# POWER QUALITY PROBLEMS AND SOLUTIONS

RAJAN BABU

# DEFINITION

- EARLIER DEFINITION
- VOLTAGE AND FREQUENCY WITHIN STATUTORY LIMITS WITH NEGLIGIBLE AMOUNT OF WAVEFORM DISTORTION

# IEEE STANDARD 1159

- DEFINES POWER QUALITY AS
- ANY POWER PROBLEM MANIFESTED IN VOLTAGE, CURRENT OR FREQUENCY THAT RESULTS IN FAILURE OR MIS OPERATION OF CUSTOMER EQUIPMENT IS BASED ON DEFICIENT POWER QUALITY

# EFFECTS OF PQ PROBLEMS

- DEPENDS ON
- THE QUALITY OF VOLTAGE SUPPLIED BY THE UTITLITY
- THE TYPE OF LOADS IN THE INSTALLATION
- THE SENSITIVITY OF EQUIPMENTS TO VARIOUS KINDS OF DISTURBANCES

# IMPACT ON INDIAN INDUSTRY

- IIT DELHI AND ASIA POWER QUALITY INITIATIVE CONDUCTED A JOINT STUDY AND FOUND THAT ALMOST ALL INDUSTRIES SUFFER FROM VARIOUS PQ PROBLEMS AND MANY ARE NOT AWARE OF IT
- IN USA LOSSES DUE TO POWR QUALITY ARE ESTIMATED AS US $ 20 BILLION/ YEAR

# VOLTAGE SAG OR DIP

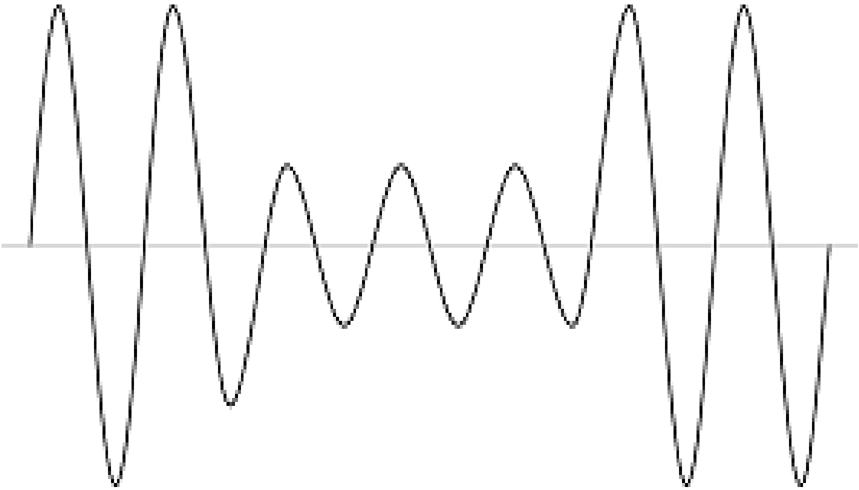
- A DECREASE IN NORMAL RMS VOLTAGE AT THE POWER FREQUENCY FOR DURATION OF 0.5 CYCLE TO 1 MINUTE
- SAGS ACCOUNT FOR VAST MAJORITY OF POWER PROBLEMS EXPERIENCED BY END USERS. CAN BE GENERATED FROM BOTH INTERNALLY AND EXTERNALLY FROM AN END USER FACILITY

# SAG

- CAUSED BY :-
- STARTING OF LARGE ELECTRICAL LOADS
- LIGHTNING
- NORMAL AND ABNORMAL UTILITY EQUIPMENT OPERATION
- SWITCHING OFF SHUNT CAPACITORS.

# SAG

- TYPICAL WAVEFORM

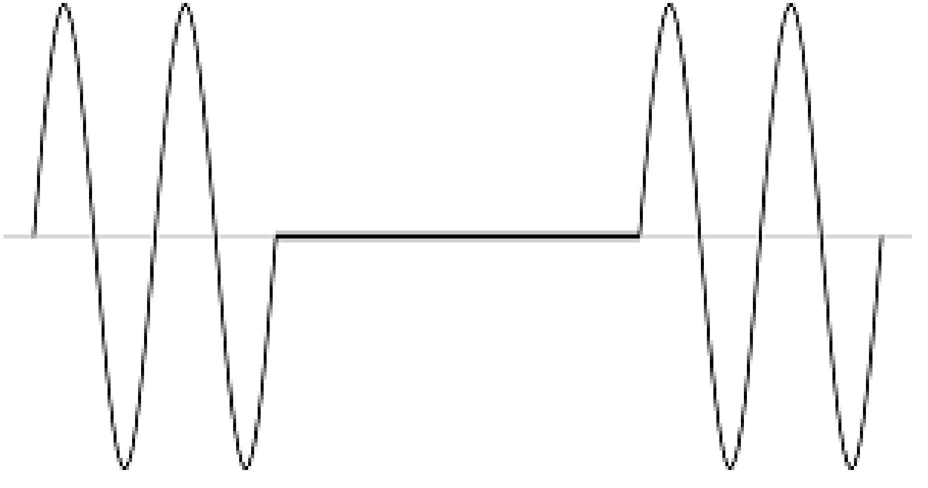


# INTERRUPTION

- WHEN VOLTAGE DROPS BELOW 10% OF ITS NORMAL VALUE IT IS CALLED INTERRUPTION OR BLACK OUT
- 3 CLASSIFICATIONS
- MOMENTARY -- LASTING 3 CYCLES TO 3 SEC
- TEMPORARY -- 3 SECONDS TO 1 MINUTE
- SUSTAINED -- LASTING MORE THAN 1 MINUTE

# Interruption

- MOMENTARY INTERRUPTION

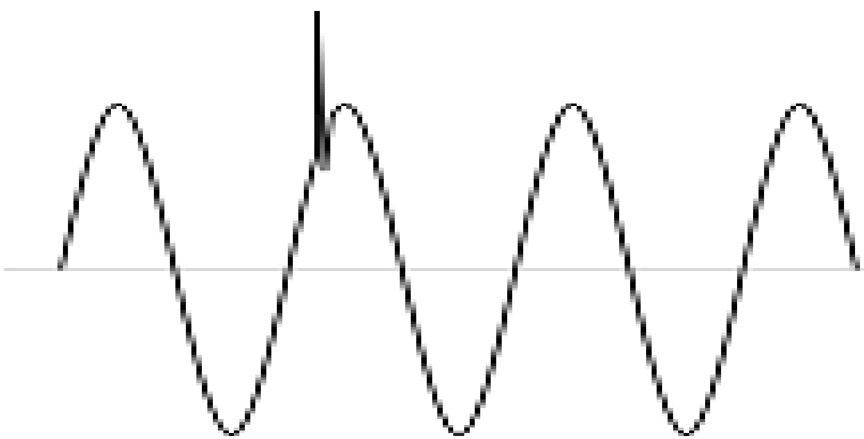


# TRANSIENT OR SURGE

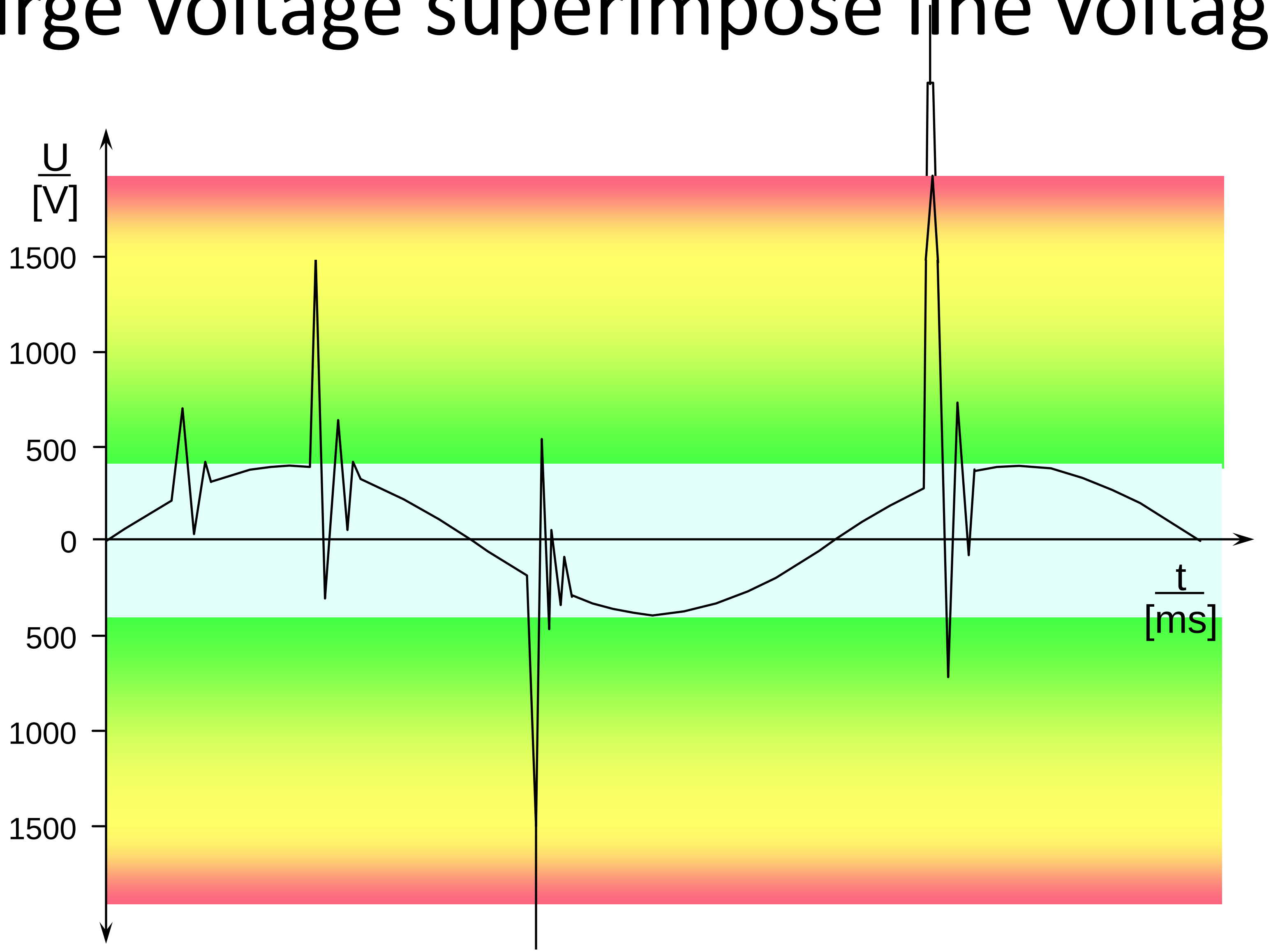
- VERY SHORT DURATION EVENTS OF VARYING AMPLITUDE.
- CAUSED BY LIGHTNING
- SWITCHING UTILITY EQUIPMENTS
- SWITCHING ON CAPACITOR BANKS

