Energy Saving Solutions to Commercial and Industrial Power Systems

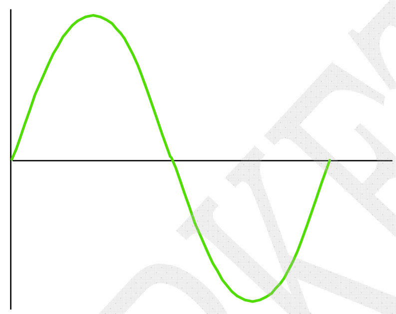
E-SAVING

U. S. MARKETING CO., LTD.

HARMONICS IN POWER SYSTEM.

INTRODUCTION.

A good assumption for most utilities in the United States is that the sine-wave voltage generated in central power stations is very good. In most areas, the voltage found on transmission systems typically has much less than 1.0 percent distortion. However, the distortion increases closer to the load. At some loads, the current waveform barely resembles a sine wave. Electronic power converters can chop the current into seemingly arbitrary waveforms.



The power company typically supplies a reasonably smooth sinusoidal waveform

While there are a few cases where the distortion is random, most distortion is periodic, or an integer multiple of the power system fundamental frequency. That is, the current waveform is nearly the same cycle after cycle, changing very slowly, if at all. This has given rise to the widespread use of the term harmonics to describe distortion of the waveform. This term must be carefully qualified to make sense.

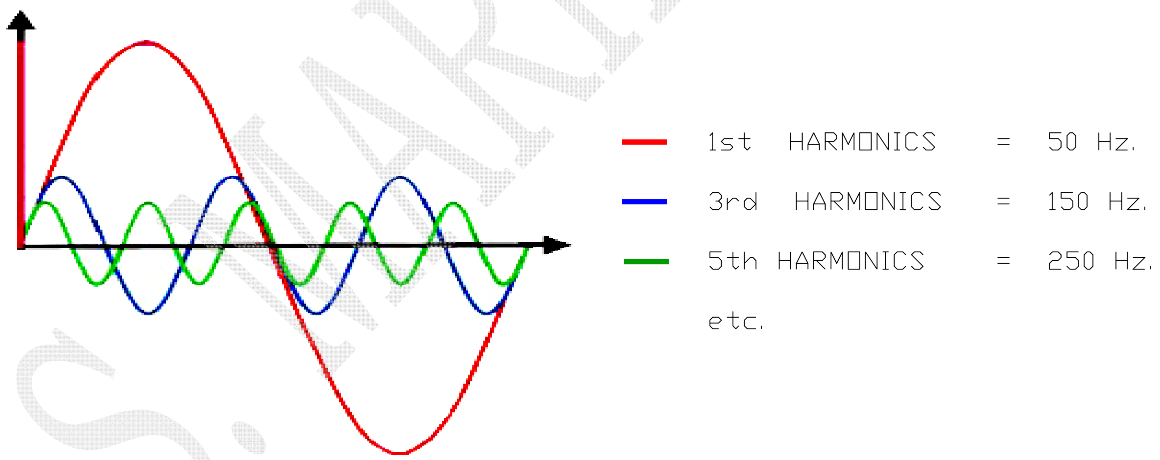
When electronic power converters first became commonplace in the late 1970s, many utility engineers became quite concerned about the ability of the power system to accommodate the harmonic distortion. Many dire predictions were made about the fate of power systems if these devices were permitted to exist. While some of these concerns were probably overstated, the field of power quality analysis owes a great debt of gratitude to these people because their concern over this "new" problem of harmonics sparked the research that has eventually led to much of the knowledge about all aspects of power quality.

Traditional power system quantities such RMS, power (reactive, active, apparent) power factor, and phase sequenced are defined for the fundamental frequency context in pure sinusoidal condition. In the presence of harmonic distortion the power system no longer operates in a sinusoidal condition, and unfortunately many of the simplifications power engineers use for the fundamental frequency analysis do not apply.

The increase in recent years of loads of electronic components has created a major change in the characteristics of electrical installations, which are evident when analyzing the waveforms of voltage and current in those circuits, which are increasingly different from pure sinusoidal signals, due to various disturbances, one of them are the harmonics.

HARMONICS.

a sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency when added together, result in a distorted waveform.

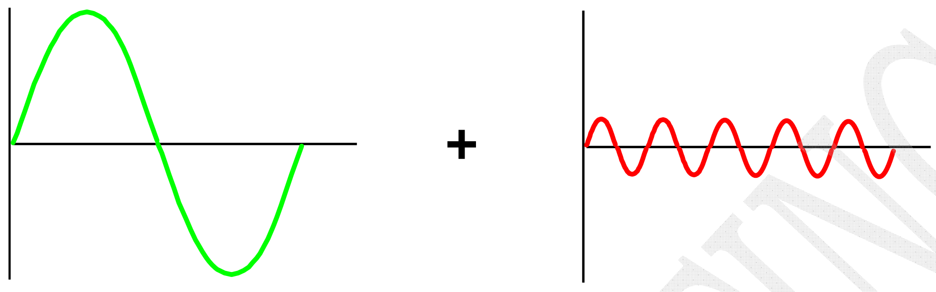


Harmonics in power system.

