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Reactive Power Compensation with Harmonics Analysis

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Abstract

The assessment of harmonic phenomena and their system effects is characterized by considering long established harmonic sources and problems, and by detailing new and future sources and their probable effects. This paper is a treatment of the concerns being addressed especially as they relate to new technologies of energy control, energy conservation, and modern power conversion. This paper illustrates the harmonics analysis of a technical college and the mitigation technique taken. In this paper harmonics without compensation and with compensation and their effects on common power system, and well known equipments are presented comprehensively. The study is expected to yield recommendatory suggestions for specific usages and their merits and difficulties.

Introduction: Reliability and quality of power has become one of the most critical issues facing business today. For critical loads, such as transformers, motors, computer hardware components, instrumentation and control systems and protective devices, anything less than high quality power and reliability means possible equipment malfunction and system downtime. All the sources of electrical energy are basically designed on the consumption of balanced three phase loads at fundamental frequency (50 Hz). Therefore the performance of the equipments and system elements to other frequencies has not been given great importance. Non linear loads distorts like any thyristor/transistor operated devices distorts the sinusoidal waveform of the power supplied to it, generate harmonics. These harmonics have a negative impact on electric utility distribution systems and components. Various harmonics Sources are mentioned below.

Harmonic Sources

Domestic Loads

- TV Receivers
- Audio Visual System
- UPS Systems

Industrial Loads

- Diode/Thyristor converters
- Laboratory testing equipment
- SCR Drives

Control Devices

- Static VAR compensators
- Transformers
- Light Fixture Ballasts

AC System Harmonics

Problems: The ac power system harmonic problems are mainly due to the substantial increase of non-linear loads due to technological advances, such as the use of power electronics circuits and devices, in ac/dc transmission links, or loads in the control of power systems using power electronic or microprocessor controllers. Such equipment creates load-generated harmonics throughout the system. In the past, equipment designs tended to be under-rated or over-designed. Now, in order to be competitive, power devices and equipments are more critically designed and, in the case of iron core devices, their operating points are more into non linear regions. Operation in these region results in a sharp rise in harmonics.

The significant harmonics (above the fundamental, i.e., the first harmonic) are usually the 3^{rd}, 5^{th}, and 7^{th} multiples of 50/60 Hz, so that the frequencies of interest in harmonic studies are in the low audible range. The most damaging frequencies to power devices and machines appear to be the lower-below 5 KHz-frequency range. In past years the magnitudes and sources of these lower frequency harmonics were limited and in most cases, power systems could tolerate them. The increase in power loss due to harmonics was also neglected because energy costs were low. These conditions no longer apply and concerns for harmonic are now becoming widespread among utilities.

Causes for Harmonics: A distorted sine waveform can be resolved into many sine waves of different amplitude and multiples of the fundamental frequencies, which are called harmonics. Non linear loads generate harmonics. A non linear load drives current in a non sinusoidal manner. Consider a sinusoidal voltage V connected to a non linear load a shown in fig. 2.

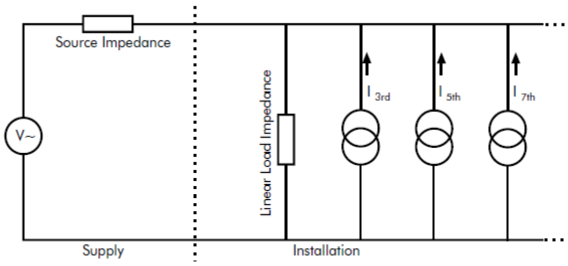

Figure 2

The load may be a rectifier or a set of mechanical switches that open and close periodically and any other electronic device. It can be modeled as a linear load in parallel with a number of current sources, one source for each harmonic frequency. The harmonic currents generated by the load – or more accurately converted by the load from fundamental to harmonic current – have to flow around the circuit via the source impedance and all other parallel paths. As a result, harmonic voltages appear across the supply impedance and are present throughout the installation.

