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Illuminating
ENGINEERING SOCIETY

Interaction of CCRs and Emergency Generators

IES of North America Airfield Lighting Conference, Galloway, NJ, October 2010

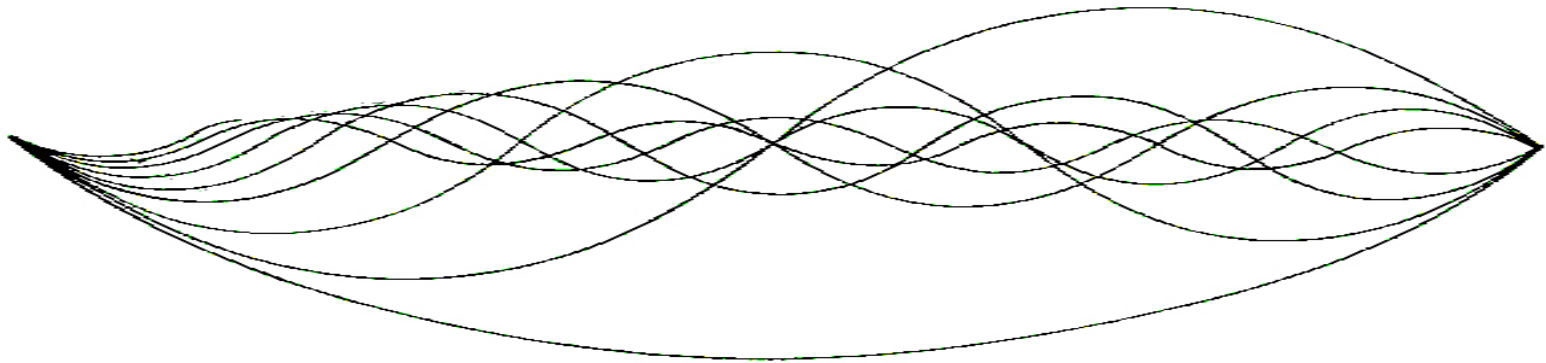
David Alm | Principal Electrical Engineer

Aviation Consultant – Aeronautical Ground Lighting



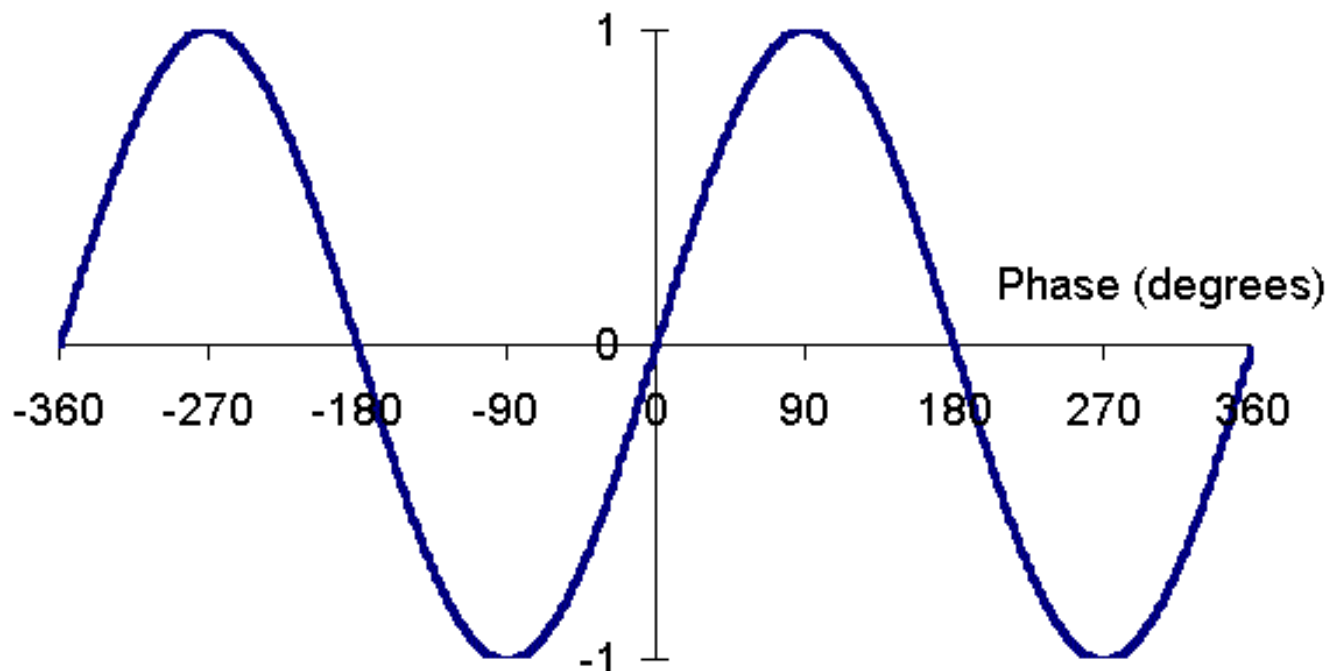
Introduction

- Introduction to **harmonics** and **harmonic** content
- **Harmonic** voltages and currents
- CCRs and their varying **harmonic** content
- Interaction of **harmonic** content with emergency generators
- Strategies to mitigate impact of **harmonics**