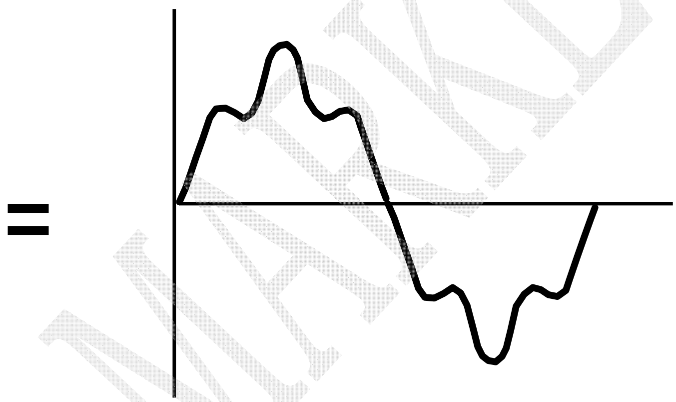
If the fundamental frequency (1st harmonic) is 50 Hz, the frequencies of the next harmonics are 100 Hz.(2nd harmonic), 150 Hz. (3rd harmonic),..., Etc.

The harmonics have the property that they are all periodic at the fundamental frequency, therefore the sum of harmonics is also periodic at that frequency.

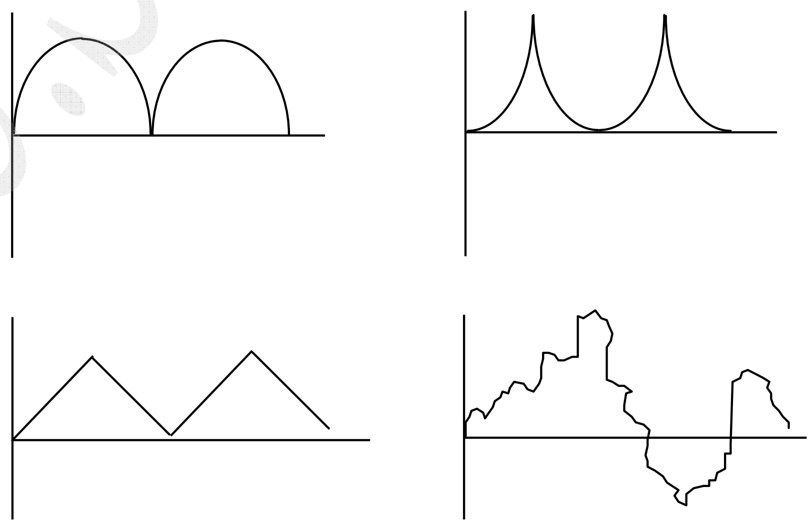
Fundamental Frequency *Harmonic Frequency*



The resulting wave shows a strong departure from the smooth waves comprising it :



In fact, any function may be constructed from a sine wave and some number of its harmonics.