# SURGE

- TYPICAL WAVEFORM



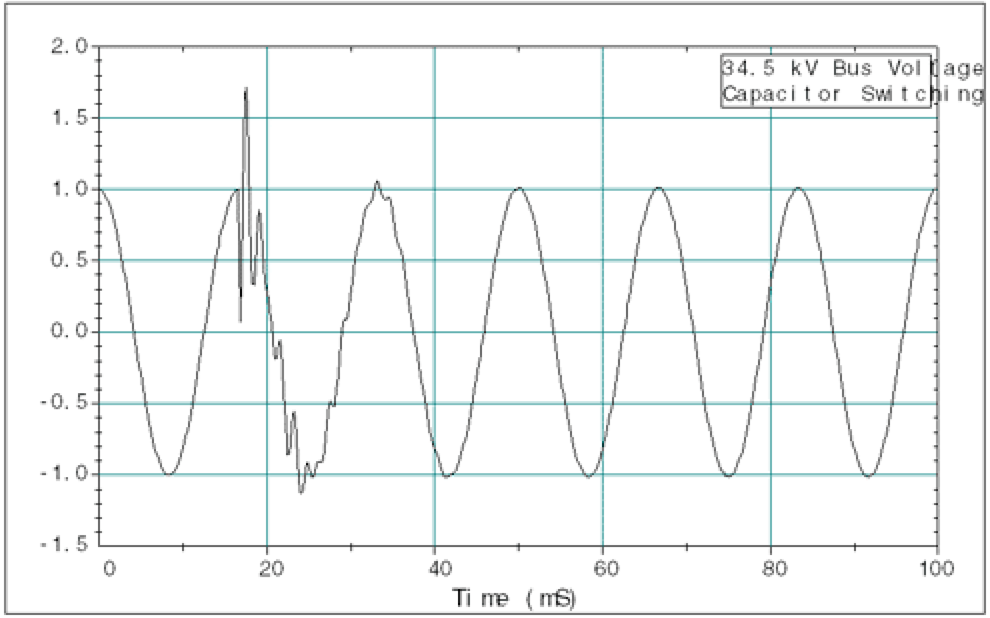
# surge voltage superimpose line voltage



# Reasons for transient surge voltage

- switching electromagnetic pulse (SEMP)
- electrostatic discharge (ESD)
- lightning electromagnetic pulse (LEMP)
- nuclear electromagnetic pulse (NEMP)

# CAPACITOR SWITCHING ON

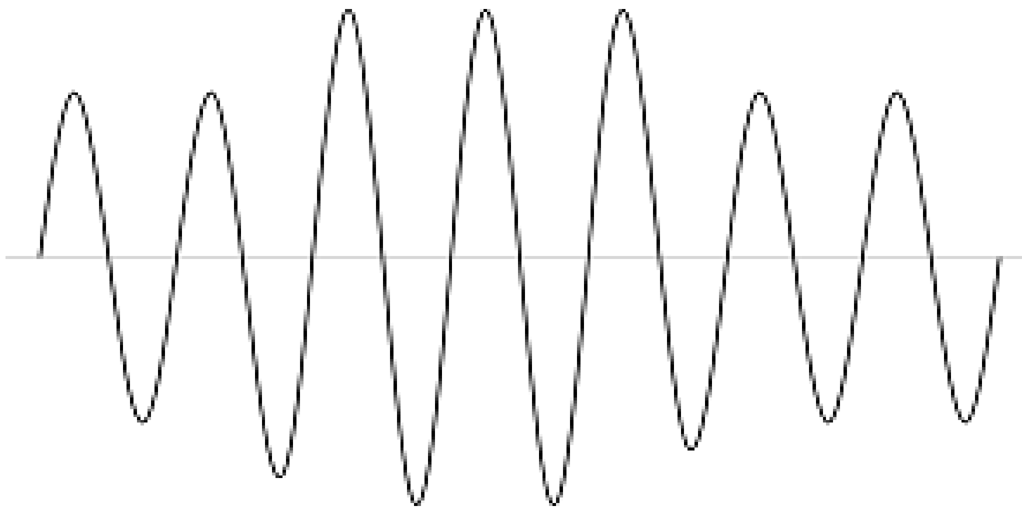


# SWELL

- SWELL IS OPPOSITE OF SAG OR DIP
- SWELL IS AN INCREASE IN VOLTAGE FROM 110% OF NORMAL FOR ONE HALF CYCLE TO ONE MINUTE
- CAUSED BY SWITCHING OFF LARGE LOADS,
- SWITCHING ON CAPACITOR BANKS

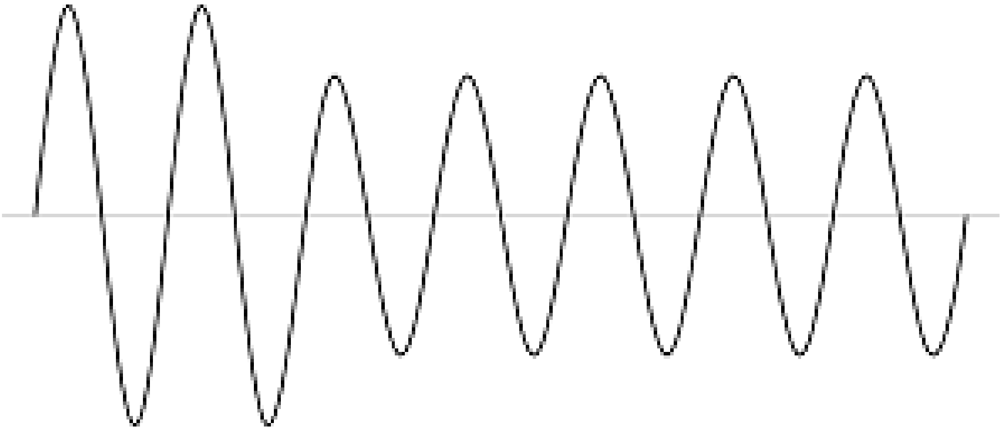
# SWELL

- TYPICAL WAVEFORM



# UNDER VOLTAGE

- TYPICAL WAVE FORM



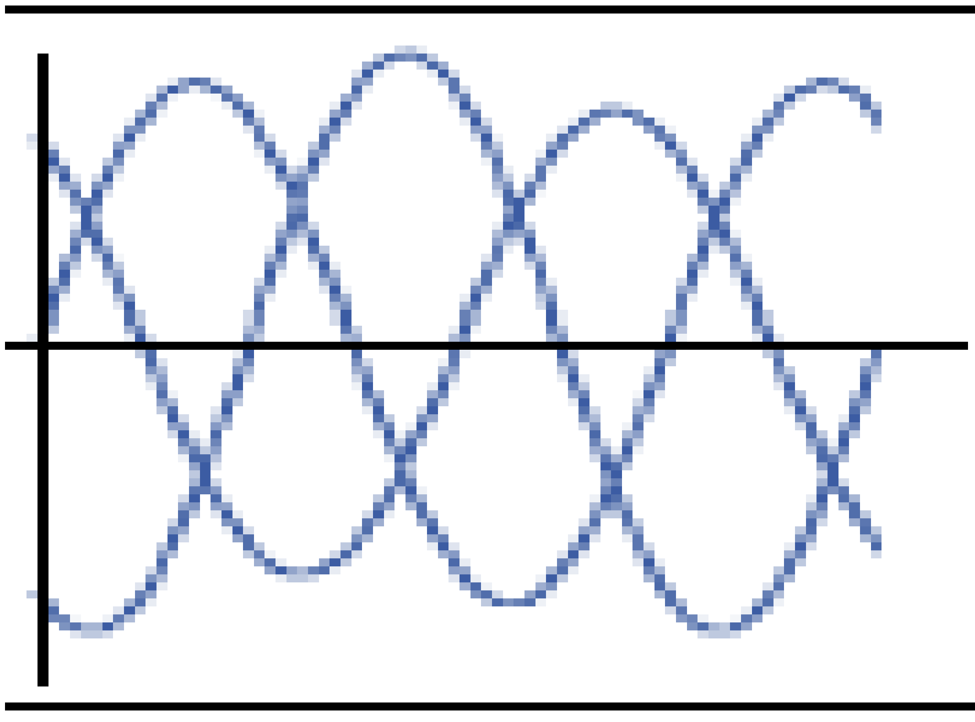
# OVER VOLTAGE

- A MAJOR PROBLEM EXPERIENCED BY END USERS
- MAINLY CAUSED BY UTILITY EQUIPMENTS
- MAJOR CAUSE FOR FIALURE OF ELECTRONIC COMPONENTS
- PROLONGED OVEVOLTAGE IS DISASTROUS