Introduction to harmonics and harmonic content

Sinusoidal Waveform



$$v(t) = A \sin(\omega t + \theta)$$

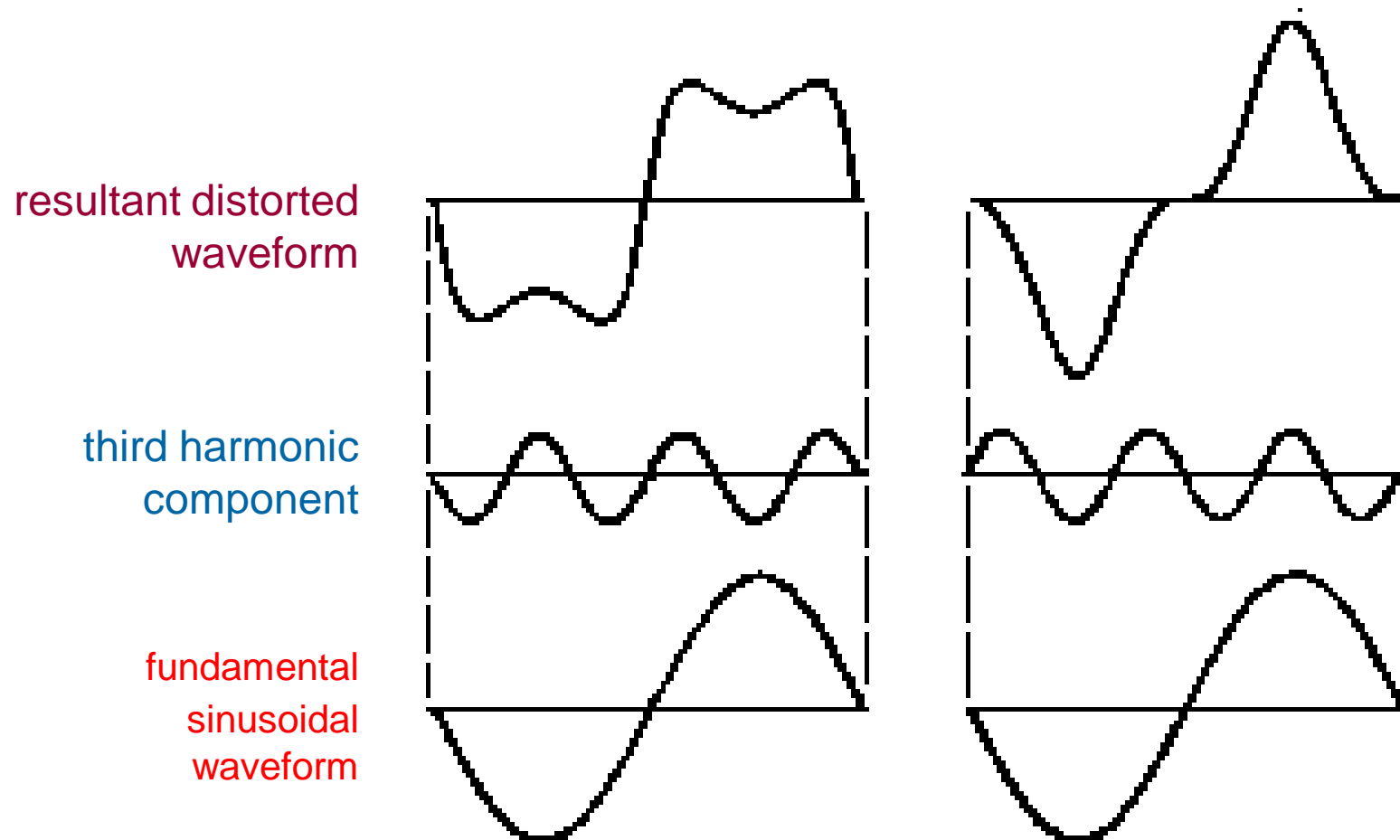
instantaneous
amplitude

peak amplitude deviating
from centre

angular frequency

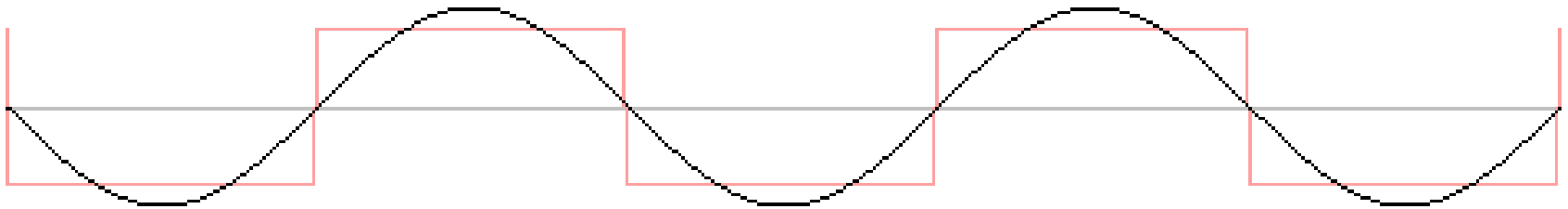
horizontal
displacement

Harmonics and Harmonic Distortion



Fourier Transformations

harmonics: 1



Harmonic Content

- Total Harmonic Content (THD)
- Total Demand Distortion (TDD)

$$THD_I = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + I_5^2 + \dots}}{I_1}$$

$$TDD_I = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + I_5^2 + \dots}}{I_L}$$