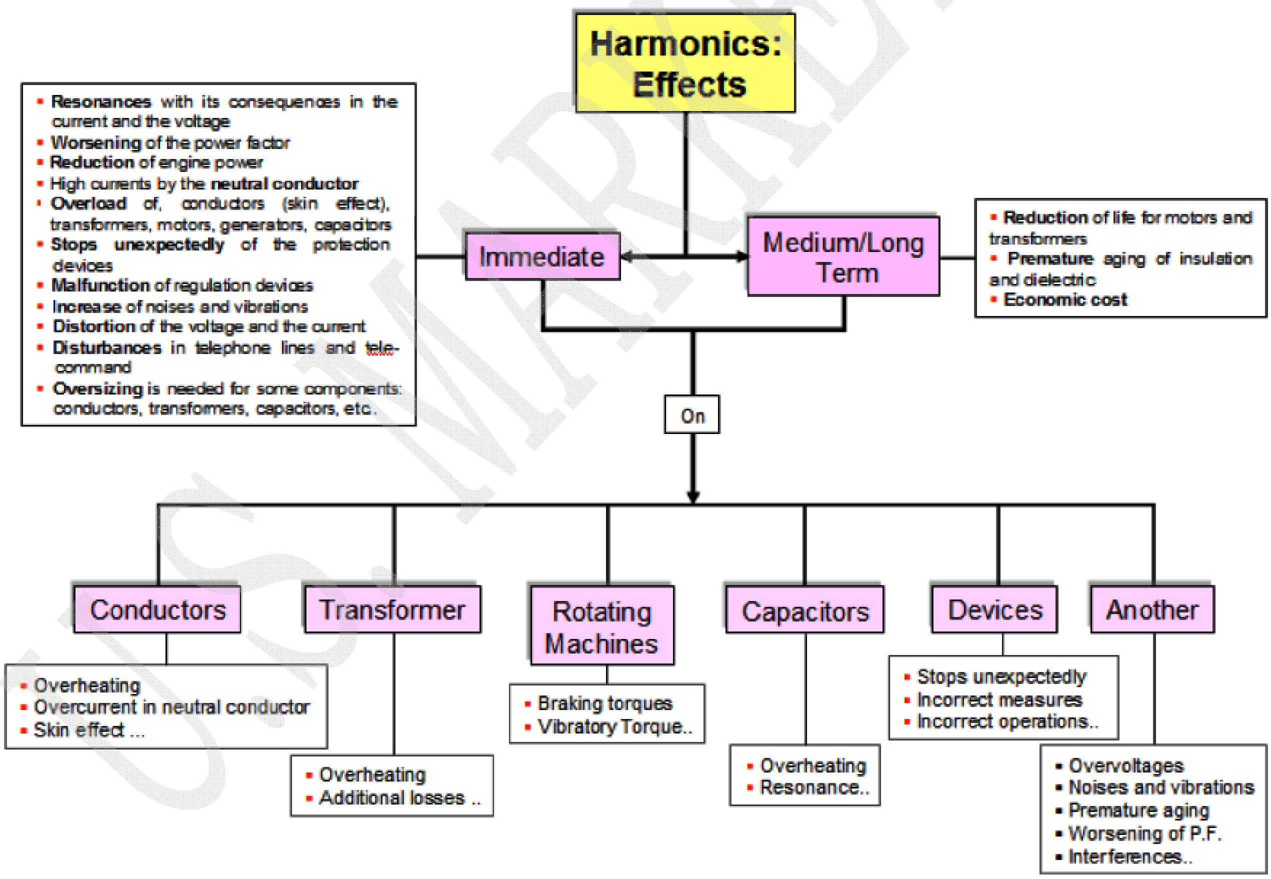


HARMONICS IN POWER SYSTEM.

Harmonics are electric voltages and currents that appear on the electric power system as a result of non-linear electric loads. When a linear electrical load is connected to the alternating current power system, it draws an unnecessarily sinusoidal current at the same frequency as the voltage (though usually not in phase with the voltage).

Harmonic frequencies in the power grid are a frequent cause of power quality problems. Not only can motors and other components on the system be overloaded, the increase to the current and voltage also results in the generation of huge amounts of heat.

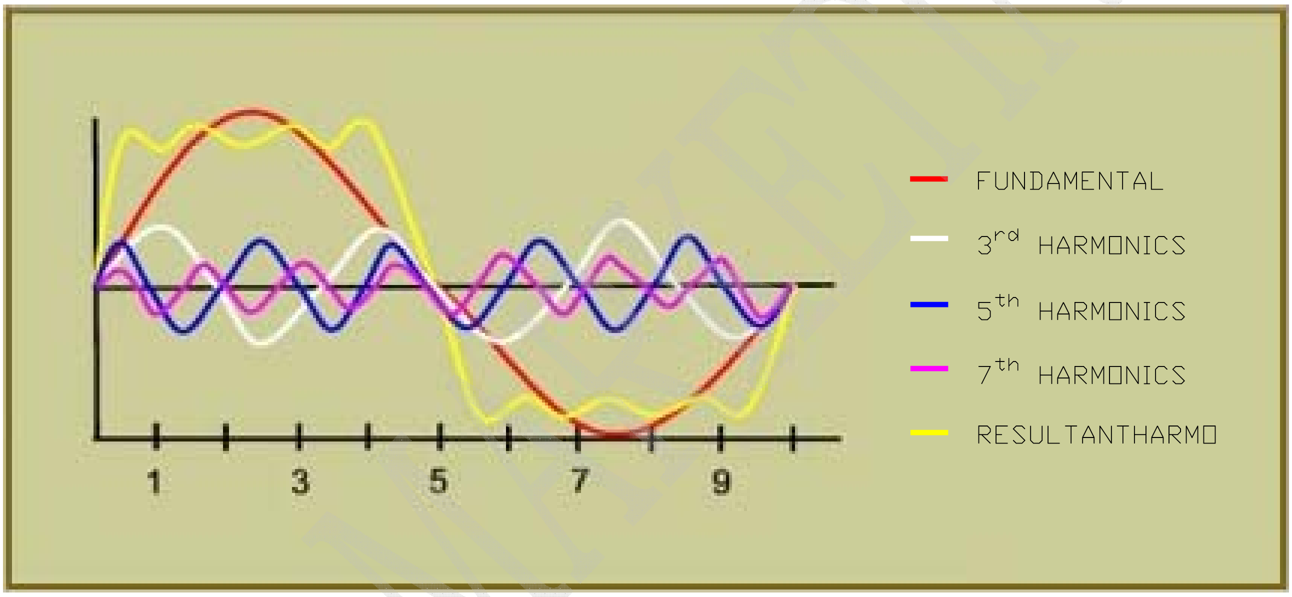
Therefore harmonic components should be reduced as much as possible.