# UNBALANCE

- CAUSED BY UNEQUAL LOADING ON PHASES
- WINDING ERRORS ON TRANSFORMERS AND GENERATORS
- CAUSES BURNING OF MOTORS AND GENERAORS DUE TO OVERHEATING
- LARGE SINGLE PHASE LOADS

# UNBALANCE

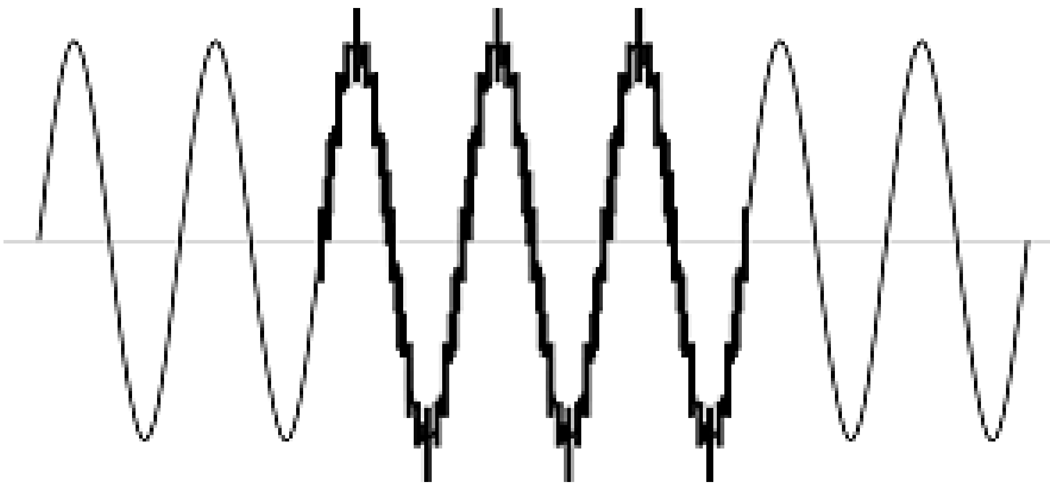


# NOISE

- NOISE IS A HIGH FREQUENCY DISTURBANCE OF THE VOLTAGE WAVEFORM
- CAUSED BY EQUIPMENTS SUCH AS WELDERS, TRANSMITTERS
- FREQUENTLY GO UN NOTICED
- HIGH LEVEL OF NOISE CAN CAUSE EQUIPMENT MAL FUNCTION AND PREMATURE WEAR.

# NOISE

- WAVEFORM AFFECTED BY NOISE



# HARMONICS

- Harmonics are a mathematical model of the real world.
- A non-sinusoidal periodical function can be represented as the sum of :-

A sinusoidal term of the fundamental frequency

Sinusoidal terms (harmonics) whose frequencies are multiples of fundamental frequency

A DC component where applicable

Figure 1 shows an example of a current wave affected by harmonic distortion.

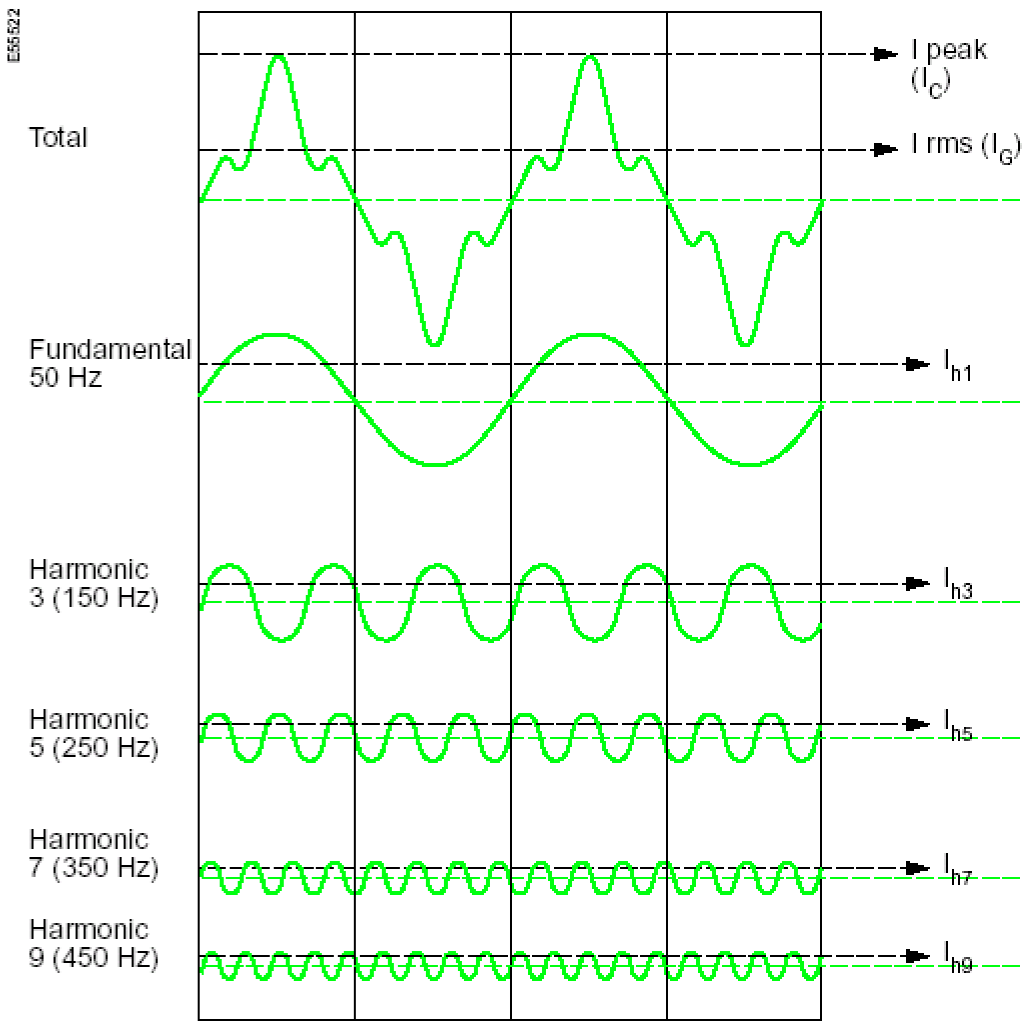



***Figure 1*** *- example of a current containing harmonics and expansion of the overall current into its harmonic orders 1 (fundamental), 3, 5, 7 and 9*

# Representation of Harmonics

Figure 2 shows the frequency spectrum of the signal presented in figure 1.

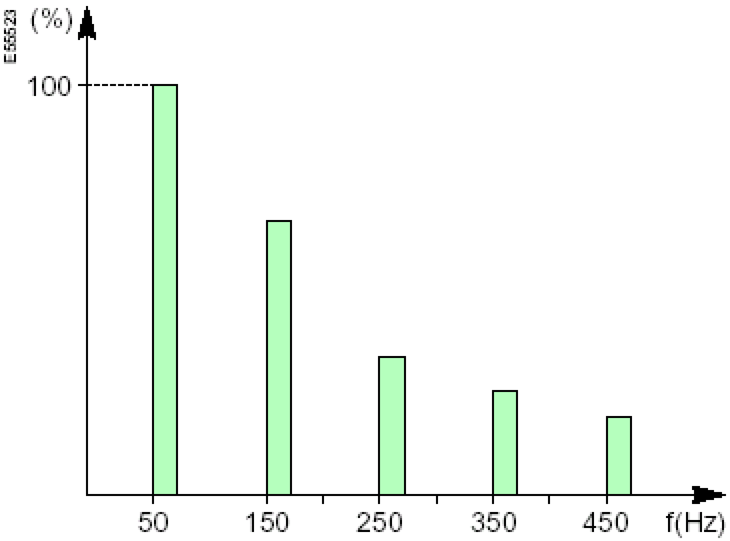



***Figure 2** - spectrum of a signal comprising a 50 Hz fundamental and harmonic orders 3 (150 Hz), 5 (250 Hz), 7 (350 Hz) and 9 (450 Hz)*

# Origin of Harmonics

- Harmonics are caused by nonlinear loads
- A load is said to be non linear when the current drawn does not have the same wave form as the supply voltage

# Non linear loads

- Industrial equipment
  - rectifiers
  - arc furnace
  - induction furnace
  - variable speed drives
  - welding machines
  - inverters

# Nonlinear loads

- Office equipments
  - personal computers
  - copy machine
  - fax machine
  - UPS

# Nonlinear loads

- Household appliances
  - Television sets
  - Microwave oven
  - Fluorescent lamps
  - PC
  - UPS

# Disturbance caused by nonlinear loads

- Harmonic currents are caused by nonlinear loads
- The flow of harmonic current through system impedances creates voltage harmonics which distort the supply voltage

# Disturbances caused by harmonics

- Overloads the neutral conductor
- Overloads, vibration and premature ageing of generators,transformers, motors,etc
- Overloading and premature ageing of capacitors
- Distortion of supply voltage
- Disturbance on communication networks

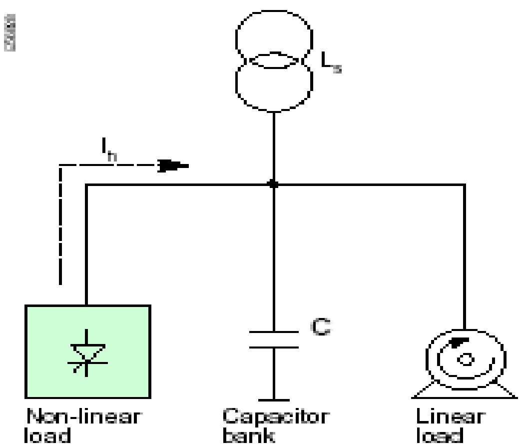
# Which harmonics must be measured and reduced?