Harmonic voltages and currents

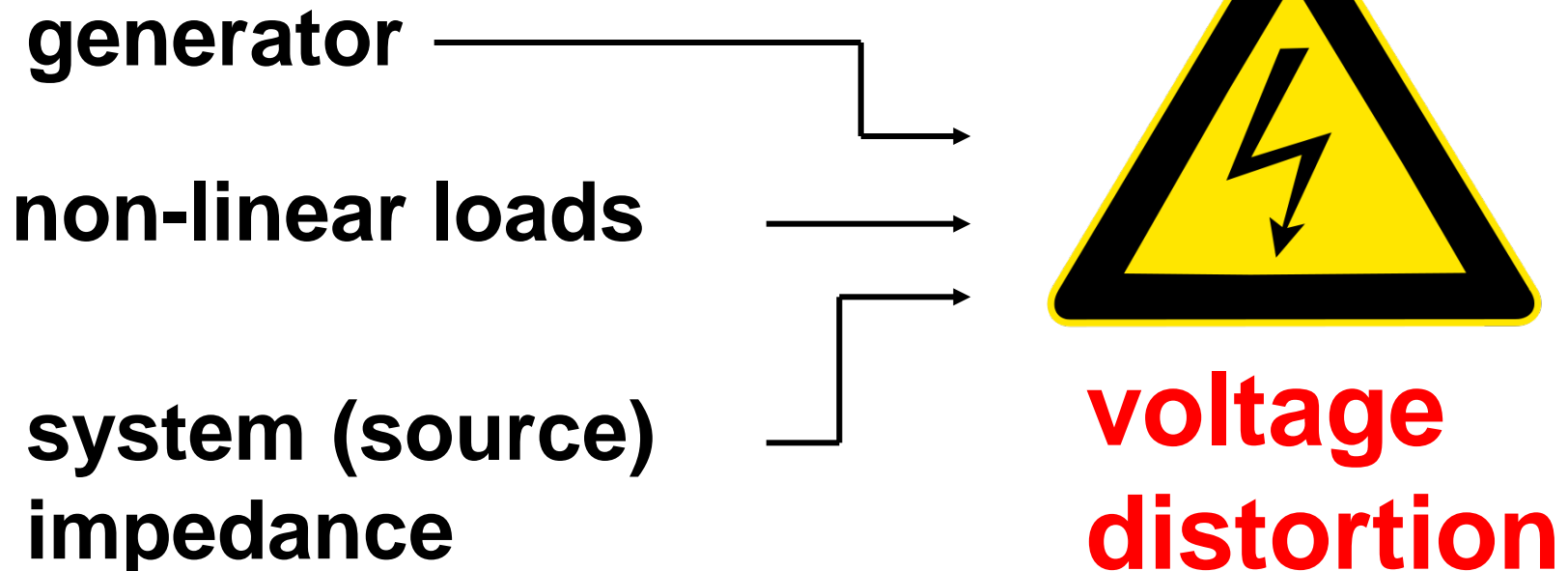
Waveforms and Harmonics

- AC generators do not produce pure sinusoidal waveforms
 - Winding distribution and magnetic field are not uniform
- Voltage **waveform distortions** created
- Resolved in a number of **pure sinusoidal waveforms**
 - Different frequencies that are multiples (**harmonics**) of the fundamental frequency

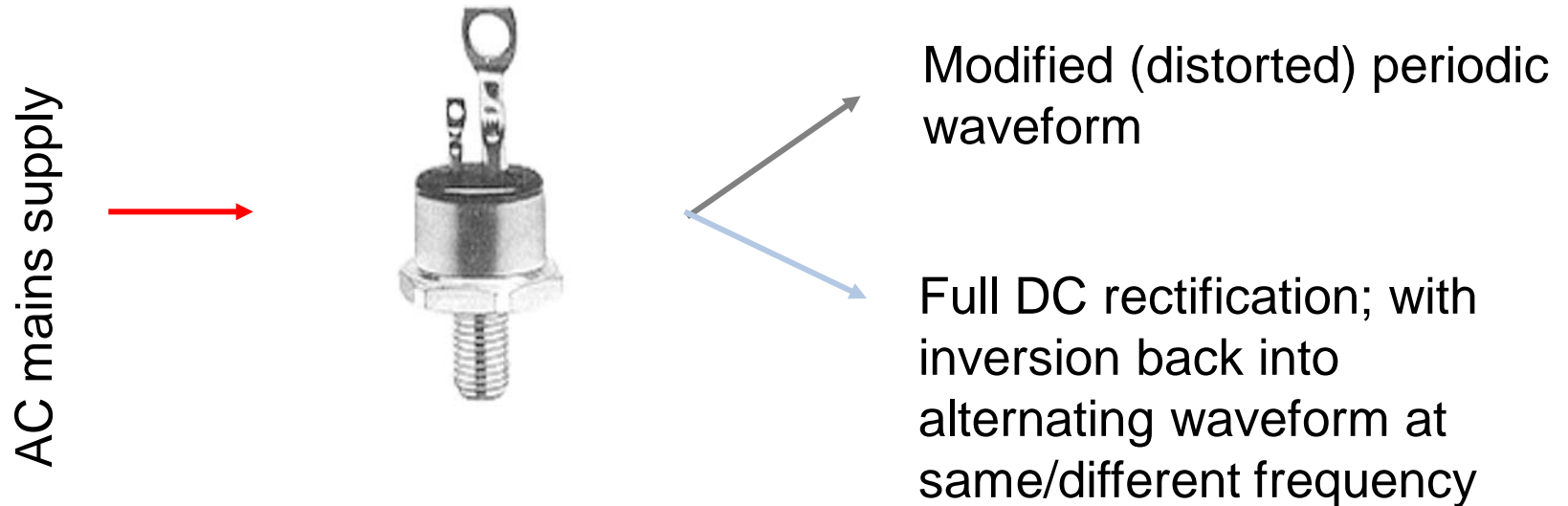


Linear and Non-Linear Loads

- **Linear:** Current drawn is **proportional** to supply voltage and impedance
- **Non-Linear:** Current drawn **varies** in shape from supply voltage

