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Current Source Control Phase Shifting For Minimization of Harmonic Current in Distribution System

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Abstract

Power electronic loads inject harmonic currents into the utility system. This paper presents a comparative evaluation of harmonic reduction techniques which satisfy the current harmonic limits specified by the IEEE Standard 519, and at the same time provide a regulated DC output voltage. The techniques considered include active and hybrid filters, and various current waveshaping approaches for a three-phase utility interface. These techniques are compared in terms of their complexity (number of switches) and their component ratings. Based on the application requirements and the cost of active and passive components, this paper enables the estimation of the minimum cost topology.

Keywords: Harmoic, Topology,Waveshaping, Hybrid filters.

Introduction

Harmonics current are created by non-linear loads that generate non-sinusoidal current on distribution power system. However, because of the increased popularity of electronic and other non-linear loads, the current waveform quite often became distorted. To understand the distortion phenomena, it is necessary to analyze the distorted waveform by a process called harmonic analysis. It allows us to express the distorted waveform as a sum of dc component, fundamental sine wave of the distorted waveform and a series of pure sine waves. These sine waves have different magnitudes and their frequencies are integer multiple of the fundamental distorted waveform. In this chapter provides a quantities discussion of harmonics analysis. Distorted waveform, effective value, Total Harmonics Distortion (THD), effect of harmonic for power and power factor are analyzed and presented using Fourier series. Characteristic of symmetrical component and their relation with sequence of harmonic on three phase distribution system are also presented in this chapter. The end of this chapter is describe current harmonic generation by three phase rectifier.

Harmonics are usually defined as periodic steady state distortions of voltage and current waveforms in power system. The purpose of this chapter is to present basic harmonic theory. Initially, the Fourier Series and analysis method that can be used to interpret waveform phenomenon are reviewed. The general harmonics theory, the definitions of harmonic quantities, harmonic indices in common use, and power system response are then described.

Effects of harmonics & minimization method

1.Effects of Harmonic Distortion

The effect of current distortion on power distribution systems can be serious, primarily because of the increased current flowing in the system. In other words, because the harmonic current doesn't deliver any power, its presence simply uses up system capacity and reduces the number of loads that can be powered. Harmonic current occur in a facility's electrical system can cause equipment malfunction, data distortion, transformer and motor insulation failure, overheating of neutral buses, tripping of circuit breakers, and solid-state component breakdown. The cost of these problems can be enormous.

Harmonic currents also increase heat losses in transformers and wiring. Since transformer impedance is frequency dependent, increasing with harmonic number, the impedance at the 5th harmonic is five times that of the fundamental frequency. So each ampere of 5th harmonic current causes five times as much heating as an ampere of fundamental current. More specifically, the effects of the harmonics can be observed in many sections of electrical equipment and a lot machines and motors.

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2.Effects of Harmonics on Rotating Machines

For both the synchronous and the induction machines, the main problems of the harmonics are increasing on the iron and copper losses, and heating by result of the high current caused by harmonics as a result reducing the efficiency. The harmonics can be a one reason as an introduction of oscillating motor torque. Also, the high current can cause high noise level in these machines.

3. Effects of Harmonics on Transformers

Transformers are designed to deliver the required power to the connected loads with minimum losses at fundamental frequency. Harmonic distortion of the current, in particular, as well as the voltage will contribute significantly to additional heating. There are three effects that result in increased transformer heating when the load current includes harmonic components.

*1. **RMS current**.* If the transformer is sized only for the KVA requirements of the load, harmonic currents may result in the transformer rms current being higher than its capacity. The increased total rms current results increase conductor losses.

*2. **Eddy-current losses***. These are induced currents in the transformer caused by the magnetic fluxes. These induced currents flow in the windings, in the core, and in the other connecting bodies subjected to the magnetic field of the transformer and cause additional heating. This component of the transformer losses increases with the square of the frequency of the current causing the eddy current. Therefore, this becomes a very important component of transformer losses for harmonic heating.