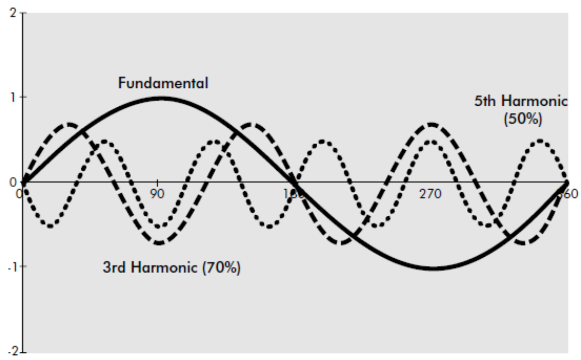

Figure 3: Fundamental with third and fifth harmonics.

Harmonic frequencies are integral multiples of the fundamental supply frequency, i.e. for a fundamental of 50 Hz, the third harmonic would be 150 Hz and the fifth harmonic would be 250 Hz. Figure 1 shows a fundamental sine-wave with third and fifth harmonics.

There are several common problem areas caused by harmonics:

Problems caused by harmonic currents

- overloading of neutrals
- overheating of transformers
- nuisance tripping of circuit breakers
- over-stressing of power factor correction capacitors
- skin effect

Problems caused by harmonic voltages

- voltage distortion
- induction motors
- zero-crossing noise
- problems caused when harmonic currents reach the supply

Sources of Harmonics

Harmonic sources are divided in two categories

1. Established and known
2. New and future

Established Harmonic Sources

- Tooth ripple in the voltage waveform of rotating machines.
- Variations in air gap reluctance over synchronous machine pole pitch.
- Flux distortion in the synchronous machine from sudden load changes.
- Non sinusoidal distribution of the flux in the air gap of synchronous machines

New Harmonic Sources: While established sources of harmonics are still present in the system, the power network is also subjected to new harmonic sources.

- Energy conservation measures, such as those for improved motor efficiency and load matching, which employ power semiconductor devices and switching for their operation. These devices often produce irregular voltage and current waveforms that are rich in harmonics.
- Motor control devices such as speed control for traction.
- Static Var Compensators which have largely replaced synchronous condensers as continuously variable-Var sources.
- Interconnection of wind and solar power converters with distribution system.
- The potential use of direct energy conversion devices, such as magneto-hydro dynamics, storage batteries, and fuel cells, that require dc/ac power converters

Harmonic effects on devices and load

Harmonics on Transformers: The primary effect of power system harmonics on transformers is the additional heat generated by the losses caused by the harmonic contents generated by the load current. Other problems include possible resonance between the transformer inductance and the system capacitance, mechanical insulation stresses due to temperature cycling and possible small core vibrations. In other words The losses due to harmonic current in the transformers are a combination of load loss and excitation. i.e. eddy current, stray losses dissipating in the form of heat leads to increase in temperature. It is found that, losses from the winding eddy-current increase with the square of the load current and the square of the frequency.

Insulation Stress (Voltage Effect): Insulation Stress depends on the instantaneous voltages, as well as its firing rate.

Thermal Stress (Current effect): Thermal stress depends on the presence of harmonic currents which can cause copper losses, iron losses and dielectric losses in the equipment.

Harmonic currents in a 3-phase, 4-wire distribution system: The lighting systems of commercial and industrial buildings often use fluorescent lamp that are connected between the line and the neural of a 3-phase, 4-wire feeder. The problem is that these devices usually draw non sinusoidal current that contain strong 3rd harmonic. When the load on the 3-phases is balanced, the fundamental components cancel out in the neutral conductor because their phasor sum is zero. Un fortunately, instead on cancelling out, the 3rd, 9th, 15th etc. (Triple N harmonic) harmonics add up in the neutral conductor. Consequently these Triple N components are three times greater in the neutral conductor than they are in lines.