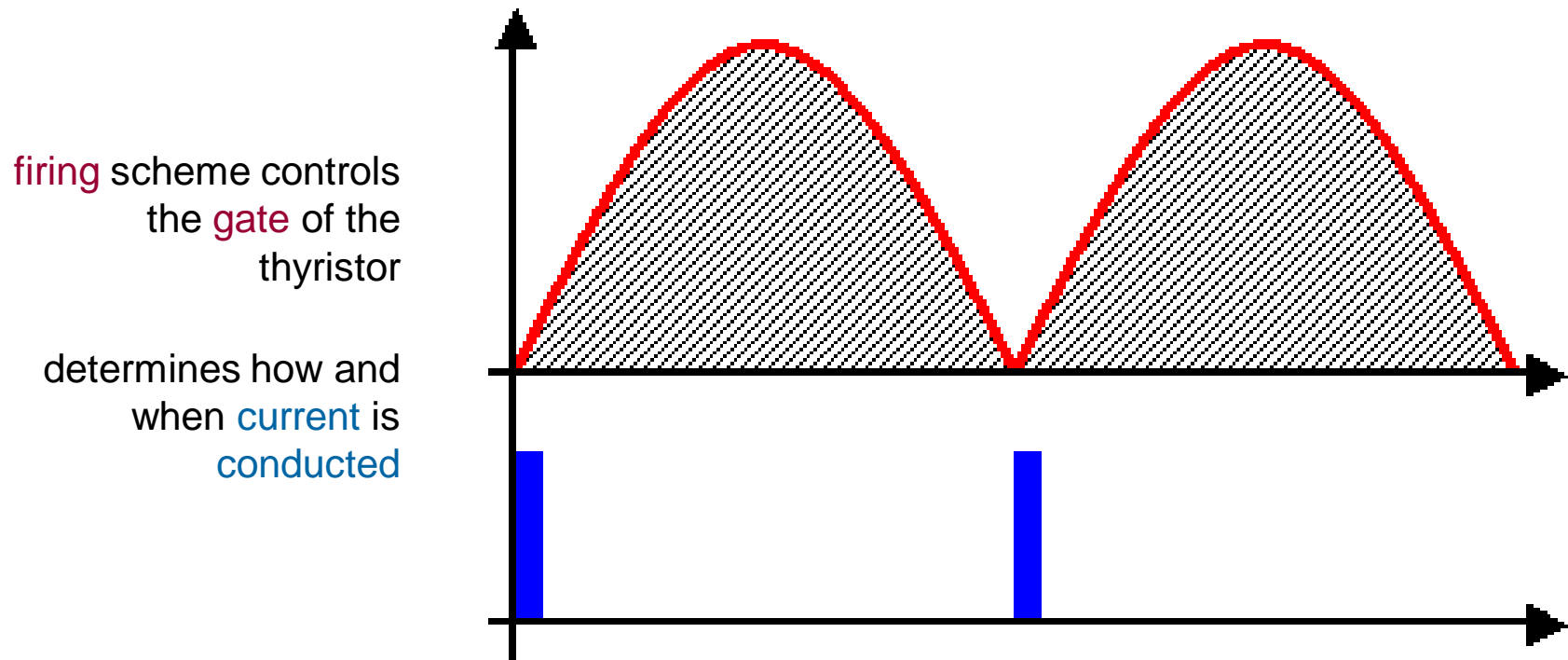


Phase Angle Controlled Thyristors



Distorted current waveform drawn that generates **harmonic** content

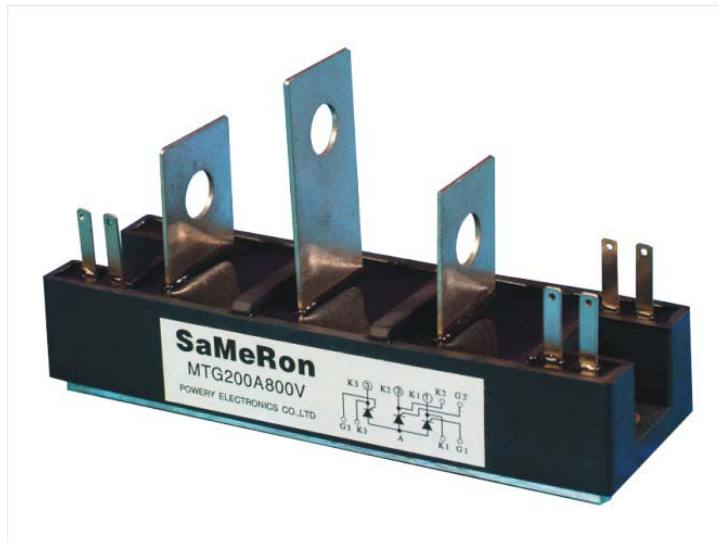
Thyristor Operation



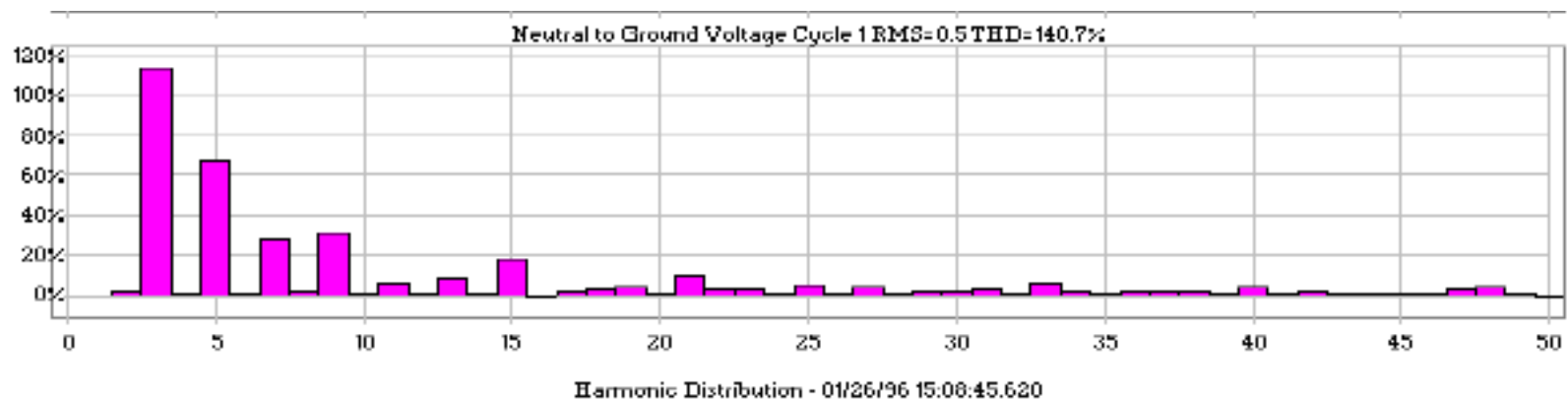
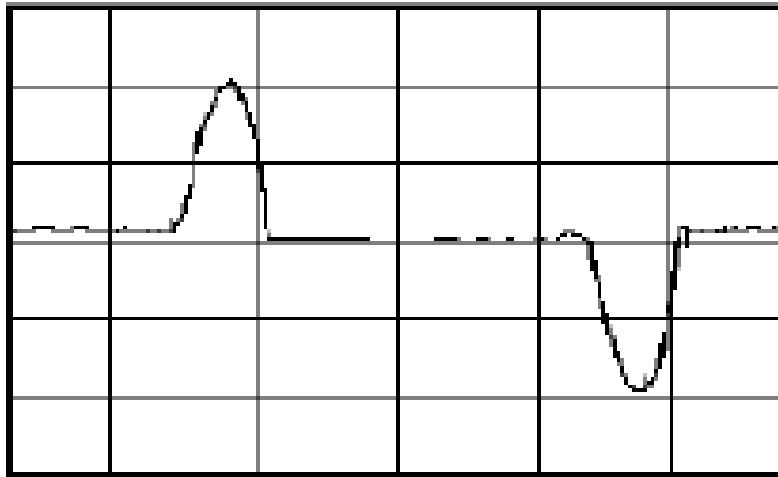
Device remains latched on and conducts current until current falls back to zero