*3. **Core losses***. The increase in core losses in the presence of the harmonics will be dependent on the effect of the harmonics on the applied voltage and the design of the transformer core. Increasing the voltage distortion may increase the eddy currents in the core laminations. The net impact that this will have depends on the thickness of the core laminations and the quality of the core steel. The increase in these losses due to harmonics is generally not as critical as the previous two.

4. Effects of Harmonics on Lines and Cables: The main problems associated with harmonics are: increased losses and heating, serious damages in the dielectric for capacitor banks and cables, appearance of the corona (the amount of the ionization of the air around the conductor or the transmission line) due to higher peak voltages and corrosion in aluminum cables due to DC current.

5. Effects of Harmonics on Converter Equipments: These equipments can be expressed as switches or On-Off equipment because of the switching the current and voltage by some devices such as diodes and thyristors. These converters can switch the current so, creating notches in voltage waveforms, which may affect the synchronizing of the other converter equipment. These voltage notches cause misfiring of the thyristors and creating unarranged other firing instances of the other thyristors in the equipment.

6. Effects of Harmonics on Capacitor Banks

Resonance due capacitor banks can magnify the harmonic problems. Capacitors used by both electricity suppliers and customers to improve their power factor. There is an intermediate range of frequencies where the capacitive and inductive effects can combine to give very high impedance. A small harmonic current within this frequency range can give a very high and undesirable harmonic voltage. This is the condition, which is called resonance. At harmonic frequencies, from the perspective of harmonic sources, shunt capacitors appear to be in parallel with the equivalent system inductance as shown in the equivalent circuit in Figure 2.1 PCC is the nearest point that the additional installation might be added. At the frequency where capacitor reactance Xc and the total system reactance are equal, the apparent impedance of the parallel combination of inductance and capacitance becomes very large. This results in the typical parallel resonance condition.

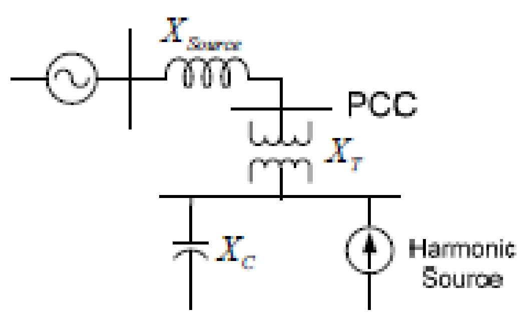

Fig 2.1.a

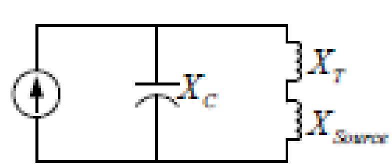

Fig 2.1.b

Figure 2.1 The effect of capacitor size on parallel resonant frequency

(a) ***System with potential for problem parallel harmonic (b) Equivalent circuit***

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7. Three Phase Non- Linear Load

In fact, the non linear load is the source of the harmonic. A three phase electrical power system distribution has high capacity non-linear load such as converter for electric motor control use to power drive in industries, factories, LRT power supply and direct current transmission system. In general, this nonlinear load base on three phase bridge diode rectifier, also known as the six pulse bridge because it is six pulses per cycle on the DC output. It is shown in Figure (2.2). The diodes are numbered in order of conduction sequence and each is conduct for 1200. A three phase bridge diode rectifier is a circuit that converts an ac signal in to a dc signal. The six pulse bridge produces harmonics at order 6n+1 and 6n-1, at one more and one less than each multiple of six. In theory, the magnitude of each harmonic number is the reciprocal of the harmonic order, so there would be 20% fifth harmonic and 9% eleventh harmonic.

To assume that three phase bridge diode rectifier is ideal, therefore no ripple of instantaneous output current. The input current of three phase bridge rectifier is square wave perform. It is shown in Figure (2.3).