- The most troublesome are

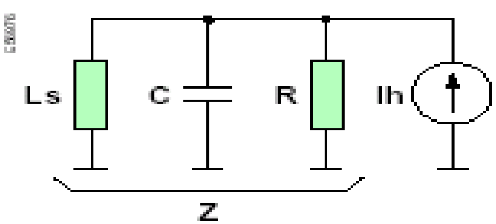
  3,5,7,11,13,23,25

  Beyond the 50th order harmonic currents are negligible

# Effects of harmonics in installations




For harmonic-analysis purposes, the equivalent diagram is shown below:




**Ls**: supply inductance (distribution system + transformer + line)
**C**: power factor correction capacitance
**R**: resistance of the linear loads
**Ih**: harmonic current

$$Z = \frac{jL_s\omega}{1 - L_sC\omega^2}$$ when R is neglected

# Resonance

Resonance occurs when the denominator $1-LsC\omega^2$ approaches zero. The corresponding frequency is called the resonant frequency of the circuit. At this frequency, the impedance is at its maximum value, resulting in considerable voltage harmonics and consequently major voltage distortion. This voltage distortion is accompanied by the circulation of harmonic currents in the Ls + C circuit which are greater than the injected harmonic currents.

The distribution system and the power factor correction capacitors are subjected to considerable harmonic currents, resulting in the risk of overloads.

# Effects on transformers

■ The curve in figure 9 below shows typical derating values for a transformer supplying electronic (i.e. non-linear) loads.

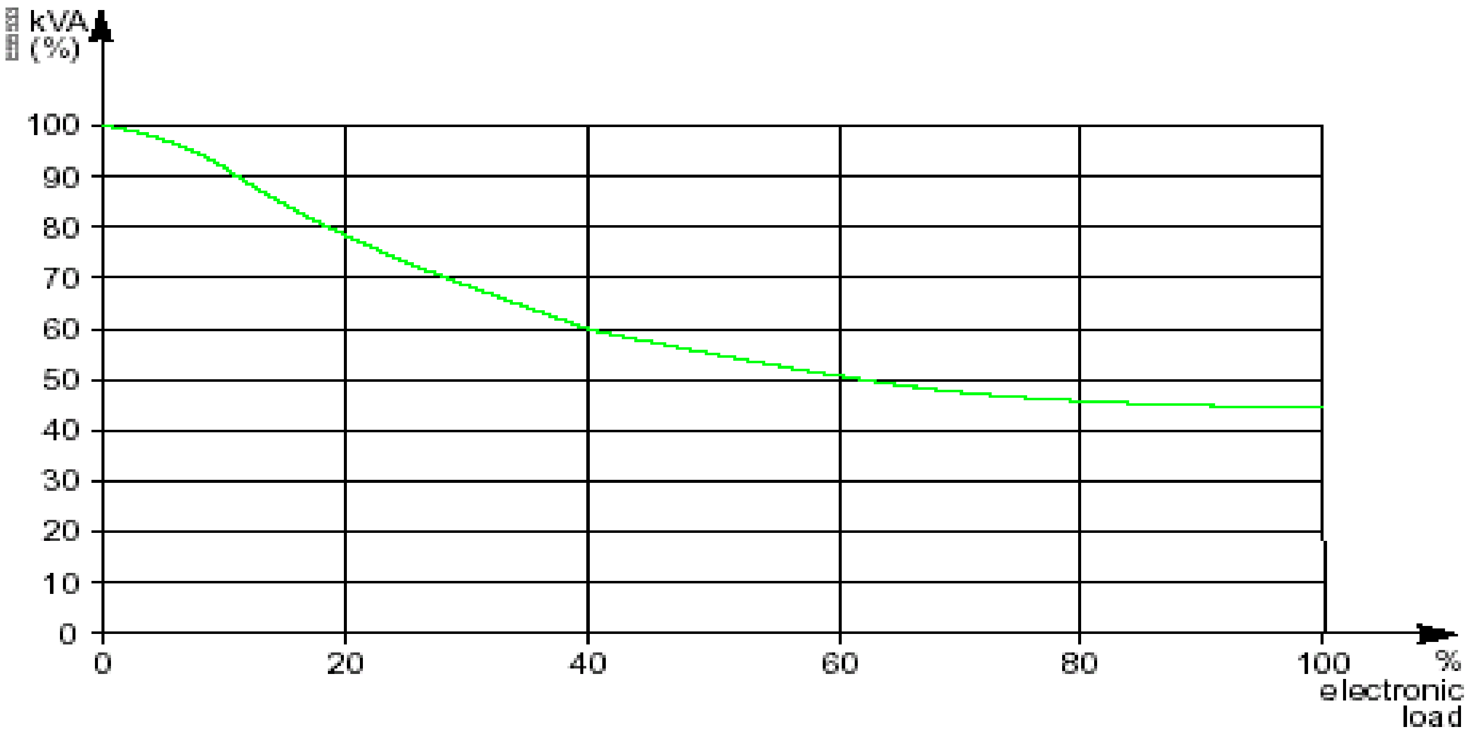



***Figure 9** - derating values for a transformer supplying electronic loads*

Example: a **transformer supplying loads that are 40%** electronic must be derated 40 %.

# Effects on generators

- Generators supplying non-linear loads must be derated due to the additional losses caused by the harmonic currents. The **derating coefficient is approximately 10%** for a generator supplying a set of loads in which 30% are non-linear loads. As a result, the generator must be oversized.

# Effects on motors

- Harmonics such as 5th and 7th have a potential for creating mechanical oscillations in a motor load system

# Reduction in service life of equipment

When distortion of the supply voltage is in the 10% range, equipment service life is significantly reduced. Depending on the type of device, the reduction in service life may be estimated at:

- 32.5% for single-phase machines,
- 18% for three-phase machines,
- 5% for transformers.
- To maintain the service life observed with a normal supply voltage, devices must be oversized.

# Nuisance tripping

- Installation circuit breakers are subjected to current peaks caused by harmonics.
- These current peaks cause nuisance tripping and result in production losses as well

  as costs corresponding to the time required to put the installation back into running

  order.

# Solutions to attenuate harmonics

## 6.1.1 Positioning the disturbing loads upstream in the system

The overall level of harmonic disturbance increases as the short-circuit power decreases.

Economic considerations aside, it is therefore preferable to connect the disturbing loads as far upstream as possible (see figure 13a).

