



ELECTRICAL POWER SYSTEMS - CEM REFRESHER TRAINING

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FOR ENERGY MANAGEMENT AND EFFICIENCY PROFESSIONALS





HARMONICS FOR ENERGY PROFESSIONALS

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WHAT SHOULD YOU LEARN



- System Distribution Losses example
- Introduction to Harmonics
- Analysis of Electrical Power Systems



SYSTEM DISTRIBUTION LOSSES

For example the cable losses in any industrial plant will be up to 6 percent depending on the size and complexity of the distribution system. Note that all of these are current dependent, and can be readily mitigated by any technique that reduces facility current load. Various losses in distribution equipment is given in the Table1.3.

TABLE 1.3 LOSSES IN ELECTRICAL DISTRIBUTION EQUIPMENT

S.No	Equipment	% Energy Loss at Full Load Variation	
		Min	Max
1.	Outdoor circuit breaker (15 to 250 KV)	0.002	0.015
2.	Circuit breakers	0.019	1.5
3.	Medium voltage switchgear (5 to 15 KV)	0.005	0.02
4.	Current limiting reactors	0.09	0.30
5.	Transformers	0.40	1.00
6.	Load break switches	0.005	0.025
7.	Medium voltage starters	0.02	0.15
8.	Bus ways less than 450 V	0.03	0.30
9.	Low voltage switchgear	0.13	0.34
10.	Motor control centres	0.01	0.40
11.	Cables	1.00	4.00
12.	Large motors	3.0	10
13.	Static variable speed drives	6.0	15.0
14.	Capacitors (Watts / KVA)	0.50	6.0

In system distribution loss optimization, the various options available include:

- ✓ Relocating transformers and sub-stations near to load centers
- ✓ Rerouting and re-conductoring such feeders and lines where the losses or voltage drops are higher
- ✓ Power factor improvement by incorporating capacitors at load end.
- ✓ Optimum loading of transformers in the system.
- ✓ Opting for lower resistance All Aluminium Alloy Conductors (AAAC) in place of conventional Aluminium Cored Steel Reinforced (ACSR) lines
- ✓ Minimizing losses due to weak links in distribution network such as jumpers, loose contacts, old brittle conductors.

HARMONICS

In any alternating current network, flow of current depends upon the voltage applied and the impedance (resistance to AC) provided by elements like resistances, reactances of inductive and capacitive nature. As the value of impedance in above devices is constant, they are called lin- ear whereby the voltage and current relation is of linear nature.

However in real life situation, various devices like diodes, silicon controlled rectifiers, PWM systems, thyristors, voltage & current chopping saturated core reactors, induction & arc furnaces are also deployed for various requirements and due to their varying impedance characteristic, these NON LINEAR devices cause distortion in voltage and current waveforms which is of increasing concern in recent times. Harmonics occurs as spikes at intervals which are multiples of the mains (supply) frequency and these distort the pure sine wave form of the supply voltage & current.

HARMONICS

Harmonics are multiples of the fundamental frequency of an electrical power system. If, for example, the fundamental frequency is 50 Hz, then the 5th harmonic is five times that frequency, or 250 Hz. Likewise, the 7th harmonic is seven times the fundamental or 350 Hz, and so on for higher order harmonics.

Harmonics can be discussed in terms of current or voltage. A 5th harmonic current is simply a current flowing at 250 Hz on a 50 Hz system. The 5th harmonic current flowing through the system impedance creates a 5th harmonic voltage. Total Harmonic Distortion (THD) expresses the amount of harmonics. The following is the formula for calculating the THD for current:

HARMONICS +

$$THD_{current} = \sqrt{\sum_{n=2}^{\infty} \left(\frac{I_n}{I_1} \right)^2} \times 100$$

Then...

$$I_{THD} = \sqrt{\left(\frac{50}{250} \right)^2 + \left(\frac{35}{250} \right)^2} \times 100 = 24\%$$

When harmonic currents flow in a power system, they are known as "poor power quality" or "dirty power". Other causes of poor power quality include transients such as voltage spikes, surges, sags, and ringing. Because they repeat every cycle, harmonics are regarded as a steady-state cause of poor power quality.

When expressed as a percentage of fundamental voltage THD is given by,

$$THD_{voltage} = \sqrt{\sum_{n=2}^{\infty} \left(\frac{V_n}{V_1} \right)^2} \times 100$$

where V_1 is the fundamental frequency voltage and V_n is n^{th} harmonic voltage component.