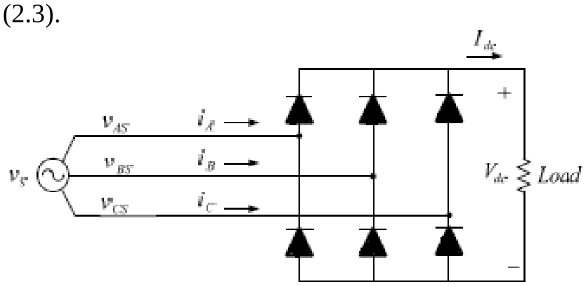

Figure 2.2 Three phase bridge diode rectifier

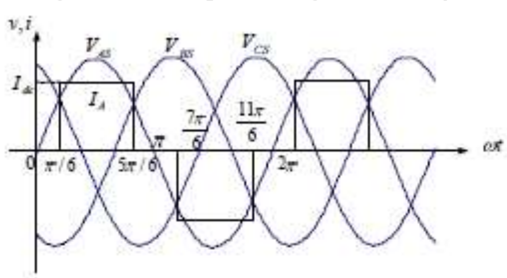

Figure 2.3 Input line current and voltage wave form

Harmonic analysis

Harmonics current are created by non-linear loads that generate non-sinusoidal current on distribution power system. However, because of the increased popularity of electronic and other non-linear loads, the current waveform quite often became distorted. To understand the distortion phenomena, it is necessary to analyze the distorted waveform by a process called harmonic analysis. It allows us to express the distorted waveform as a sum of dc component, fundamental sine wave of the distorted waveform and a series of pure sine waves. These sine waves have different magnitudes and their frequencies are integer multiple of the fundamental distorted waveform. In this chapter provides a quantities discussion of harmonics analysis. Distorted waveform, effective value, Total Harmonics Distortion (THD), effect of harmonic for power and power factor are analyzed and presented using Fourier series. Characteristic of symmetrical component and their relation with sequence of harmonic on three phase distribution system are also presented in this analysis. The end of this analysis is describe current harmonic generation by three phase rectifier.

Harmonics are usually defined as periodic steady state distortions of voltage and current waveforms in power system. The purpose of this chapter is to present basic harmonic theory. Initially, the Fourier Series and analysis method that can be used to interpret waveform phenomenon are reviewed. The general harmonics theory, the definitions of harmonic quantities, harmonic indices in common use, and power system response are then described.

Fourier Series and Analysis

Fourier Series proves that any non-sinusoidal periodic function f(t) in an interval of time T could be represented by the sum of a fundamental and a series of higher orders of harmonic components at frequencies which are integral multiples of the fundamental component. The series establishes a relationship between the function in time and frequency domains. This expression is called Fourier series representation.

A distorted waveform can be analyzed using Fourier series representation given as the following equation

$$f(t) = F_o + \sum_{h=1}^{\infty} f_h(t) = \frac{1}{2}a_o + \sum_{h=1}^{\infty}\{a_h \cos(h\omega t) + b_h \sin(h\omega t)\}$$

…………(3.1)

where:

$f(t)$ is called non sinusoidal periodic of the function

$F_o = \frac{1}{2}a_o$ is average value of the function $f(t)$

$$a_o = \frac{1}{2\pi}\int_0^{2\pi} f(t)d(\omega t)$$

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which $\omega = \frac{2\pi}{T}$ and T is periodic of the function $f(t)$ and $T = \frac{1}{f}$

f = frequency

a_h and b_h is series coefficient that can be determined as follow:

$$a_h = \frac{1}{\pi}\int_0^{2\pi} f(t)\cos(h\omega t)d(\omega t) \qquad ; h=1,2,3,.$$

$$b_h = \frac{1}{\pi}\int_0^{2\pi} f(t)\sin(h\omega t)d(\omega t) \qquad ; h=1,2,3,.$$

…………(3.2)