In some cases the 3rd harmonic is so large the neutral overheats and special measures must be taken to reduce the current. One way to block it is to interpose a transformer connected in delta-star between the source and the load. Under these conditions, the 3rd harmonic on the primary side (delta connection) cannot flow in the lines because the neutral is absent. However, the 3rd harmonic will continue to flow in the star connected windings as well as in the delta connected windings. In effect, the transformers act as a filter as far as the 3rd harmonic is concerned. Unfortunately, the other harmonic in the secondary feeder continue to flow in the primary feeder.

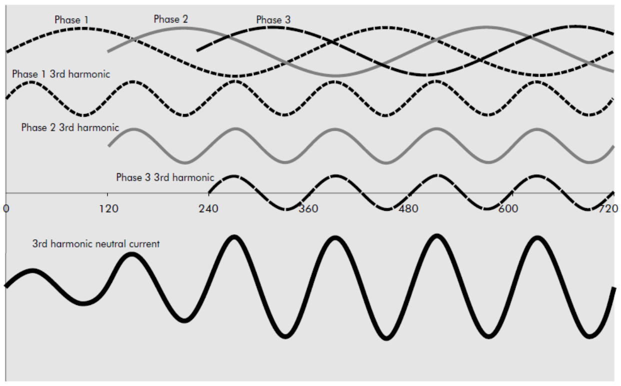

Figure 4: Triple N currents add in Neutral.

Power Factor in the Presence of Harmonics

There are two different types of power factor that must be considered when voltage and current waveforms are not perfectly sinusoidal. The first type of power factor is the Input Displacement Factor (IDF) which refers to the cosine of the angle between the 50 Hz voltage and current waveforms. Distortion Factor (DF) is defined as follows:

$$DF = \frac{1}{\sqrt{1 + THD^2}}$$

The Distortion Factor will decrease as the harmonic content goes up. The Distortion Factor will be lower for voltage source type drives at reduced speed and load. Total Power Factor (PF) is the product of the Input Displacement Factor and the Distortion Factor as follows:

$$PF = IDF \times DF$$

In order to make a valid comparison of power factor between drives of different topologies, it is essential to look at Distortion Factor. The Displacement Power Factor may look attractive for certain types of drives, but the actual power factor may be somewhat lower when the effect of harmonics is taken into account.

Practical Harmonic analysis of a Technical college

In this paper it is explained about the harmonics, its causes and effects previously. Now it accounts on the practical harmonic analysis that comprises of all the terms that are related to the harmonics analysis. The analysis was done using the three phase power quality analyzer in the technical college. This 3-phase power quality measurement not only lead to the analysis of frequency balancing, crest factor, fundamental varying voltages, but also helps in analyzing the harmonics up to 11th term. The measurement was done for twenty four hours without compensation and again the another analysis was done with compensation. The comparative study can observed by considering the figures shown below.

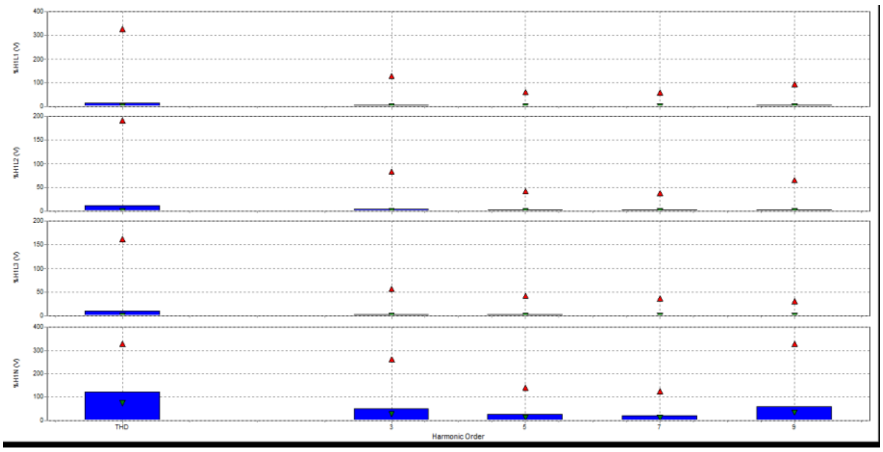

Figure 5: 3rd, 5th, 7th, 9th harmonic observed in the power of technical college at no load.