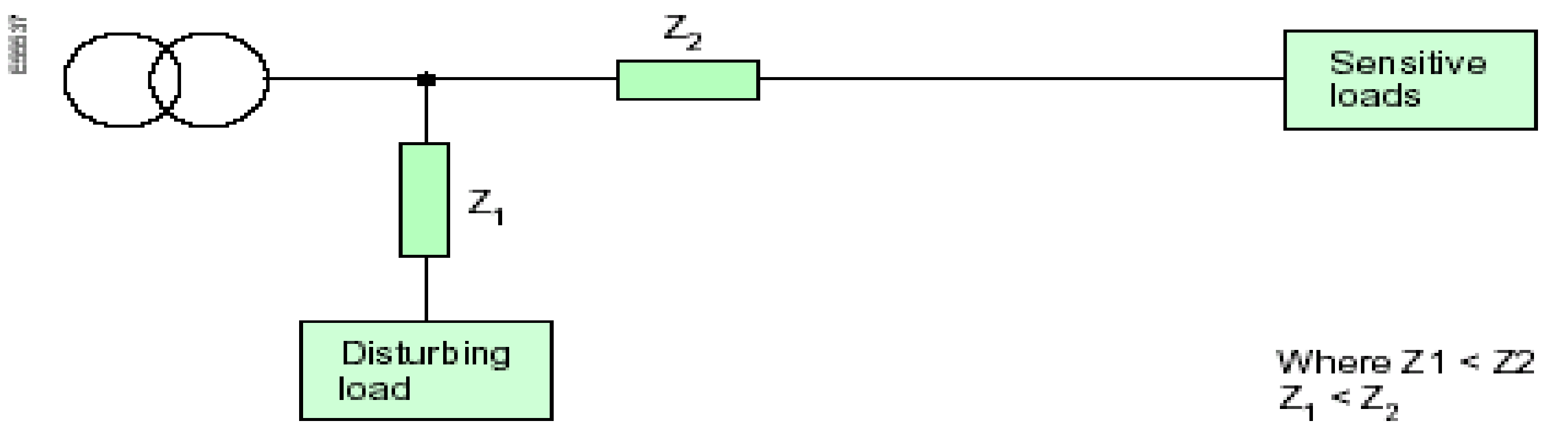



***Figure 13a** - supply of non-linear loads as far upstream as possible (recommended diagram)*

# Separating the sources

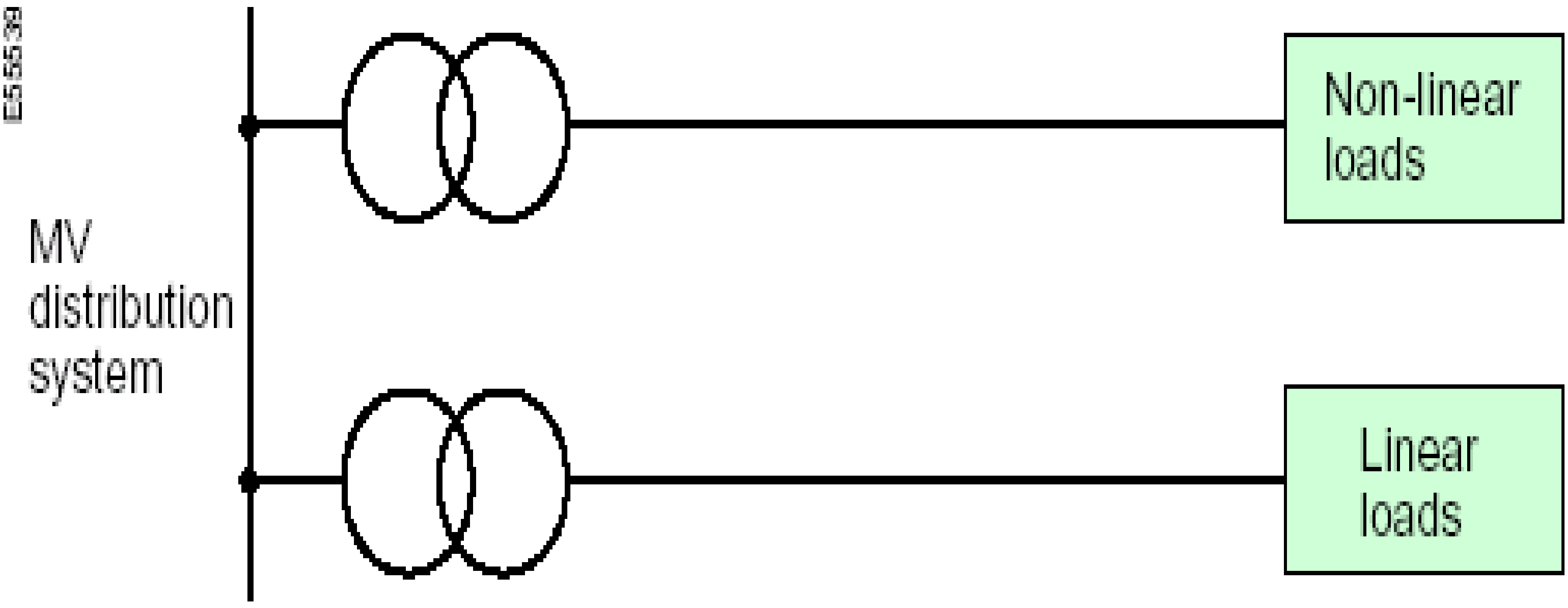



***Figure 14** - supply of the disturbing loads via a separate transformer*

# Using transformers with special connections

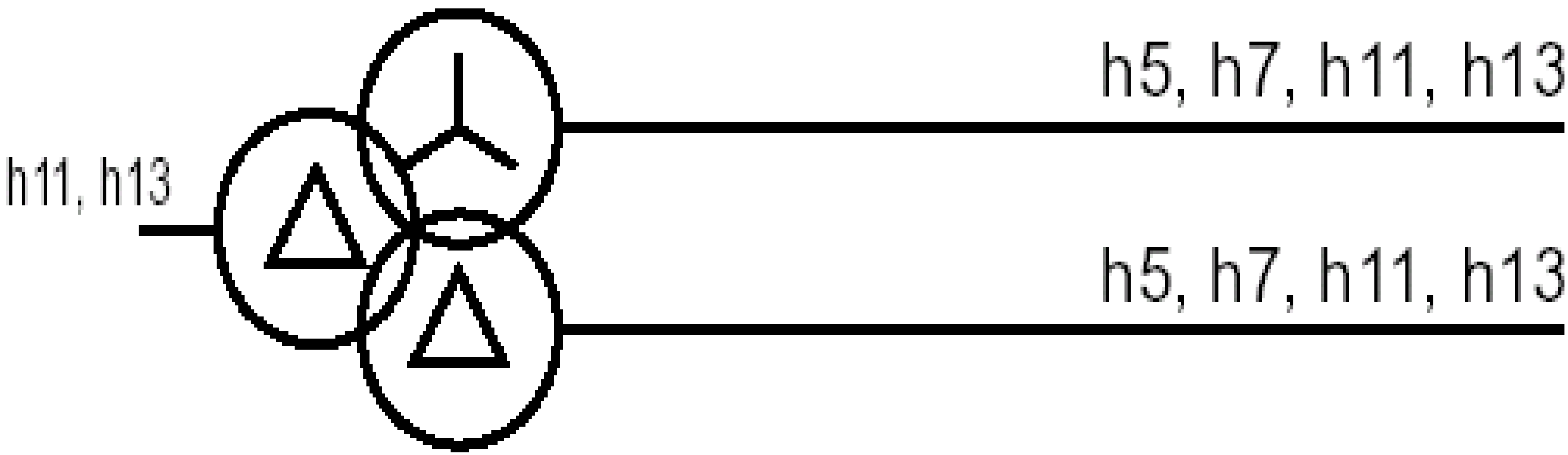



***Figure 15*** *- a delta-star-delta transformer prevents propagation of harmonic orders 5 and 7 upstream in the distribution system*

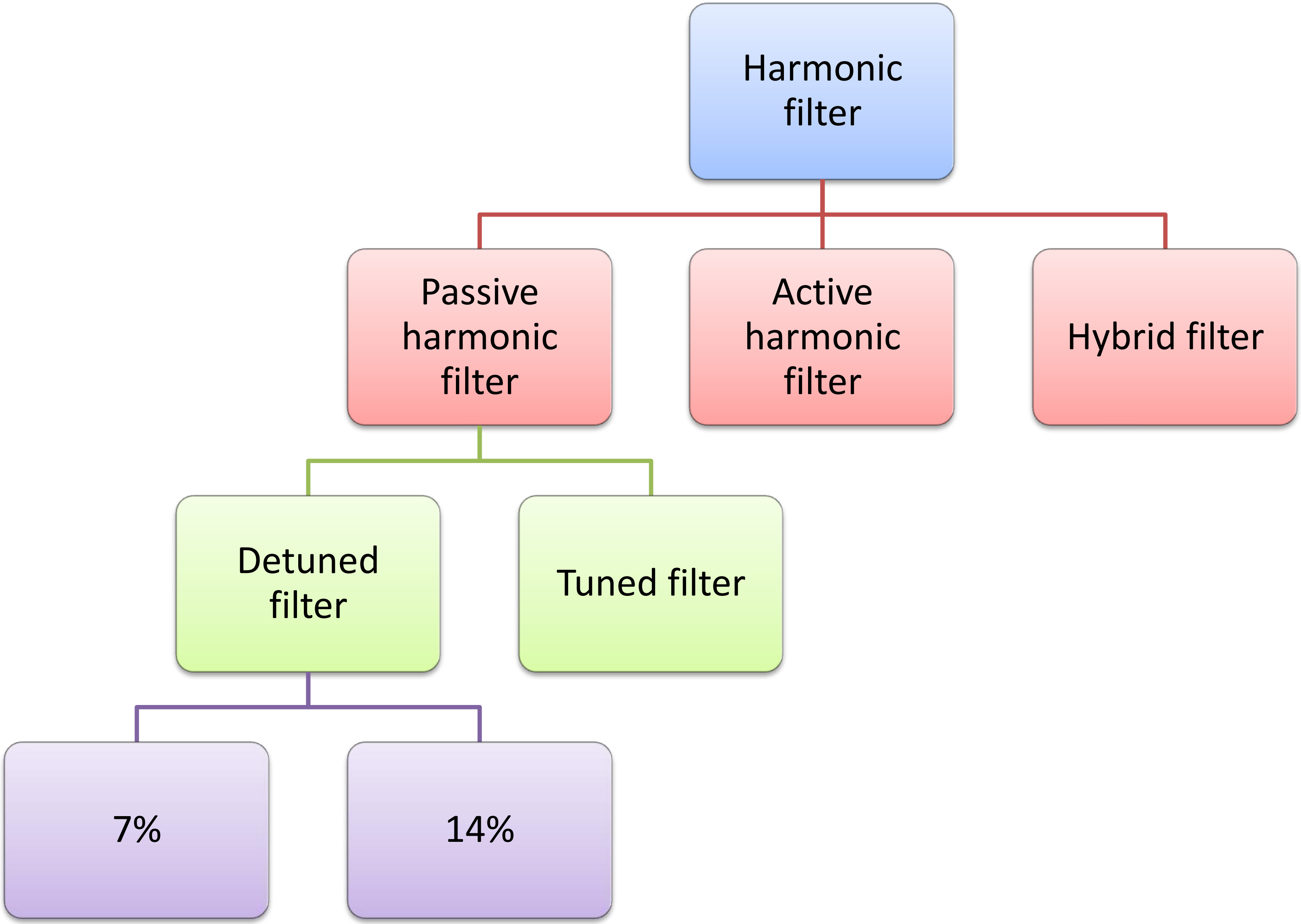
# Solutions when limit values are exceeded

In cases where the preventive measures presented above are not sufficient, the installation must be equipped with filters.

There are three types of filters:

- passive filters,
- active filters,
- hybrid filters.