Thyristors and Harmonics

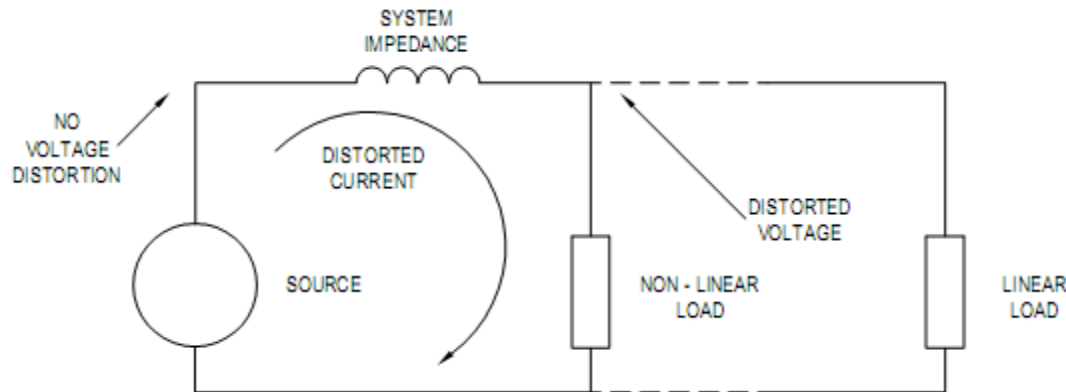
- As **thyristors** triggered or gated **later** in half wave cycle – range of **harmonic** content **increases**
- As magnitude of **current** drawn **increases** – magnitude of **harmonics** in distorted waveform **increases**



Harmonic Spectrum of Current Waveform



Interaction of Non-Sinusoidal Waveform with Mains Supply



non-linear load draws **current** through the **source impedance**

$$V_h = I_h \times Z_h$$

for each harmonic...

- **Harmonic current** passing through **harmonic impedance** produces **harmonic voltage**
- Linear load will also see **harmonic voltage**

CCRs and their varying harmonic content

Constant Current Regulators (CCRs)

- CCRs use Thyristors (or silicon controlled rectifiers) to vary applied voltage to maintain constant current
- This in turn varies power drawn from supply
- No limit in IEC/FAA CCR standards for harmonics produced by CCRs
 - IEEE STD 519 defines harmonic current limits at Point of Common Coupling
 - AS/NZS 61000.3.12 defines harmonic current limits for items of equipment
- RMS voltage and current; used to define the effective or mean power transferred to primary circuit