HARMONICS DISTORTION.

Harmonics distortion is caused by nonlinear devices in the power system. A nonlinear device is one in which the current is not proportional to the applied voltage. When a sinusoidal voltage applied to a simple nonlinear resistor in which the voltage and current vary according to the curve shown. While the applied voltage is perfectly sinusoidal, the resulting current is distorted.

Increasing the voltage by a few percent may cause the current to double and take on a different wave shape. This is the source of most harmonics distortion in a power system.



Distortion of Harmonics Wave Form.

One of the major effects of power system harmonics is to increase the current in the system. This causes a sharp increase in the zero sequence current, and therefore increases the current in the neutral conductors. This effect requires special consideration in the design of an electric system to serve non-linear loads.

Beside the increased line current, different pieces of electrical equipment can suffer effects from harmonics on the power system by Total Harmonics Distortion (THD).

TOTAL HARMONICS DISTORTION : %THD.

Minimum Total Harmonics Distortion (THD) is one of the most important requirement from concerning good Power Quality. The fundamental frequency waveform which is always predominant, has been distorted by the addition of harmonic sinusoidal waveforms.

The measurement of harmonics distortion is measured by considering Percent Total Harmonic Distortion of the Fundamental (%THDv [voltage] & %THDI [current]).

* TOTAL HARMONICS CURRENT DISTORTION : %THDI

$$\%THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I^2_{h(rms)}}}{I_{1(rms)}} \times 100\%$$

* TOTAL HARMONICS VOLTAGE DISTORTION : %THDV

$$\%THD_V = \frac{\sqrt{\sum_{h=2}^{\infty} V^2_{h(rms)}}}{V_{1(rms)}} \times 100\%$$

THDI	:	Total Current Harmonics Distortion
THDV	:	Total Voltage Harmonics Distortion
Ih(rms)	:	Current RMS of h-Harmonic
Vh(rms)	:	Voltage RMS of h-Harmonic
I1(rms)	:	Current RMS of Fundamental Frequency
V1(rms)	:	Voltage RMS of Fundamental Frequency

IEEE 519-1992 Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems provides guidelines from determining what are acceptable limits. For voltage harmonics, the voltage level of the system is used to determine the limits, as shown in Table below . At the higher voltages, more customers will be effective, hence, the lower limits.

The table should be used as system design values for the “worst case” for normal operation (conditions lasting longer than one hour).

For shorter periods, during start-ups or unusual conditions, the limits may be exceeded by 50%.

Voltage Distortion Limits

Bus Voltage at PCC	Individual Voltage Distortion (%)	Total Voltage Distortion THD (%)
69kV and below	3.0	5.0 [1]
69.001kV through 161kV	1.5	2.5
161.001kV and above	1.0	1.5

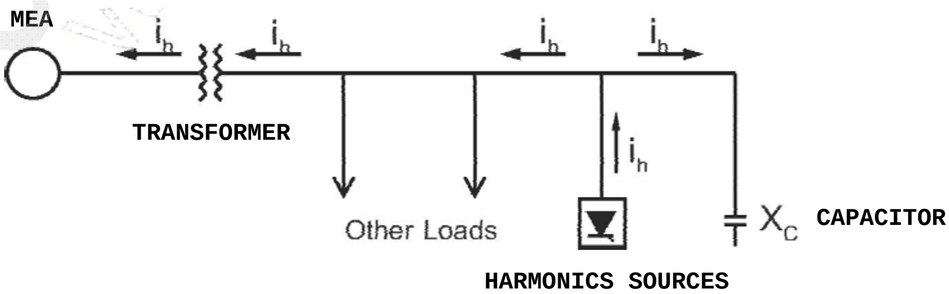
It is important to understand that THDv limits apply at the point of load connection. THDv levels at the loads may be several times higher than those at the distribution transformer's secondary terminals.

It is, after all, the loads that require reasonable levels of voltage distortion.

NATURE OF HARMONIC CURRENT FLOW.