# Harmonic Filters



# Passive filters

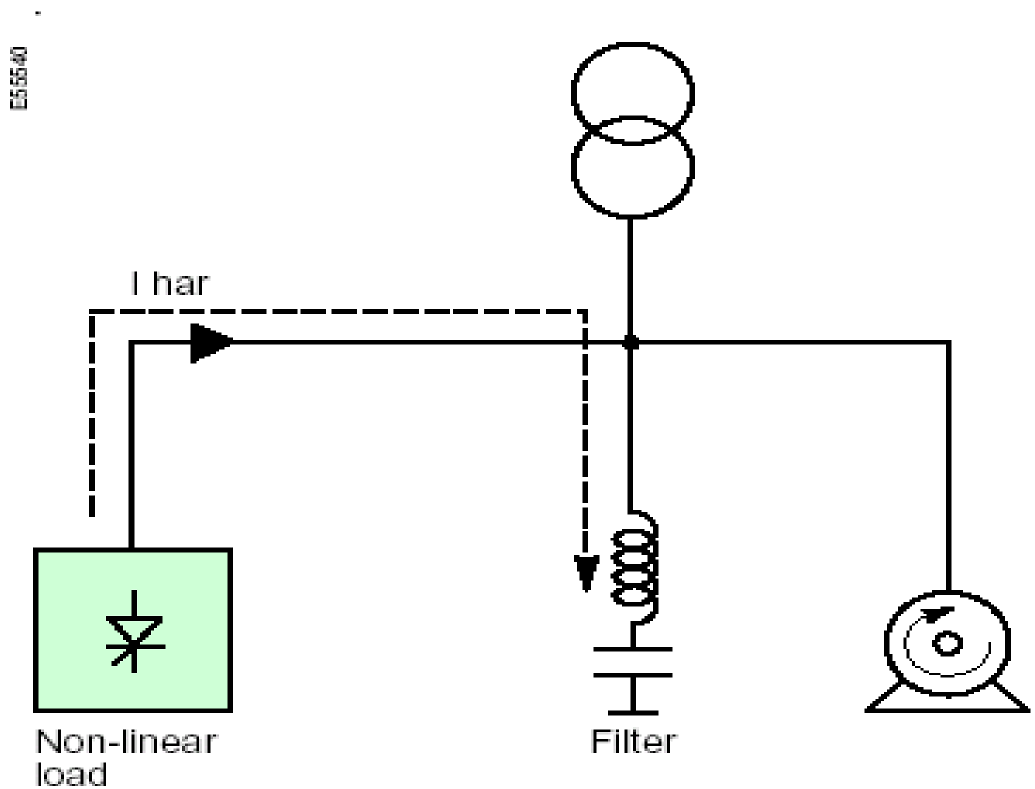
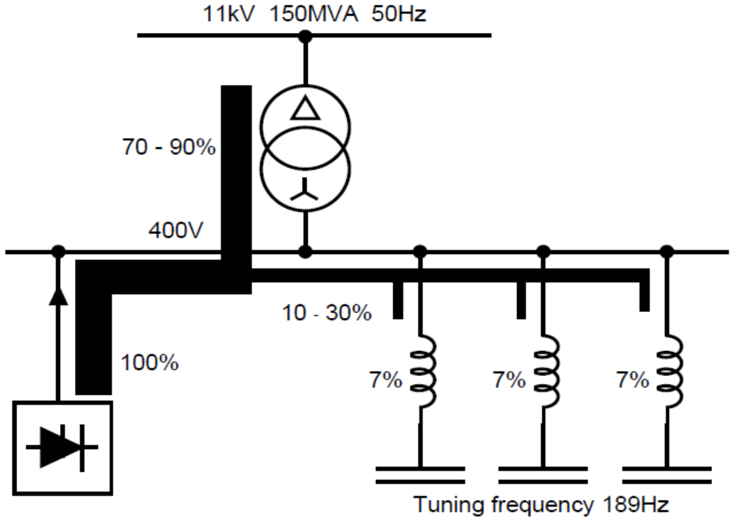
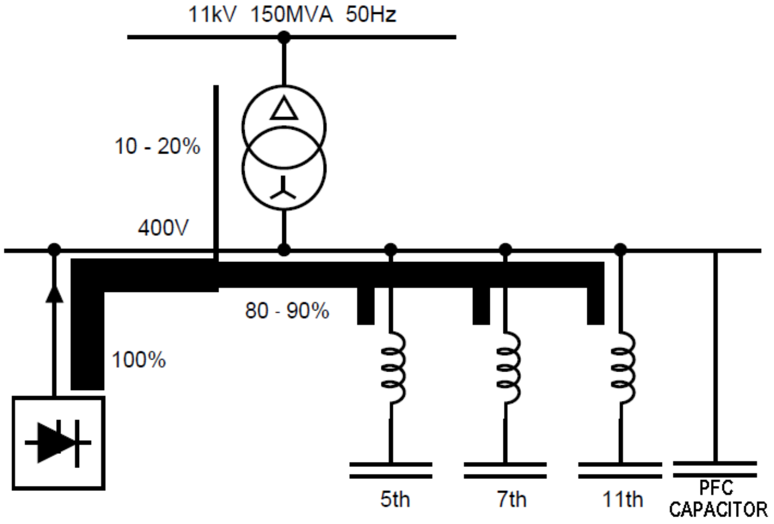



***Figure 16*** *- operating principle of a passive filter*

# Filters




## Detuned Filters




## Tuned Filters

***Using the right filter , will limit harmonic within standard limits***

Figure 17 shows an example of an active filter compensating the harmonic current ($I_{har} = -I_{act}$).

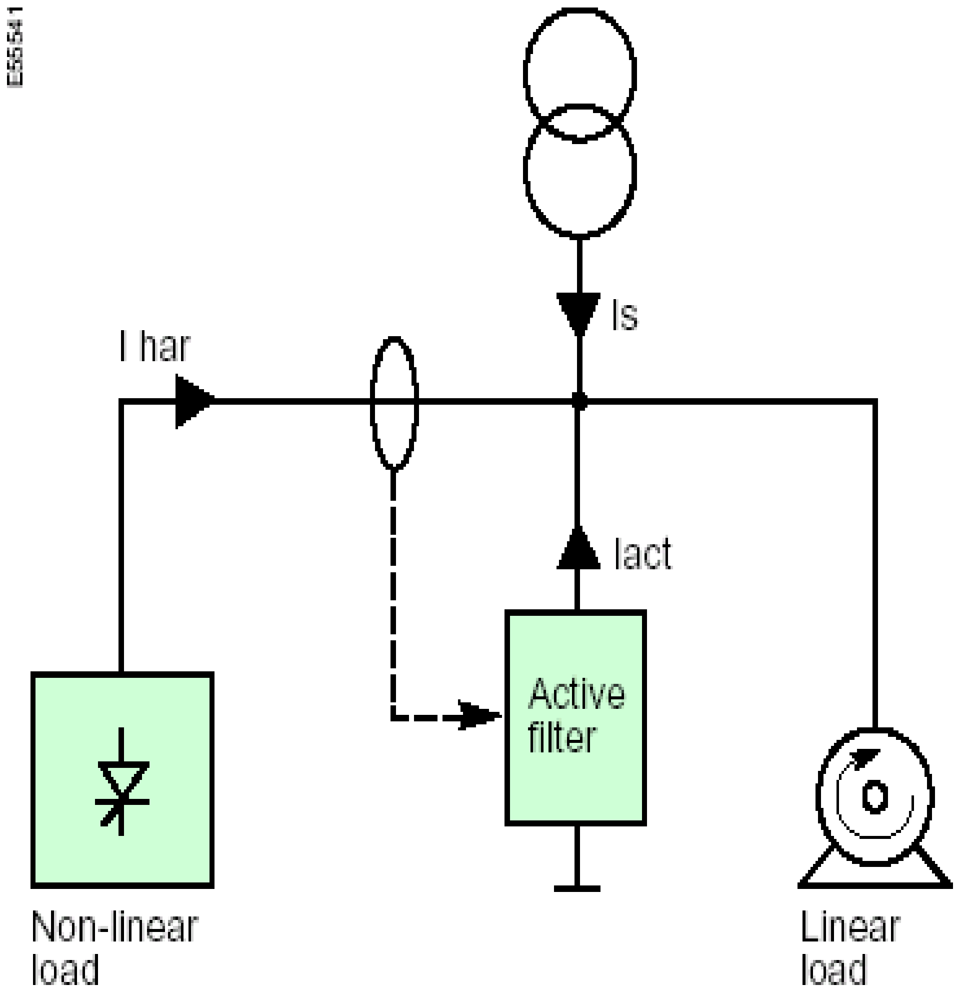



***Figure 17** - operating principle of an active filter*

# Hybrid filters

- Typical applications:
  - industrial installations comprising a set of devices causing harmonics with a total power rating greater than 200 kVA approximately (variable-speed drives, UPSs, rectifiers, etc.),
  - installations where power factor correction is required,
  - situations where voltage distortion must be reduced to avoid disturbing sensitive loads,
  - situations where current distortion must be reduced to avoid overloads,
  - situations where conformity with strict harmonic-emission limits is required.