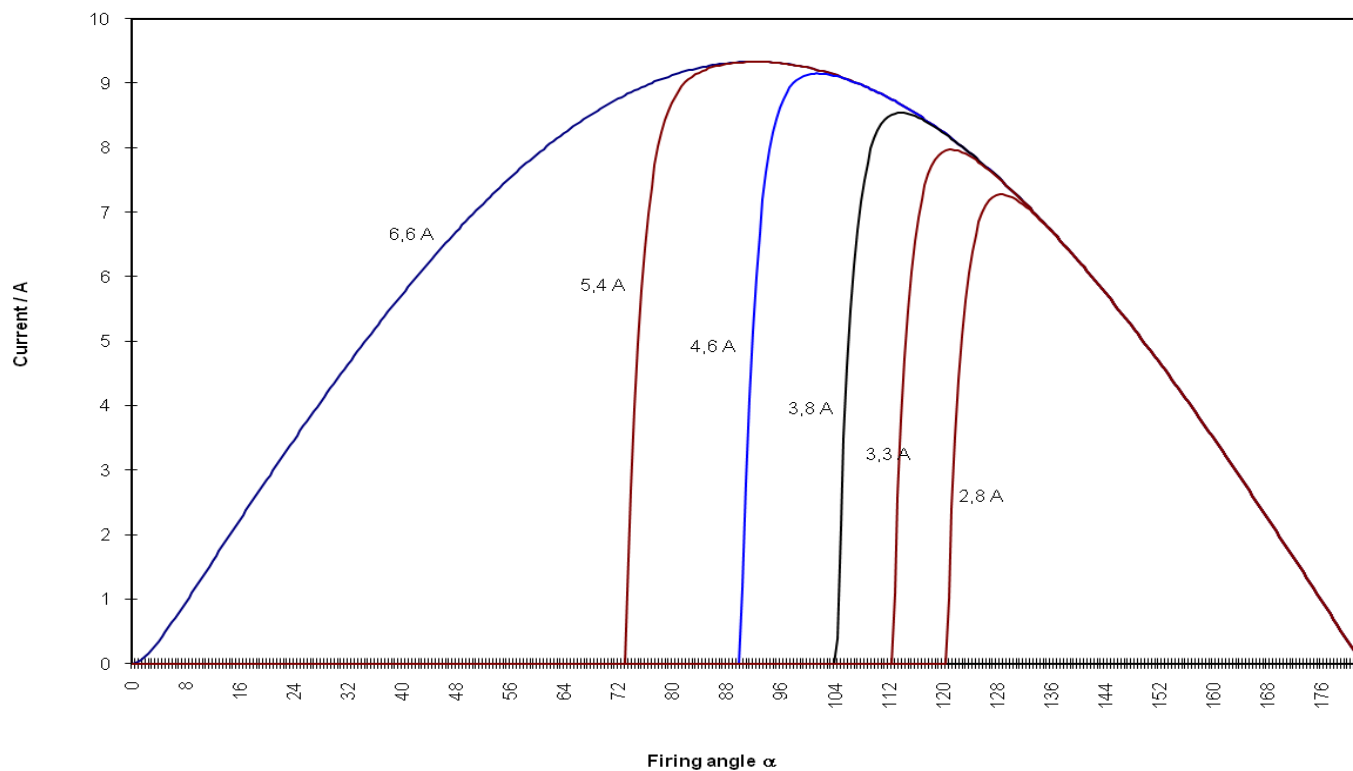
CCRs and Varying Harmonic Content

- Changing of intensity of lights
varying current, fixed load
- Switching TWY lighting segments on/off
fixed current, varying load



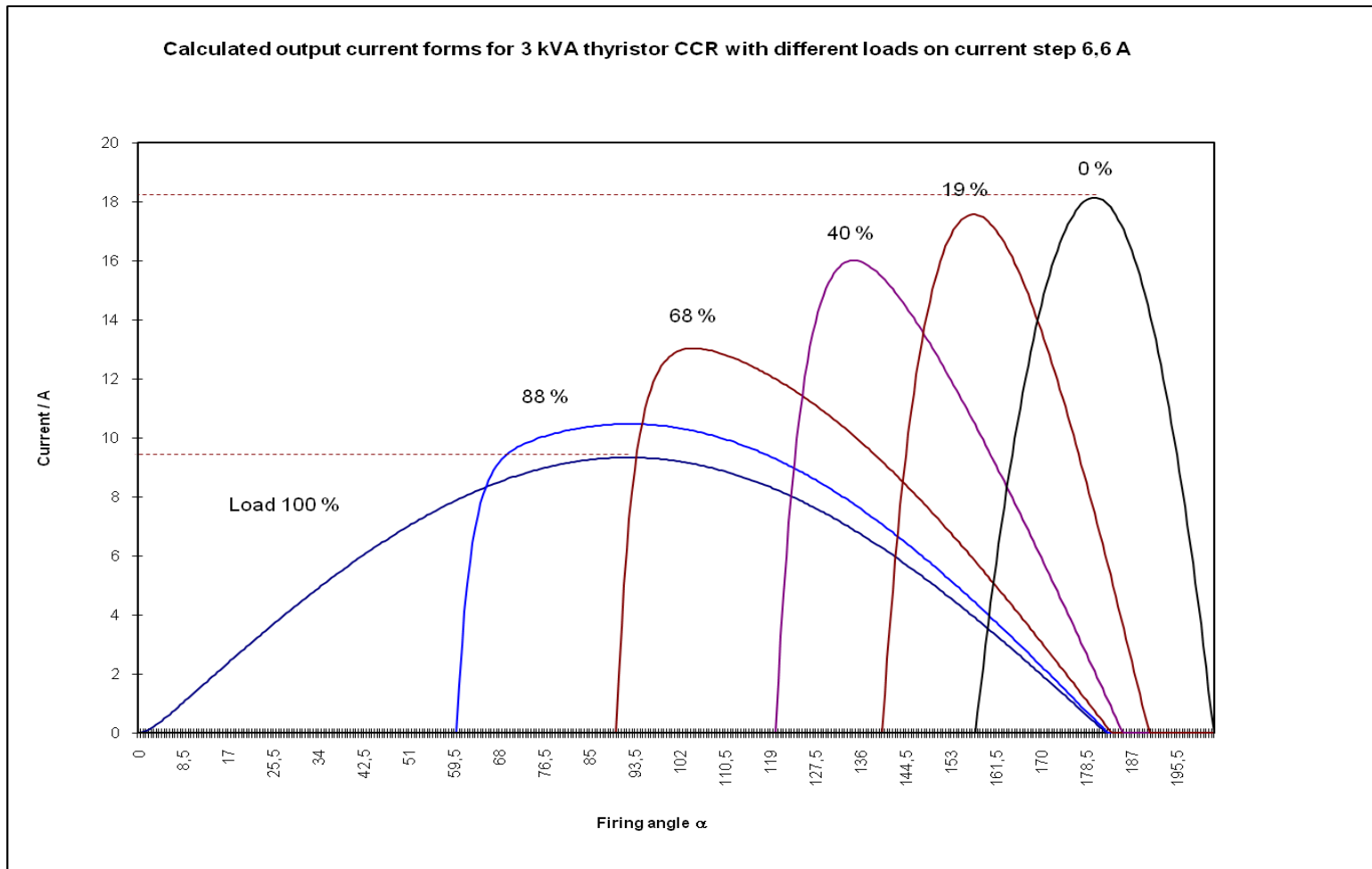
CCR Firing Angle vs Intensity Stage

Calculated output current forms for 3 kVA thyristor CCR with different current steps on nominal load