The above figure 5. Shows the odd harmonics present in the power coming to the technical college. The various terms concerned to the harmonic analysis are illustrated in the table shown in fig 6.1 & 6.2. These data were observed when the power quality analyzer is placed at no load. The graph shown in fig5 show harmonics up to 9th level.

This graph can also be extended up to 11th level when the recorded data is being analyzed on computer.

Phase	Voltage fundamental Average (V)	Average Frequency (Hz)	THD V Average
L1	227.26	49.47	1.41
L2	225.27		2.81
L3	232.21		1.41
N	2.97		106.86

Figure 6.1: Tabular representation of various aspects observed without compensation.

Phase	Volts Harmonics 3rd	Volts Harmonics 5th	Volts Harmonics 7th	Volts Harmonics 9th
L1	0.56	0.84	0.40	0.43
L2	1.63	1.64	1.12	0.39
L3	0.50	0.62	0.86	0.26
N	79.45	61.34	27.31	37.99

Figure 6.2: Tabular representation of volt harmonics observed without compensation.

In the other case when instrument was placed for next twenty four hours with compensation, it was observed that that all the factors are consistently varying in comparison to that of when connected without compensation. The figure shown in fig7 gives a graphical representation of fundamental voltages varying in the three lines along with neutral line. The fig8 shows the average frequency unbalancing waveform observed after the analysis of power of a technical college.

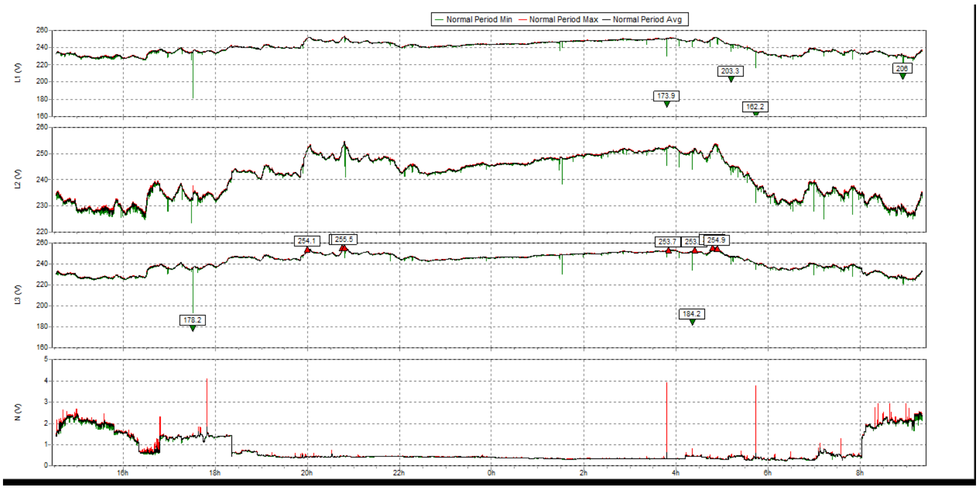

Figure 7: Variations in the three phase power of technical college when connected at load.