In a system powering phase-to-neutral, Harmonics can cause overheating of neutral conductors. Inherently, harmonic currents will travel throughout the power system in the paths of the least impedance. In a balanced, 3-phase, 4-wire system with phase-to-neutral linear loads, the neutral currents will be zero. Even with a maximum unbalance, the resulting neutral current will be no greater than the maximum phase current. *Therefore, harmonics are currents additive in the neutral conductors.*

Moreover, since these harmonics oscillate at higher than fundamental frequency, they affect the impedance of any capacitors and inductive reactance (line, motor, transformer impedances) that is seen by the harmonics.
(It's common knowledge that inductance increases and capacitance decreases as frequency increases.)

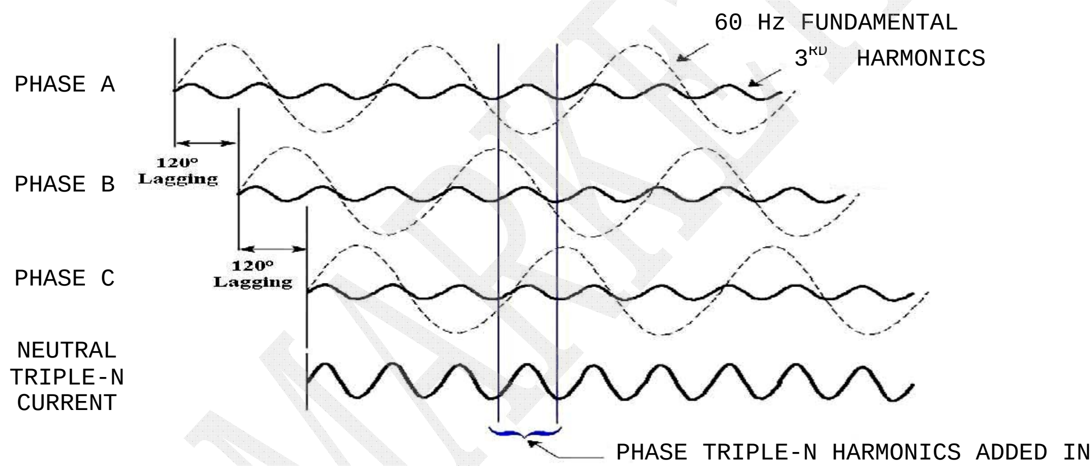


NORMAL FLOW of HARMONICS CURRENTS.

UNBALANCE SINGLE PHASE LOADS WITH TRIPLE-N.

Electronic equipment generates more than one harmonic frequency. For example, computers generate 3rd, 9th, and 15th harmonics. These are known as ***triple-n harmonics***. The triple-n harmonics are defined as the odd multiples of the 3rd harmonic (ex. 3rd, 9th, 15th, 21st etc.). Triple-n harmonics can especially cause overheating of neutral conductors on 3-phase, 4-wire systems. While the fundamental frequency and even harmonics cancel out in the neutral conductor, odd-order harmonics are additive.

Even in a balanced load condition, neutral currents can reach magnitudes as high as 1.73 times of the average phase current.

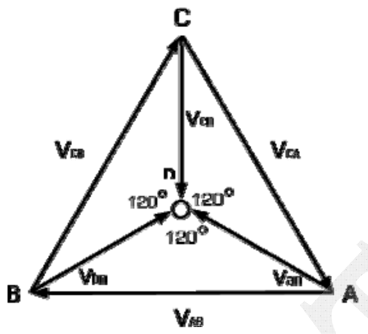


Unbalance Single Phase Loads with Triple-N Harmonics,
Triple-N Harmonics is Constructive Superposition in Neutral Conductor

Even in a balanced load condition, the current in neutral conductor can reach magnitudes as high as 1.73 times of the average phase current.

VOLTAGE UNBALANCE.

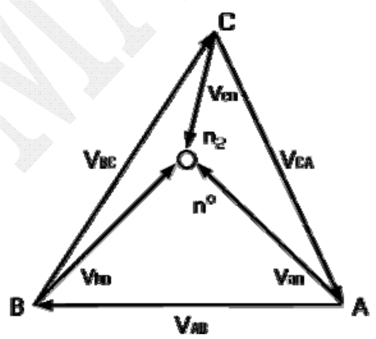
Voltage balance is probably the most important aspect of three-phase power quality. Just a slight voltage imbalance can lead to motor overheating and parameter motor failure.



Symmetrical Phasor Diagram of A.C. Voltage.

In a balanced sinusoidal supply system the three line-neutral voltages are equal in magnitude and are phase displaced from each other by 120 degrees.

If any differences that exist in the three voltage magnitudes and/or a shift in the phase separation from 120 degrees is said to give rise to an unbalanced supply.



Asymmetrical Phase to Phase Voltage.

From the earlier title, therefore, if harmonics increase the current in neutral conductors which should be the zero sequence current, the system becomes voltage unbalance.