varying operating current with fixed load

CCR Firing Angle vs Circuit Load



varying circuit with fixed operating current

Interaction of harmonic content with emergency generators

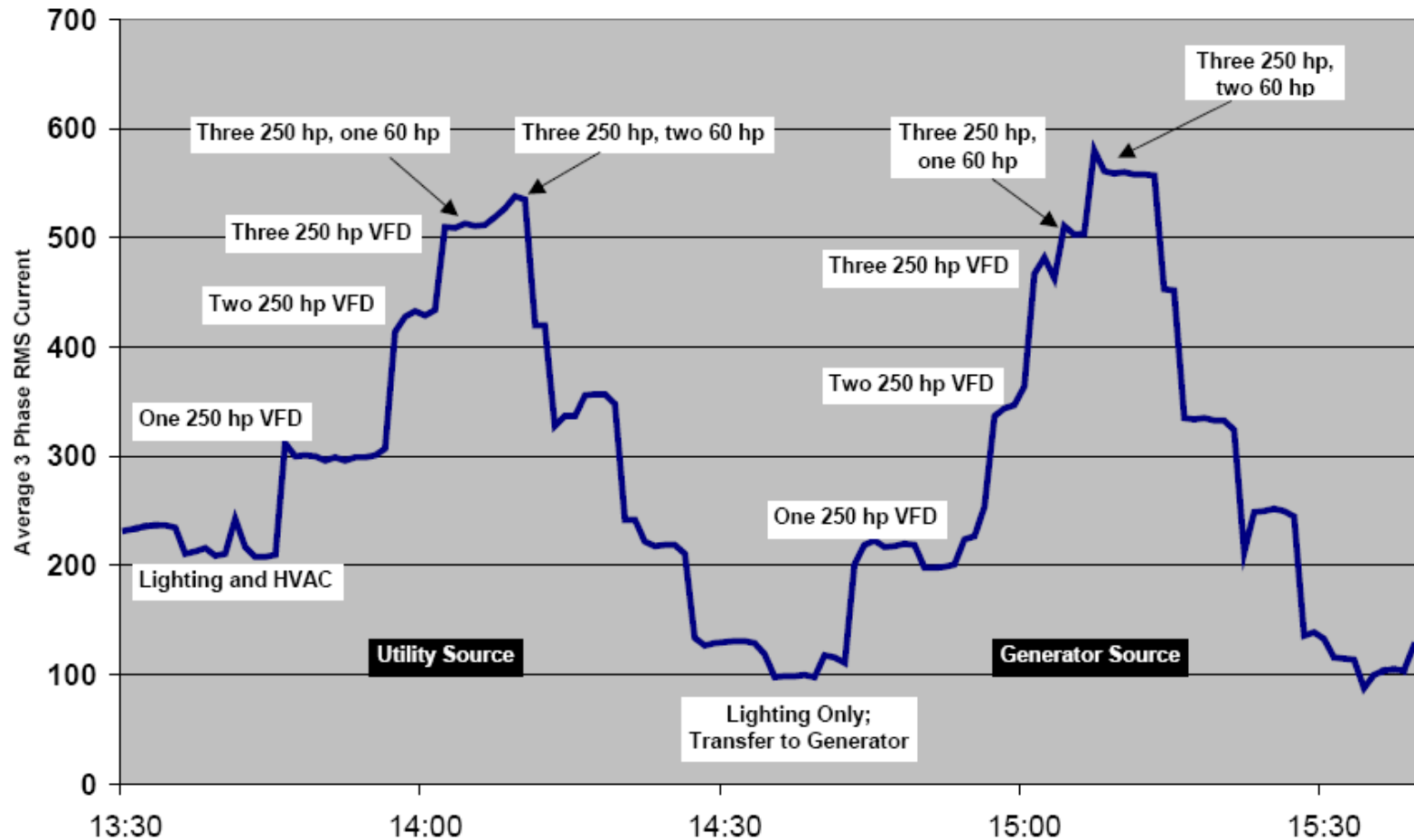
Harmonic Content of Emergency Generators

- **Harmonic voltage** distortion dependent on **harmonic current** drawn and **source impedance**
- Generator **source impedance** >> mains supply source impedance

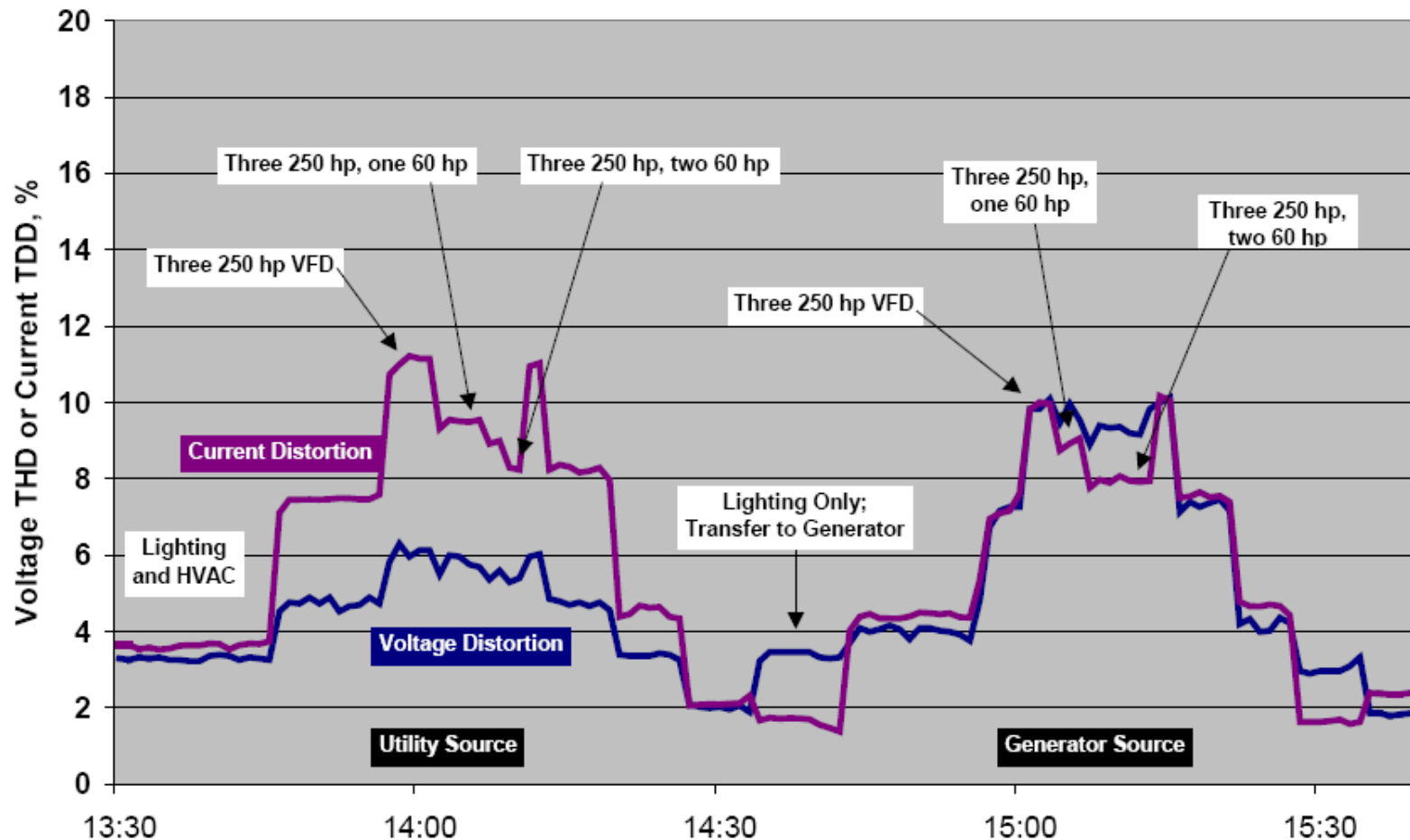
Therefore...

