analysers

Let us discuss a particular digital analyser which we have one through in our survey.

Fluke Meter for Harmonic Analysis:

This instrument is actually a multipurpose device with the combination of a multimeter with the display borrowed from oscilloscope and which having the power of a true harmonic analyser. This is a very efficient tool in trying out three-phase systems and non-linear loaded systems. There is also a facility to get a printed hardcopy of all the data recorded in the device.

The instrument is able to provide you with measurement views such as numerical values, bar graphs, waveforms etc. It also has in-built data storage service as well as safety designs.

It is capable of measuring voltages from ranges 5v to 1250 V, current from 50A to 1250 kA, frequency from 10 to 15 kHz. The main highlighting feature is the ability of this technology to measure up to the fundamental to 51^{st} harmonic.

Use of measurement devices:

The devices show both the instantaneous effects and the long-term effects of harmonics.

Correct analysis requires integrated values over time spans ranging from a few seconds to a few minutes, for observation periods of a few days.

B. Mitigation Techniques:

There are many ways to eliminate harmonics in a system such as:

1) 12- pulse converter(5^{th} and 7^{th})
2) Transformer
3) Line reactor
4) Active filter
5) Passive Filter

Different non-linear loads produce different but specific harmonic spectra. This makes identifying the harmonics that are produced from different loads easier. Since we can recognize source of harmonic we can either avoid it or balance it using available techniques. Most of the non-linear loads we see today are by-product of modern electronics.

i. 12-Pulse Converter

In this configuration, the front end of the bridge rectifier circuit uses twelve diodes instead of six. The advantages are the elimination of the 5th and 7th harmonics to a higher order where the 11th and 13th become the predominate harmonics. This will minimize the magnitude of harmonics, but will not eliminate them. The disadvantages are cost and construction, which also requires either a Delta-Delta and Delta-Wye transformer, “Zig-Zag” transformer or an autotransformer to accomplish the 30° phase shifting necessary for proper operation. Similarly 18-pulse converter also reduce harmonics.

ii. Transformers

Transformers have reactance and resistance which makes it represent the majority of the impedance found in lines feeding non-linear loads. Reactive impedance increases directly with frequency, naturally attenuating harmonics by reducing available current at higher frequencies. This technique is commonly used in reducing the current distortion of electric motor drives in industrial applications.

Delta-Delta connected transformers for some drives and Delta-Wye connected transformers for the remaining drives are used in order to trap the triple-n harmonics.

iii. Line Reactors

This method consists of connecting a line reactance in series with the harmonic source at which the reactance will reduce the harmonic current.

iv. Active Filters

Active harmonic filters uses power electronic devices in order produce harmonic current components that cancel the harmonic current components that are produced by the nonlinear loads. The active harmonic filter is configured based on a pulse width modulated (PWM) voltage source inverter that interfaces to the system through a system interface filter.

This inverter uses dc capacitors as the supply and can switch at high frequencies to generate a signal that can cancel the harmonics produced by the non-linear loads. The voltage distortion is reduced because the harmonic currents that flow through the source impedance are reduced.

v. Passive Filters

Passive filters consist of capacitor, inductor and a resistor connected in parallel to a nonlinear load. Passive filters will provide a low impedance path for the harmonic current therefore will inject them to ground. Passive filters can be tuned to absorb one type of harmonic current or many.

Another important feature of the passive filters is that they can improve the power factor since they have a capacitance in their construction. Moreover, filters can be specified according to the connection type into two main groups, the series connection and parallel.

IV.CONCLUSION

Introspection into the domestic sector in states such as Kerala is studied and the need for a mitigation technique is discussed. Also the basics about harmonics along with its measurement and mitigation methods are studied. Furthermore it provides a brief idea about harmonic analysis and its significance in a modern industrial sector.

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