Therefore, the Fourier series in Equation 3.1 can be expressed as:

$$f(t) = F_o + F_{m1}\sin(\omega t + \varphi_1) + F_{m2}\sin(2\omega t + \varphi_2) + F_{m3}\sin(3\omega t + \varphi_3) + \ldots + F_{mh}\sin(h\omega t + \varphi_h)$$

……….(3.3)

Where:

F_o is dc component
F_{m1} is the maximum value of the fundamental component
F_{m2} is the maximum value of the 2-nd harmonic order
F_{m3} is the maximum value of the 3-rd harmonic order
F_{mh} is the h order harmonic component
Ω is angular angle
π is constantan (=3.14)
t is time
ϕ_1 is the phase shift of fundamental component
ϕ_2 is the phase shift of 2-nd harmonic order component
ϕ_3 is the phase shift of 3-rd harmonic order component

The Fourier expression is an infinite series. In this equation,F0 represents the constant or the DC component of the waveform. F_{m1}, F_{m2}, F_{m3}….F_{mh} are the peak values of the successive terms of the expression. The terms are known as the harmonics of the periodic waveform. The fundamental (first harmonic) frequency has a frequency of f, the fifth harmonic has a frequency of (5 × f), the seventh harmonic has a frequency of (7 x f) and the n-th harmonic has a frequency of (n x f). If the fundamental frequency is

50 Hz, the fifth harmonic frequency is 250 Hz, and the seventh harmonic frequency is 350 Hz. The ability to express a non sinusoidal waveform as a sum of sinusoidal waves can use the more common mathematical expressions and formulas to solve power distribution system problems. The harmonic current on the three phases power distribution system is defined as frequency components which is an integer multiple of the fundamental frequency. A pure sine wave not contains harmonic. When a wave becomes distorted, it means harmonics current are present in this distorted waveform. The harmonics current generated by three phase converter in three phases three wires power distribution system are 5-th, 7-th, 11-th, 13-th, 19-th and so on. The following is shown the current waveform distorted i (t) s caused by the three phases converter connected to power distribution system. Figure 3.1 illustrates how individual harmonics that are sinusoidal can be added to form a non sinusoidal waveform. The current distorted waveform in Figure 3.1 is the summation of fundamental frequency and 5th, 7th, 11th, 13th, 17th, 19^{th} harmonics.

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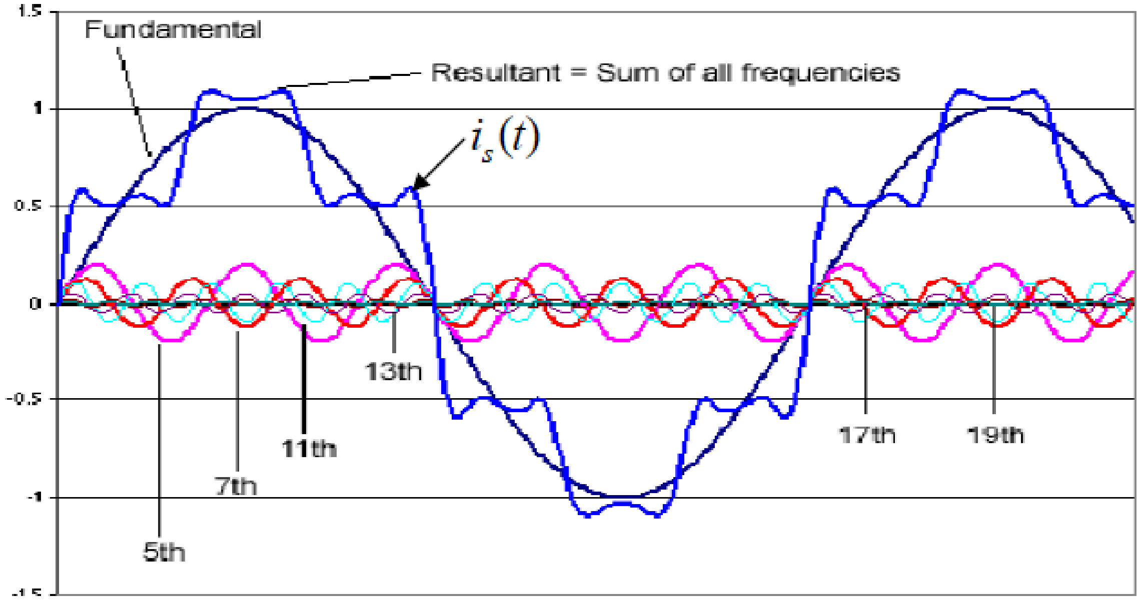