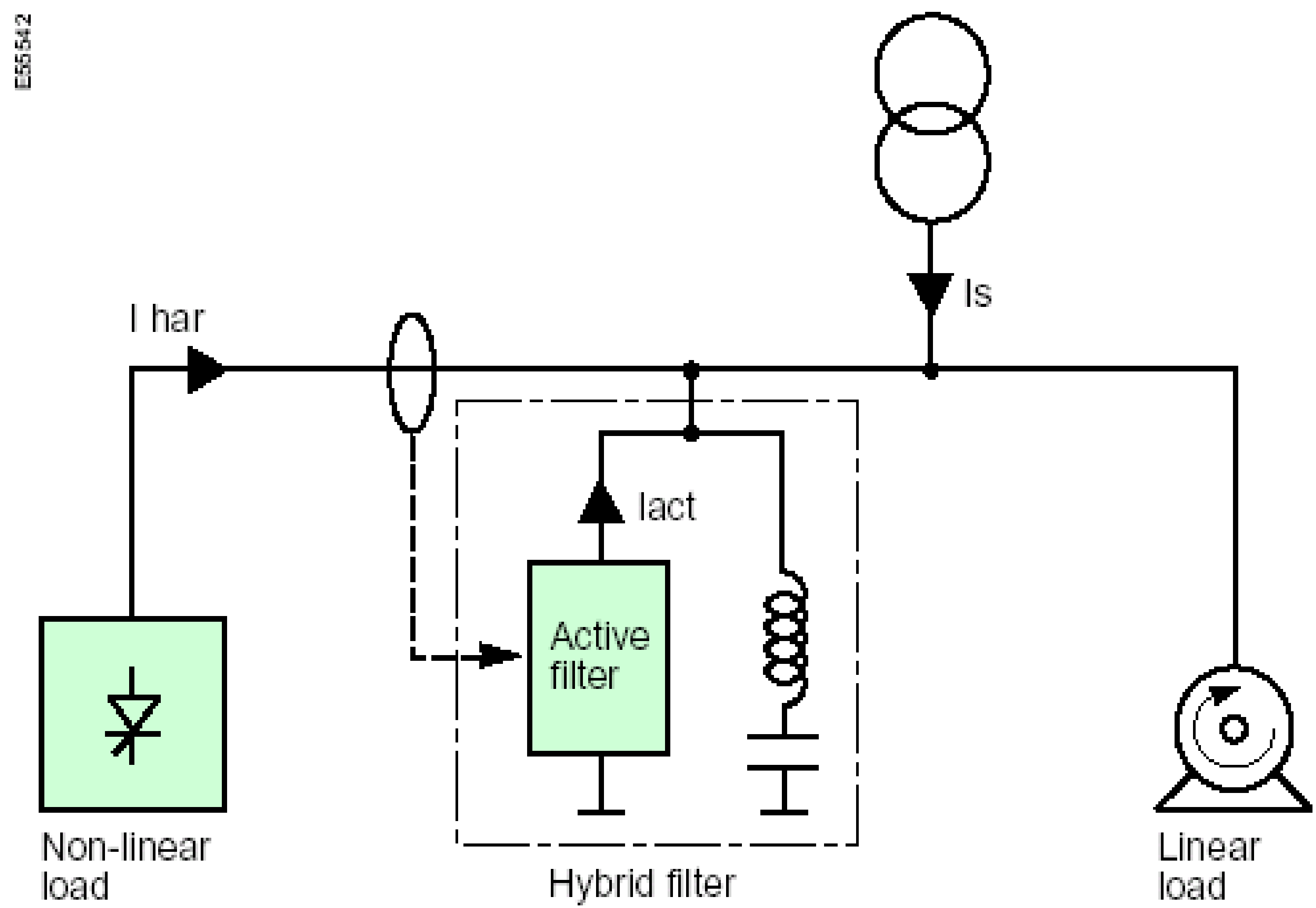



***Figure 18*** *- operating principle of a hybrid filter*

# IEEE 519-1992 Standard

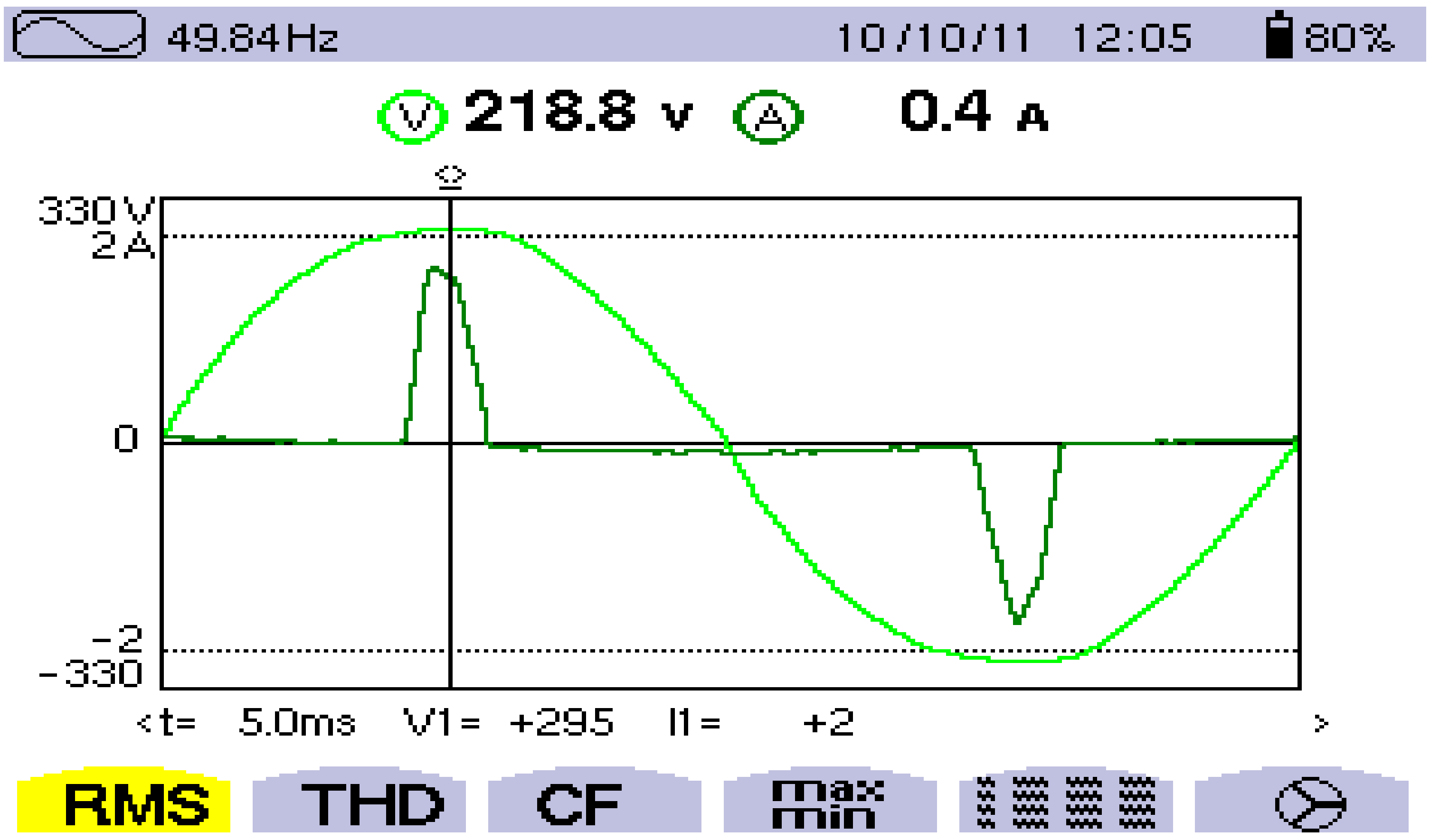
### Current harmonic limits

| Ratio $I_{scc} / I_{load}$ | Harmonic odd numbers (<11) | Harmonic odd numbers (>35) | ITHD |
|---|---|---|---|
| < 20 | 4.00% | 0.30% | 5.00% |
| 20 - 50 | 7.00% | 0.50% | 8.00% |
| 50 - 100 | 10.00% | 0.70% | 12.00% |
| >1000 | 15.00% | 1.40% | 20.00% |

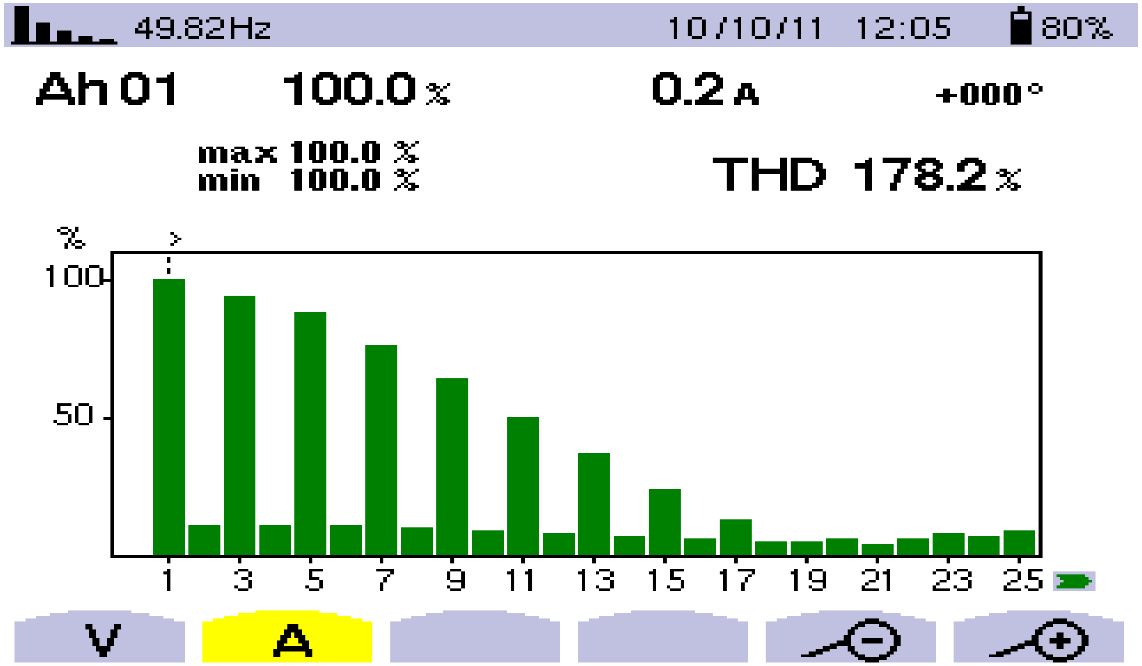
### Voltage harmonic limits

| Bus Voltage at PCC | Individual Voltage Distortion (%) | Total Voltage Distortion THD (%) |
|---|---|---|
| 69 kV and below | 3.00% | 5.00% |
| 69.001 kV through 161 kV | 1.50% | 2.50% |
| 161.001 kV and above | 1.00% | 1.50% |