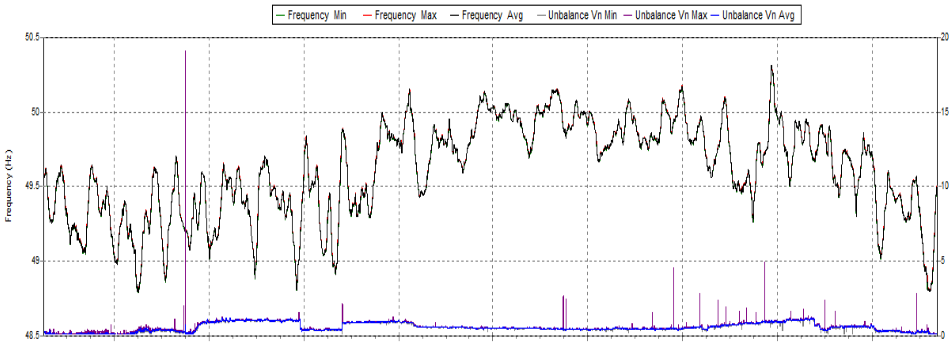

Figure 8: Frequency unbalancing observed in 24 hrs when analyzer is connected at load.

Various terms that were also studied and analyzed to get help in the harmonic analysis are shown in tabular format in the figure 9.1 & 9.2.

Phase	Voltage fundamental Average (V)	Average Frequency (Hz)	THD V Average
L1	230.88	49.57	1.35
L2	231.54		1.98
L3	233.84		1.4
N	1.32		102.49

Figure 9.1: Tabular representation of various aspects observed with compensation.

Phase	Volts Harmonics 3rd	Volts Harmonics 5th	Volts Harmonics 7th	Volts Harmonics 9th
L1	0.54	0.46	0.72	0.45
L2	0.91	0.88	0.98	0.40
L3	0.34	0.50	0.91	0.20
N	73.47	42.25	20.36	30.85

Figure 9.2: Tabular representation of volt harmonics with compensation.

The variations In the crest factor and harmonics up to 9th level is shown in fig 10 & fig 11.

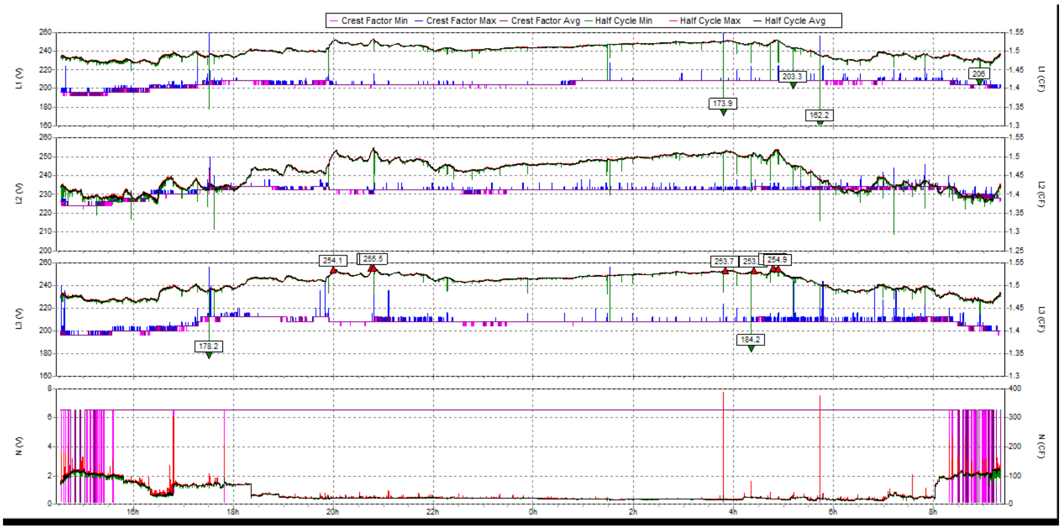

Figure 10: Crest Factor observed while analyzing the power quality of technical college when connected at load.

The harmonics shown in fig11 illustrates the harmonics present in the power of a technical college when connected at load for complete twenty four hours. To minimize the effect of harmonics preventive measures are taken i.e. explained in the minimization section of this paper.