Figure 3.1 The current waveform distortions caused by odd harmonic component in three phases three wires power distribution system

The voltage phase shifting concept to minimize harmonic current

Phase Shifting and Harmonics

The best way to eliminate harmonics is to use a technique known as "phase shifting." The concept of phase shifting involves separating the electrical supply into several outputs; each output being phase shifted with the other outputs with an appropriate angle for the harmonics to be eliminated. The idea is to displace the harmonic currents in order to bring them to a 180° phase shift so that they cancel each other out.

Hence, an angular displacement of
− 60° is required between two three-phase outputs to cancel the 3rd harmonic currents.
− 30° is required between two three-phase outputs to cancel the 5th and 7th harmonic currents.
− 15° is required between two three-phase outputs to cancel the 11th and 13th harmonic currents.

For instance, in the case of two variable-speed drives of similar ratings, installing a Delta Wye transformer (30° phase shift with respect to the primary) on one drive and a delta-delta transformer (0° phase shift with respect to the primary) on the other drive gives an angular displacement of 30° between the two outputs. On the common primary supply of both transformers, phase shifting between the systems will cancel the 5th and 7th harmonic currents.

The above approach, i.e. phase-shifting non-linear loads, can be used to reduce the effects of certain harmonics.

Current Harmonics, Voltage Distortion and Transformers

The mathematical equation V = RI shows that any current flowing within a resistance (impedance) generates voltage at the terminals. This equation also applies to harmonic currents flowing through the electrical system.

The higher the harmonic current levels, the greater the resulting harmonic voltages, thus creating distortion in the electrical system voltage. As transformers also have impedance, voltage distortion appears at the transformer's secondary terminals when harmonic currents flow through it

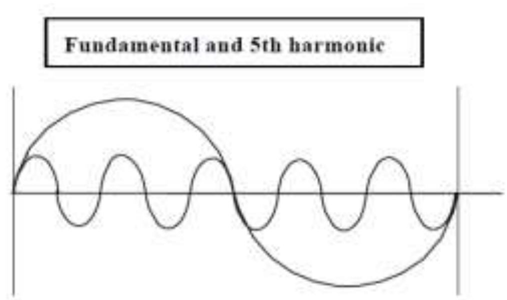

Figure 4.1 Fundamental & 5th harmonic

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Therefore, to reduce voltage distortion two factors can be modified: the level of harmonic currents and transformer impedance.

Phase-Shifting Transformers Designed for Non-Linear Loads

The level of harmonic currents may be reduced using phase-shifting transformers. Low impedance plays a crucial role in reducing voltage distortion.

New low-impedance phase-shifting transformers allow the treatment of harmonic currents while providing a path of low impedance. Moreover, these transformers have been designed to withstand the additional overheating caused by harmonic currents. The quality and reliability of the electrical system can be improved considerably through the use of a single piece of equipment.

Below are a few examples of such transformers along with a description of their respective use.

Harmonic Mitigating Transformer

(Using 0° or -30° primary-secondary angular displacement)

The primary of the transformer has a delta connection and the secondary has a special double winding connection. Although there is only one secondary three-phase output, the electromagnetic effect of its secondary winding with a zigzag connection ends up cancelling the 3^{rd}, 9^{th} and 15^{th} harmonic currents. Features of the Harmonic Mitigating Transformers include:

• A capacity for handling nonlinear loads.
• Low-impedance cancellation of the 3^{rd}, 9^{th} and 15^{th} harmonic currents (zigzag-connected secondary).
• A reduction in voltage distortion (3^{rd} harmonic voltage reduced by low zero-sequence impedance).