Voltage unbalance is regarded as a power quality problem, which can have a serious impacts on induction motors, adjustable speed driver and any other 3-phase equipments.

NEGATIVE SEQUENCE VOLTAGE.

Harmonic currents can cause an induction motor to run backwards. Besides running backwards, the motors will overheat due to the additional horsepower required to overcome the harmonic "torque fight."

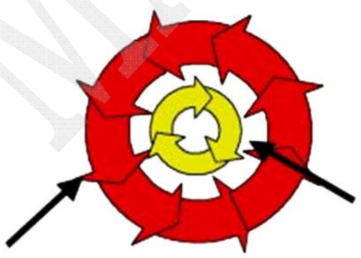
Rotate with Fundamental	+	1st	7th	13th	9th
Does not Rotate	0	3rd	9th	15th	21th
Rotate against Fundamental	–	5th	11th	17th	23th

Rotation sequences according to harmonic number.

Harmonics which rotate with the same sequence as the fundamental, are called ***positive sequence harmonics***.

Harmonics which rotate in the opposite sequence as the fundamental are called ***negative sequence harmonics***.

Triple-n harmonics which don't rotate at all because they're in phase with each other, are called ***zero sequence harmonics***.



Sequence especially matters when we deal with AC motors, since the mechanical rotation of the rotor depends on the torque produced by the sequential rotation of the applied 3-phase power.

A 0°	B 120°	C 240°	A-B-C
A' 3 x 0° (0°)	B' 3 x 120° (360° = 0°)	C' 3 x 240° (720° = 0°)	*no rotation*
A'' 5 x 0° (0°)	B'' 5 x 120° (-120°)	C'' 5 x 240° (-240°)	C-B-A
A''' 7 x 0° (0°)	B''' 7 x 120° (120°)	C''' 7 x 240° (240°)	A-B-C
A'''' 9 x 0° (0°)	B'''' 9 x 120° (1080° = 0°)	C'''' 9 x 240° (2160° = 0°)	*no rotation*

- Positive-sequence harmonics, for instance 1st, 4th, 7th, 10th, and 13th work to push the rotor in the proper direction.
- Whereas negative-sequence harmonics, for instance 2nd, 5th, 8th, 11th, and 14th actually work against the direction of the rotor's rotation.
- Zero-sequence harmonics, for instance 3rd, 9th, 15th, and 21st neither contribute to nor detract from the rotor's torque.

An excess of negative-sequence harmonics in the power supplied to a three-phase AC motor will result in a degradation of performance and possible overheating.

SKIN EFFECT PHENOMENON.

Harmonic frequencies are always higher than the 60 Hz fundamental frequency so "skin effect" also becomes a factor. Skin effect is a phenomenon where the higher frequency causes the electrons to flow toward the outer sides of a conductor.

This phenomenon reduces the ability of the conductor to carry current by reducing the cross sectional diameter of the conductor and thereby reduces the ampere capacity rating of the conductor.

Skin effect increases as the frequency and the amplitude increase. These are the reason that higher harmonic frequencies (since 7th harmonics) cause a greater degree of heating in conductors.

HARMONICS AND CAP BANK.

Inherently, The impedance of a circuit dictates the current flow in that circuit. As the supply impedance is generally considered to be inductive, the network impedance increases with frequency while the impedance of a capacitor decreases, as equation below.

$$X_C = 1/2\pi F_C$$

X_C : Impedance of Capacitor

F_C : Frequency of Capacitor

This causes a greater proportion of the currents circulating at frequencies above the fundamental supply frequency to be absorbed by the capacitor, and all equipment associated with the capacitor.

In certain circumstances, harmonic currents can exceed the value of the fundamental capacitor current. These harmonic problems can also cause an increased voltage across the dielectric of the capacitor which could exceed the maximum voltage rating of the capacitor, resulting in premature capacitor failure.

EFFECT OF HARMONICS IN POWER SYSTEM.

HEATING EFFECTS.

STEEL PANELS

- Heat from eddy currents.
- Vibration and buzzing sounds from magnetic fields.

TRANSFORMERS

- Winding heat up from skin effect losses.
- Iron core heat up from eddy current losses.

INDUCTION MOTORS

- Overheating can occur from eddy current and skin effect.

Neutral conductors have high current

- From zero sequence or triples harmonics.

REVERSE TORQUE EFFECT.

INDUCTION MOTOR

- Negative sequence harmonics create reverse rotating magnetic fields which reduces motor's efficiency and useful life and resulting less motor's efficiencv..

INDUCTION DISK KWH METER

- Error of measurement.

RESONANCE-CURRENT AMPLIFICATION.

POWER FACTOR CAPACITOR

- From a parallel resonance circuit with power system resulting in high circulating current.