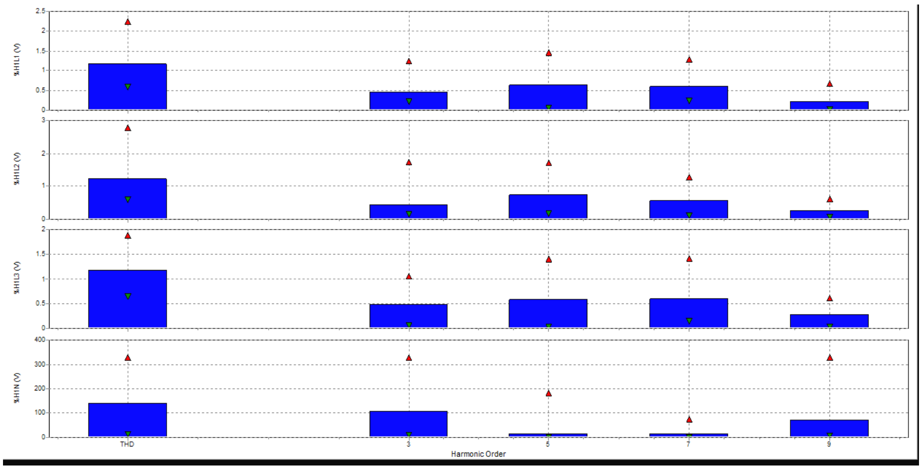

Figure 11: 3rd , 5th, 7th, 9th harmonic observed in the power of technical college at load.

This harmonic analysis study helps in analyzing the systems under steady state condition for normal power flow and harmonic under each separate switching condition. Only those switching conditions resonated near the generated harmonic frequencies need to be evaluated. The line diagram of the connection of technical college is shown below.

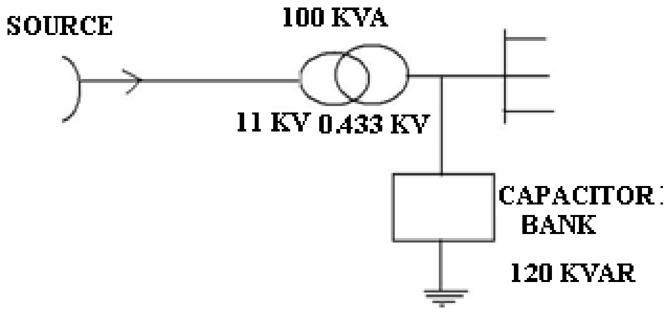

Figure 12: Line diagram of the college connection.

Technique of Harmonic Effect Minimization

Ideally, Mitigation methods fall broadly into three groups

Passive filters, Isolation transformers and Active Filters But, in this paper, it is discussed about the harmonic analysis of 3 –phase power coming to a technical college. Here when we studied the present harmonics, we found that it was much enough to reduce the poor efficiency and also intruding many power losses. A capacitor bank is used in the technical college to act as a compensator for minimizing the effects of harmonics in the college campus. Capacitor banks are mainly installed to provide capacitive reactive compensation/power factor correction. The use of capacitor bank has increased because they are relatively inexpensive, easy and quick to install and can be deployed virtually anywhere in the network. Its installation has other beneficial effects on the system such as: improvement of the voltage at the load, better voltage regulation (if they were adequately designed), reduction of losses and reduction or postponement of investments in transmission.

Conclusions

This work is designed to give the reader a comprehensive understanding of the harmonic phenomenon. This phenomenon has grown to be a problem in recent years due to ever increasing linear loads. Sources of system harmonics have been identified and concern for their proliferation on electric systems. This Paper mainly includes the practical harmonic analysis of a technical college, effect of compensation of harmonics in the analysis and the preventive measure take to minimize it. Apart from many compensation techniques, the college uses a capacitor bank for perfect minimization of harmonic thus resulting in the good power efficiency. Efforts are presently underway to develop the new and better ideas for analysis of harmonics and the concerned techniques for its minimization.

Acknowledgement

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Bibliography

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