When two transformers with a delta-zigzag connection (-30° and 0°) are used for phase-shifting, the 3^{rd} harmonic currents are cancelled due to the secondary. The 5^{th} and 7^{th} harmonic currents are cancelled in the electrical supply common to both transformers and the voltage distortion is reduced. If a single delta-zigzag transformer (0°) is used in a system made up of Delta Wye transformers (-30°), the 5^{th} and 7^{th} harmonic currents originating from the delta-zigzag transformer (0°) will attempt to cancel the 5^{th} and 7^{th} harmonic currents originating from the Delta Wye transformer (-30°) already present. This reduces the 5^{th} and 7^{th} harmonics in the system.

Double-Output Harmonic Mitigating Transformer

(Using 0° and -30° primary-secondary angular displacement)

The primary of the transformer has a delta connection and its secondary has a double-output special double winding connection. Although there is only a 30° angular displacement, the electromagnetic effect of its secondary windings with a zigzag connection ends up canceling the 3^{rd}, 9^{th} and 15^{th} harmonic currents.

Features of the Double-Output Harmonic Mitigating Transformer include:
• A capacity for handling non-linear loads.
• Low-impedance cancellation of the 3^{rd}, 9^{th} and 15^{th} harmonic currents (zigzag-connected secondary).
• Cancellation of the 5^{th} and 7^{th} harmonic currents (30° phase shift between the outputs).
• A reduction in voltage distortion (3^{rd} harmonic voltage reduced by low zero-sequence impedance).

Power Factor and Harmonics

The power factor is the ratio between the active power (W) and the apparent power (VA). Electricity supplied by Utilities has a sinusoidal voltage wave of 60 Hz. If the current and voltage curves are not aligned, the efficiency of the electrical system is diminished and the apparent power exceeds the active power. In an inductive system, the voltage curve leads the current curve. In a capacitive system, the current curve leads the voltage curve. In general, when speaking of the power factor, we are actually referring to the displacement factor.

Figure 4.2 Distortion & Displacement factor

For the past few years, because of the increase in nonlinear loads, we have had to take into account the effect of harmonics in electrical systems and modify certain mathematical equations. The power factor is now defined as:

PFtot = Fd * Fdist

Where PFtot = total power factor
Fd = displacement factor (as defined above)
Fdist = distortion factor = fundamental current / RMS current

A new term has therefore been added, the "distortion factor", which is defined as being the fundamental current divided by the RMS current (current measured with a true RMS clamp-on ammeter).

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There are two elements that combine to deteriorate the power factor; inductive or capacitive loads. These affect the displacement factor and the harmonic currents of the non-linear loads, which affects the distortion factor.

Reducing the level of harmonic currents in a system therefore improves the systems power factor. As the Utilities measure the total power factor, we will have to check the value of these two factors if it is to be corrected. The good news is that companies that manufacture measuring instruments now provide the value of both of these factors. This will help us understand the cause of the deterioration of the power factor and choose the best way to improve it.

Case Study

The power supply of four computer rooms at College is divided between two distribution panels. Power measurements were taken while a 75kVA low Z transformer was installed to supply the two panels. These readings are shown in
Table – 4.1.

This transformer was replaced with another one with the same power rating whose primary winding was delta connected and whose secondary winding was double-output special winding connected, with an angular displacement of 30° between the two outputs, with each output supplying one of the panels. New power measurements were taken. These readings are shown in Table 4.2. Since the measurements were made at different times and the number of computer stations in operation was different, there was a slight variation in power measurements between the two tables. Comparing the two tables, one can see that the double-output zigzag transformer helps to improve the power factor and greatly reduces the level of harmonic currents injected into the electrical system. The power factor of a computer load is shown in Table – 1 and Table – 2, 0.685 to 0.746. If a phase shifting transformer is used, the difference on the primary side is from 0.882 to 0.982.