INTERFERENCE

TELECOMMUNICATION SYSTEM

- Induce voltage from harmonic flux linkages.

RIPPLE CONTROL SYSTEM

- Harmonic voltage can affect ripple signal.

AUTOMATIC CONTROL SYSTEM

WAVEFORM AND TIMING EVENTS

VOLTAGE NOTCHING

- Very high dv/dt.

MULTIPLE ZERO CROSSING

- Misoperation of triggering system.

OTHERS EFFECT OF HARMONICS.

- Create Dielectric stress to capacitor bank, shorten life expectancy.
- Breakers and fuses tripping.
- Unreliable operation of electronic equipment.
- Erroneous registration of electric meters.
- Cause malfunctioning to control system such as relays, electronic meter.
- Decreased kVA capacity.
- Wasted capacity - Inefficient distribution of power.
- Increased maintenance of equipment and machinery.
- Waste energy/high electric bills - kW & kWh.

NEUTRAL BLOCKING by E-SAVING.

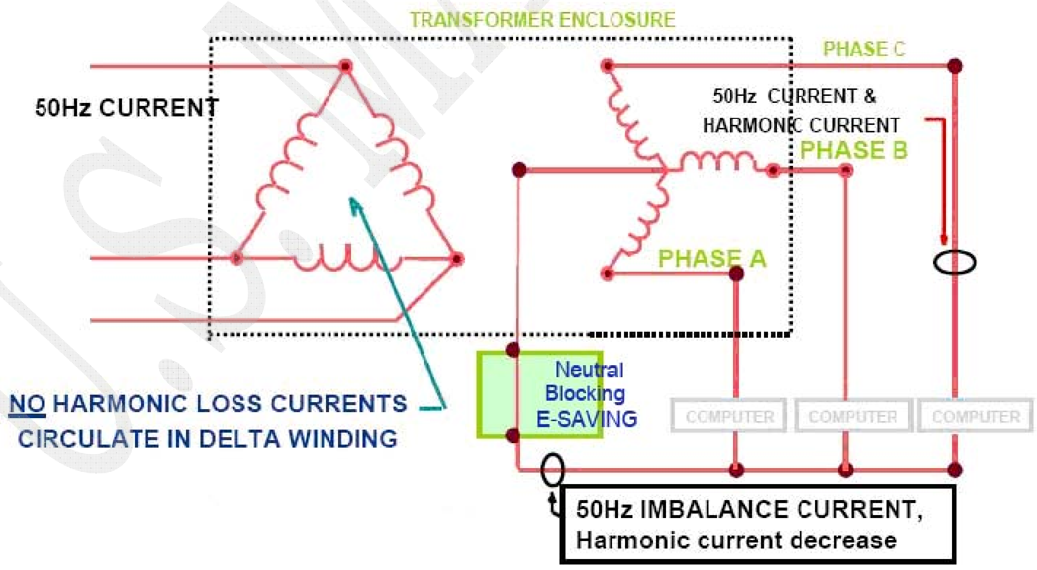
With our 10 years of experience and knowledge, Harmonic is well defined as "hidden expenses" that exists in a 3-phases electricity loop and often creates unidentified losses for the business owner in these areas.

E-saving is a harmonic blocking device that provides the solution to block harmonic current in neutral conductor in order to decrease losses and power consumption. This device will improve the power quality and efficiency of electronic equipment in terms of improving the consistency of the electric systems, prolonging product life, decrease power consumption and lastly reducing electric bills. Therefore, this is a preventive method which prevents an unpredictable loss in the electric system from the beginning than a protective method which protects when the loss is really happening.

Theory and Concept

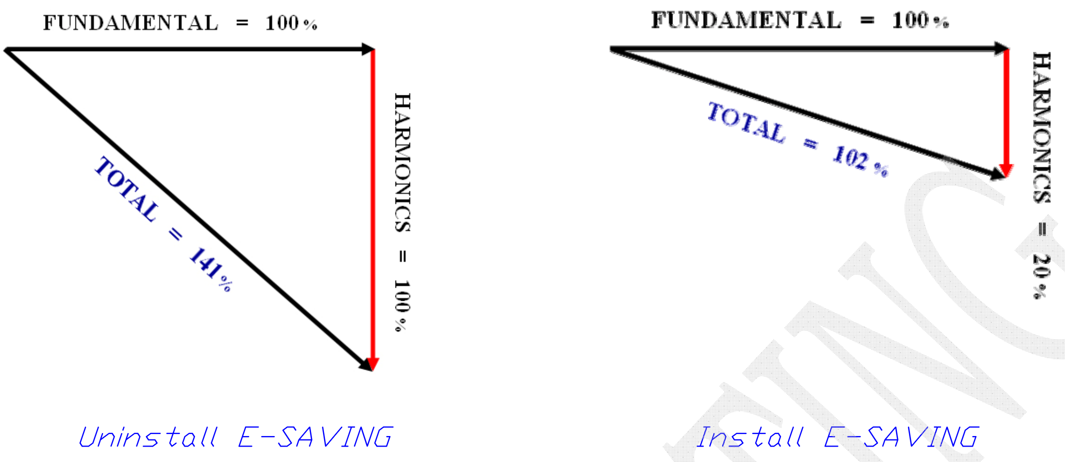
1.) Passive LC filter.