MAJOR CAUSES OF HARMONICS

Devices that draw non-sinusoidal currents when a sinusoidal voltage is applied create harmonics. Frequently these are devices that convert AC to DC. Some of these devices are listed below:

Electronic Switching Power Converters

- ✓ Computers, Uninterruptible power supplies (UPS), Solid-state rectifiers
- ✓ Electronic process control equipment, PLC's, etc
- ✓ Electronic lighting ballasts, including light dimmer
- ✓ Reduced voltage motor controllers

Arcing Devices

- ✓ Discharge lighting, e.g. Fluorescent, Sodium and Mercury vapor
- ✓ Arc furnaces, Welding equipment, Electrical traction system

MAJOR CAUSES OF HARMONICS +

Ferromagnetic Devices

- ✓ Transformers operating near saturation level
- ✓ Magnetic ballasts (Saturated Iron core)
- ✓ Induction heating equipment, Chokes, Motors

Appliances

- ✓ TV sets, air conditioners, washing machines, microwave ovens
- ✓ Fax machines, photocopiers, printers

These devices use power electronics like SCRs, diodes, and thyristors, which are a growing percentage of the load in industrial power systems. The majority use a 6-pulse converter. Most loads which produce harmonics, do so as a steady-state phenomenon. A snapshot reading of an operating load that is suspected to be non-linear can determine if it is producing harmonics. Normally each load would manifest a specific harmonic spectrum.

MAJOR CAUSES OF HARMONICS +

Many problems can arise from harmonic currents in a power system. Some problems are easy to detect; others exist and persist because harmonics are not suspected. Higher RMS current and voltage in the system are caused by harmonic currents, which can result in any of the problems listed below:

1. Blinking of Incandescent Lights - Transformer Saturation
2. Capacitor Failure - Harmonic Resonance
3. Circuit Breakers Tripping - Inductive Heating and Overload
4. Conductor Failure - Inductive Heating
5. Electronic Equipment Shutting down - Voltage Distortion
6. Flickering of Fluorescent Lights - Transformer Saturation
7. Fuses Blowing for No Apparent Reason - Inductive Heating and Overload
8. Motor Failures (overheating) - Voltage Drop
9. Neutral Conductor and Terminal Failures - Additive Triplen Currents
10. Electromagnetic Load Failures - Inductive Heating
11. Overheating of Metal Enclosures - Inductive Heating
12. Power Interference on Voice Communication - Harmonic Noise
13. Transformer Failures - Inductive Heating

OVERCOMING HARMONICS

Tuned Harmonic filters consisting of a capacitor bank and reactor in series are designed and adopted for suppressing harmonics, by providing low impedance path for harmonic component.

The Harmonic filters connected suitably near the equipment generating harmonics help to reduce THD to acceptable limits. In present Indian context where no Electro Magnetic Compatibility regulations exist as a application of Harmonic filters is very relevant for indus- tries having diesel power generation sets and co-generation units.

ANALYSIS OF ELECTRICAL POWER SYSTEMS

TABLE 1.4 TROUBLE SHOOTING OF ELECTRICAL POWER SYSTEMS

System Problem	Common Causes	Possible Effects	Solutions
Voltage imbalances among the three phases	Improper transformer tap settings, light-phase loads not balanced among phases, poor connections, bad conductors, transformer ground or fault.	Motor vibration, premature motor failure. A 5% imbalance causes a 40% increase in motor losses.	Balance loads among phases.
Voltage deviations from rated voltage (too low or high)	Improper transformer settings, incorrect selection of devices.	Over-voltage is motor motor efficiency, power factor and equipment life. Undervoltage is reduced performance.	Correct transformer settings, correct ratings and correct input voltage.
Poor connections in distribution or at connected loads	Loose bus bar connections, loose cable connections, corroded connections, poor crimps, loose or worn conductors	Produces heat, causes failure or increases the risk in voltage drops and voltage imbalances?	Use Infra Red camera to locate hot spots and correct.
Undesired conductors	Function regarding beyond original designs, poor power factor	Voltage drop and energy waste.	Reduce the load by conservation load scheduling.
Insulation damage	Degradation over time due to moisture, temperature, abrasion, moisture, chemicals	May lead to ground or to another phase. Variable energy waste.	Replace conductors, insulators
Low Power Factor	Inductive loads such as motors, transformers, and lighting ballasts. Non-linear loads, such as some electronic loads.	Reduces current carrying capacity of wiring, voltage regulation effectiveness, and equipment life.	Add capacitors to counteract reactive loads.
Harmonics (non-sinusoidal voltage and/or current wave forms)	Office electronics, UPSs, variable frequency drives, high intensity discharge lighting, and electronic and control systems.	Over-heating of neutral conductors, motors, transformers, switch gear. Voltage drop, low power factors, reduced capacity.	Take care with equipment selection and isolate sensitive electronics from noisy circuits.

An analysis of an electrical power system may uncover energy waste, fire hazards, and equipment failure. Facility /energy managers increasingly find that reliability centered maintenance can save money, energy, and downtime (see Table 1.4).