Table: 4.1

Low impedance transformer	Primary			Panel #1			Panel #2		
	A	B	C	A	B	C	A	B	C
Voltage (Volt)	573	571	574	199	199	199	198	198	198
Power (kW)	14.5			7.62			6.53		
Apparent power (kVA)	16			11			9.3		
PFtot	**.882**			.72			.707		
THDv (%)	2	1.9	1.6	2.6	3.9	4.2	2.8	3.9	4.3
THDi (%)	**55**	**50**	**52**	33.7	88.2	58.1	98.6	13.4	99.5
THDv (%) 3rd harmonic	.3	.5	.5	1.3	2.4	2.4	1.2	2.6	2.2
THDv (%) 5th harmonic	2	1.6	1.3	1.9	2.6	3	2.2	2.5	3.2
THDv (%) 7th harmonic	.2	.4	.1	.7	1	1.1	.8	.9	1
THDi (%) 3rd harmonic	**7.7**	**10.7**	**5.4**	79.5	72.2	80.6	81.4	81.5	82.5
THDi (%) 5th harmonic	**51.5**	**43.5**	**47.4**	45.3	45.5	46.5	50.5	48.5	49.8
THDi (%) 7th harmonic	**17.3**	**21.2**	**18.6**	14.4	19.2	17.8	21.9	18.6	22.6

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Table: 4.2

Double-output zigzag-connected transformer	Primary			Panel #1			Panel #2		
	A	B	C	A	B	C	A	B	C
Voltage (Volt)	570	570	571	197	197	198	198	198	198
Power (kW)	19.1			8.4			9.7		
Apparent power (kVA)	19.4			12.3			13		
PFtot	**.986**			.685			.746		
THDv (%)	2.5	2.4	2.5	2.8	2.6	2.9	4.6	4.7	4.7
THDi (%)	**19.6**	**18.4**	**18**	39.7	72.4	34	57.6	14.7	59.4
THDv (%) 3rd harmonic	.3	.3	.3	.5	.6	.2	.5	.7	.1
THDv (%) 5th harmonic	2.3	2.1	2.3	1.9	1.6	1.7	4.1	4.4	4.3
THDv (%) 7th harmonic	.5	.3	.5	1.6	1.6	2	.5	.6	.7
THDi (%) 3rd harmonic	**4.2**	**6.3**	**3.8**	85.8	77.5	82.8	73.1	74.1	75.7
THDi (%) 5th harmonic	**11.6**	**10.7**	**8.2**	61	56.5	58.9	38.6	40	44.6
THDi (%) 7th harmonic	**14**	**12.8**	**14.8**	33.5	33.4	32.3	9.8	11.1	15.5

Conclusion

It is estimated that 70% of electrical loads are now non-linear. The deterioration of the power factor will often be caused by harmonic currents (distortion factor) and not by inductive loads (displacement factor).

To find a proper technique for correcting the power factor and reduce harmonic currents in our system, the following are considered:

• Correct the displacement factor at the inductive source (by adding capacitors).

• Correct the distortion factor at the harmonic source by reducing harmonic currents and phase shifting systems.

Reference

1. *"A Comparative Evaluation of Harmonic Reduction Techniques in Three-Phase Utility Interface of Power Electronic Loads" IEEE Transactions on Industry applications vol. 30. N0.5 Sep/Oct 1994. Mukul Rastogi, Rajendra Naik, and Ned Mohan.*
2. *"Modern Power Electronics & Drives", prentice Hall PTR, 2002. The author described 'The effect of harmonics in the system & mitigation methods to reduce harmonics, such as in voltage source converters'. Bimal.K.Bose.*
3. *"Understanding FACTS" The author described 'The Concepts and Technology of Flexible AC Transmission Systems'. Narain G. Hingorani.*