2.) 3-phase compensation of reactive power by filter circuit.



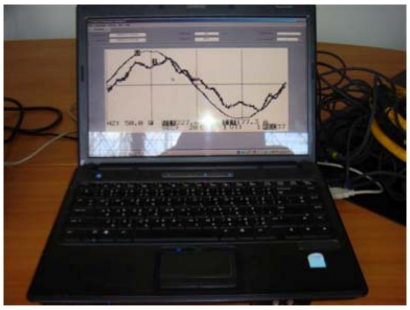
Neutral Blocking by E-SAVING

BENEFITS of E-SAVING.



- Eliminates Harmonics at the source rather than accommodating downstream.
- Provides real power-cost savings due to reduced I^2R heating.
- Reduces I^2R heat losses in the transformer and wiring system.
- Reduces the air conditioning needed to remove I^2R heat.
- Increases the number of computer loads that can be carried per circuit.
- Reduces currents in neutral conductor.
- Decreases RMS-phase current.
- Releases un-useable capacity.
- Removes harmonics current from all the system neutrals from the transformer out to the furthest outlet.
- Fast Payback based on Energy Savings.

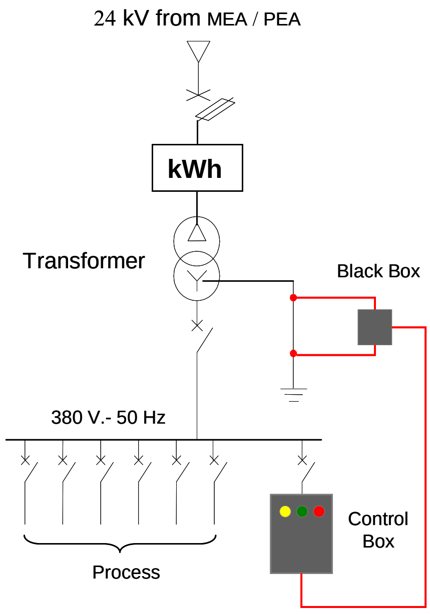
MEASURING E-SAVING.

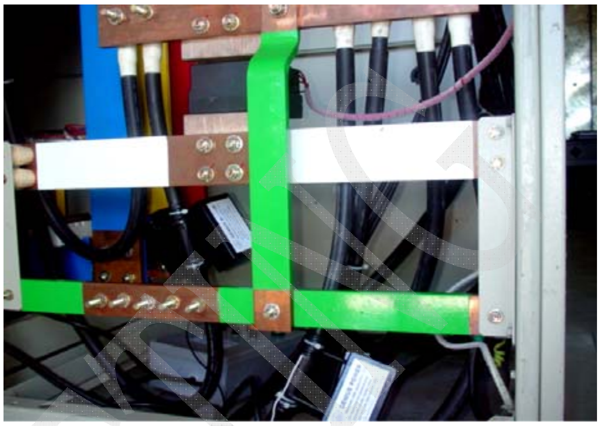


In order to analyze the quality of power system, the specialist will measure the harmonics which appear on the electric power system by using specific meters and other components in the electric system. By doing this, the specialist can compare the variation of each component from the graph which compiled by specific software program and identify the effects of harmonics in the system.

All the collected data will be applied to design E-SAVING in order to get the most efficient and suitable harmonics blocking for each power system.

INSTALLATION OF E-SAVING.





Typical of Installation

To block harmonics in the power system, **E-Saving** will be installed at MDB panel by parallel connecting to the neutral conductor of the system. All the processes must be done by specialist. During the installation, it is unnecessary to cut off power system, therefore, there is no need to postpone or stop the working process.

E-Saving is an energy-saving device which aims to improve the quality of power system by blocking harmonics in the system and reducing losses, as a result, it helps the user to save more electricity cost after installation (at least 5% per month***).

The installation of E-saving will not reduce the efficiency of other electronic devices in the power system to save cost. On the other hand, the installation of this device will improve the stability and quality of other devices.

*** Percent of cost reduction is up to factor in each power system.

PROJECT REFERENCE AND EXPERIENCE.


JOMTAIN THANEE
PATTAYA


LOTUS CRYSTAL
FACTORY


GOVERNMENT
OFFICE

KHUM-SUPHAN
HOTEL