- Increased **harmonic voltage** created on generator supply (compared with mains supply)

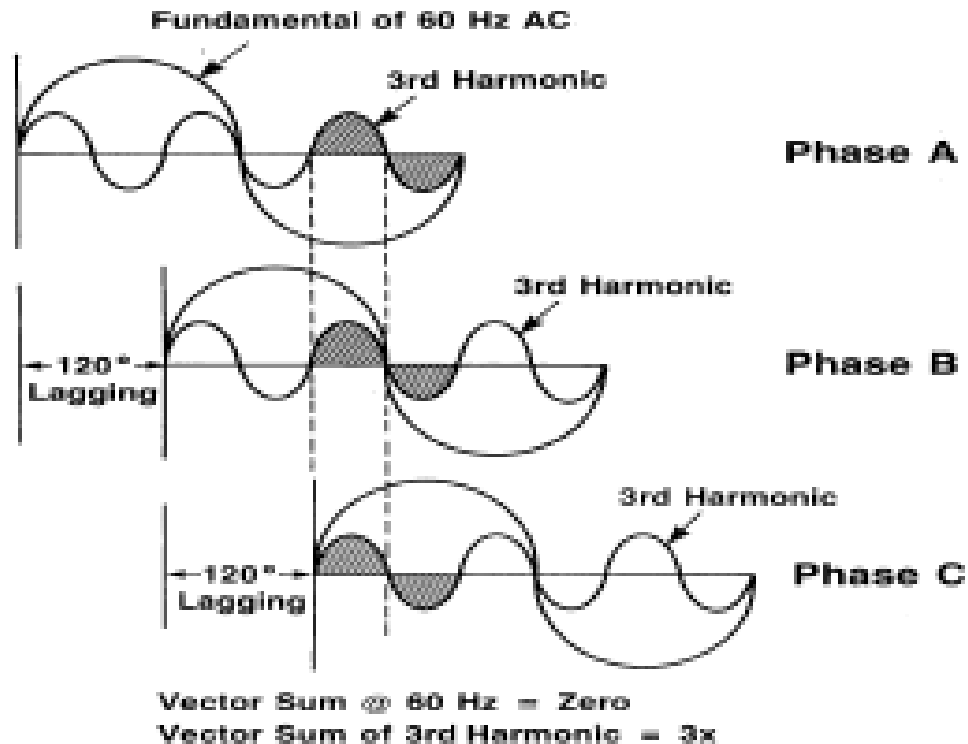
Average Current



Harmonic Distortion



Odd Triplen Harmonics in 3 Phase Circuits



Effect of Harmonic Current

- Harmonic currents cause **temperature rise** in generator's winding, core and rotor
- Inability to determine true rms values – **incorrect metering**
- Effect of zero & negative sequence voltages on motors/generators
 - +ve (fund, 4th, 7th, ...)
 - -ve (fund, 2nd, 5th, 8th, ...)
 - zero (3rd, 6th, 9th, ...)
- **Bearing failure** of rotating machines
- Increased **voltage drop** in supply cable
- **Overload** neutral conductors and burn off neutral connections
- **Nuisance operation** of protective devices
- **Mis-operation or failure** of electronic equipment; including voltage regulator

rotate motor forward

rotate motor backward

neither, just heat

Emergency Generators Supplying CCRs

- **Generator system** impedance typically larger than **mains supply** impedance which...
- **Exacerbates voltage harmonics** generated by harmonic current drawn by CCRs that may...
- Interfere with generator's voltage regulation circuitry and stability of supply

May result in:

- Generator **“hunting”** for load stability
- Possible **load fluctuations** on generator associated with circuit resonance
- Generator **“shutting down”** on overload or fault condition
- **Voltage instability** in system

Strategies to mitigate impact of harmonics

Strategies to Mitigate Impacts

- Limitation of Harmonic Current

- Optimise CCR output **voltage tapping**
- Be aware of **harmonic current** created by non linear load (I_{THD})
- Note that there is **no limit** defined in IEC/FAA CCR standards
- Be aware that Total Demand Distortion (TDD) management typically **protects other consumers rather than your own network**

Strategies to Mitigate Impacts - Generator

- Load **profile**
- **Rating** (over sizing) of alternator
- Winding **pitch** of alternator
- Harmonic filtering





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At a glance



Where are we?



Where are we – in North America?