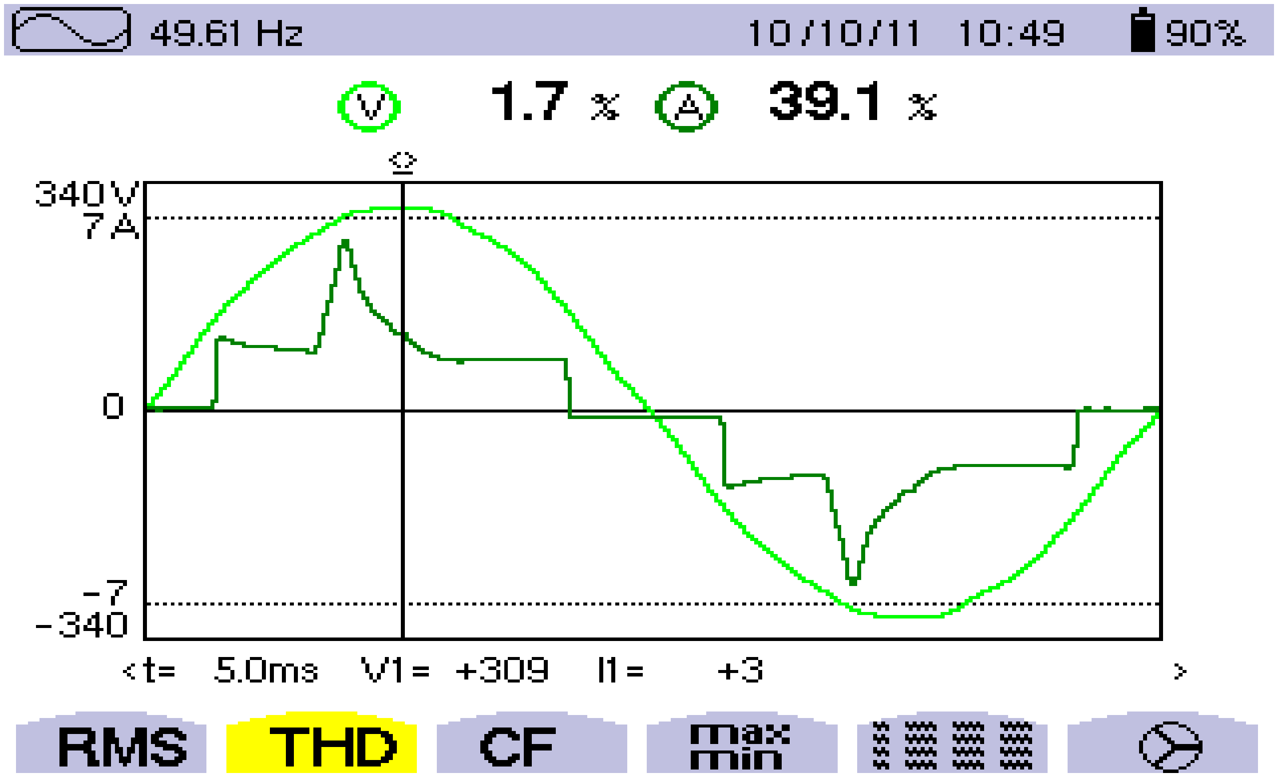
# COMPUTER MONITOR



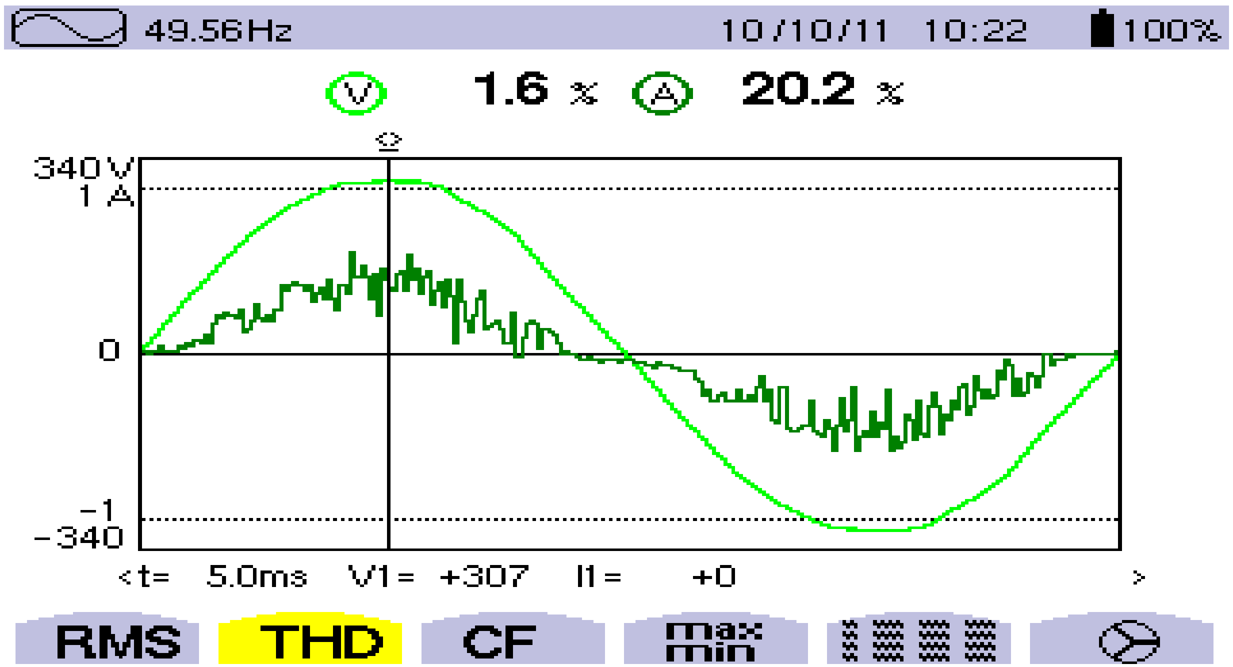
# COMPUTER MONITOR CURRENT HARMONICS



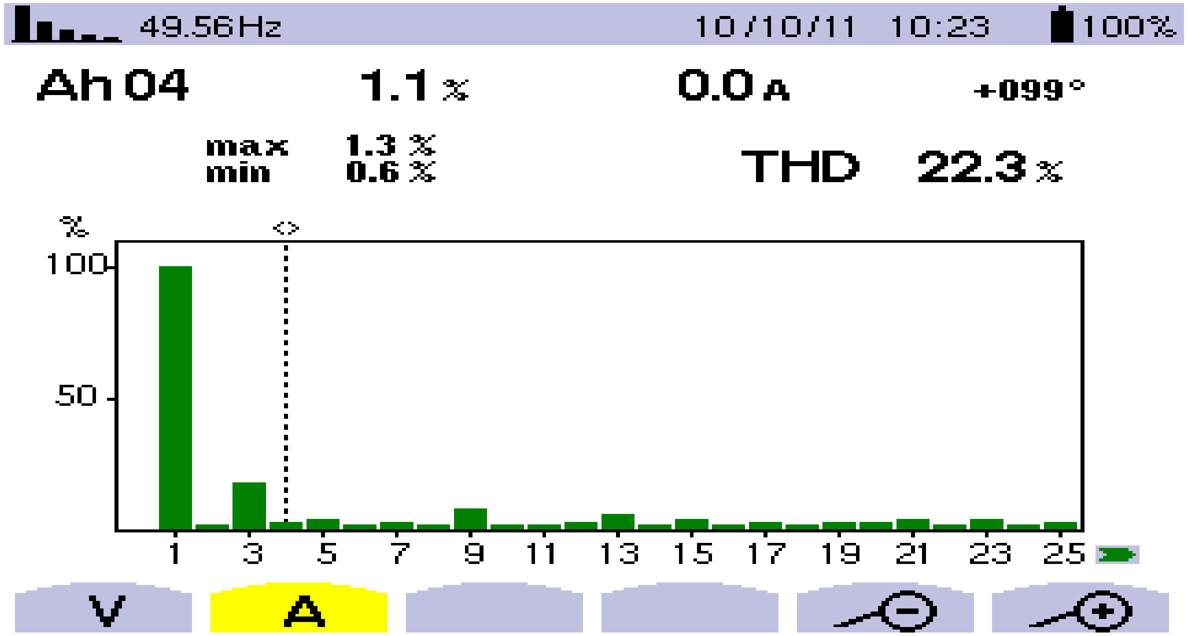
# FLUORESCENT TUBE WITH ELECTRONIC BALLAST



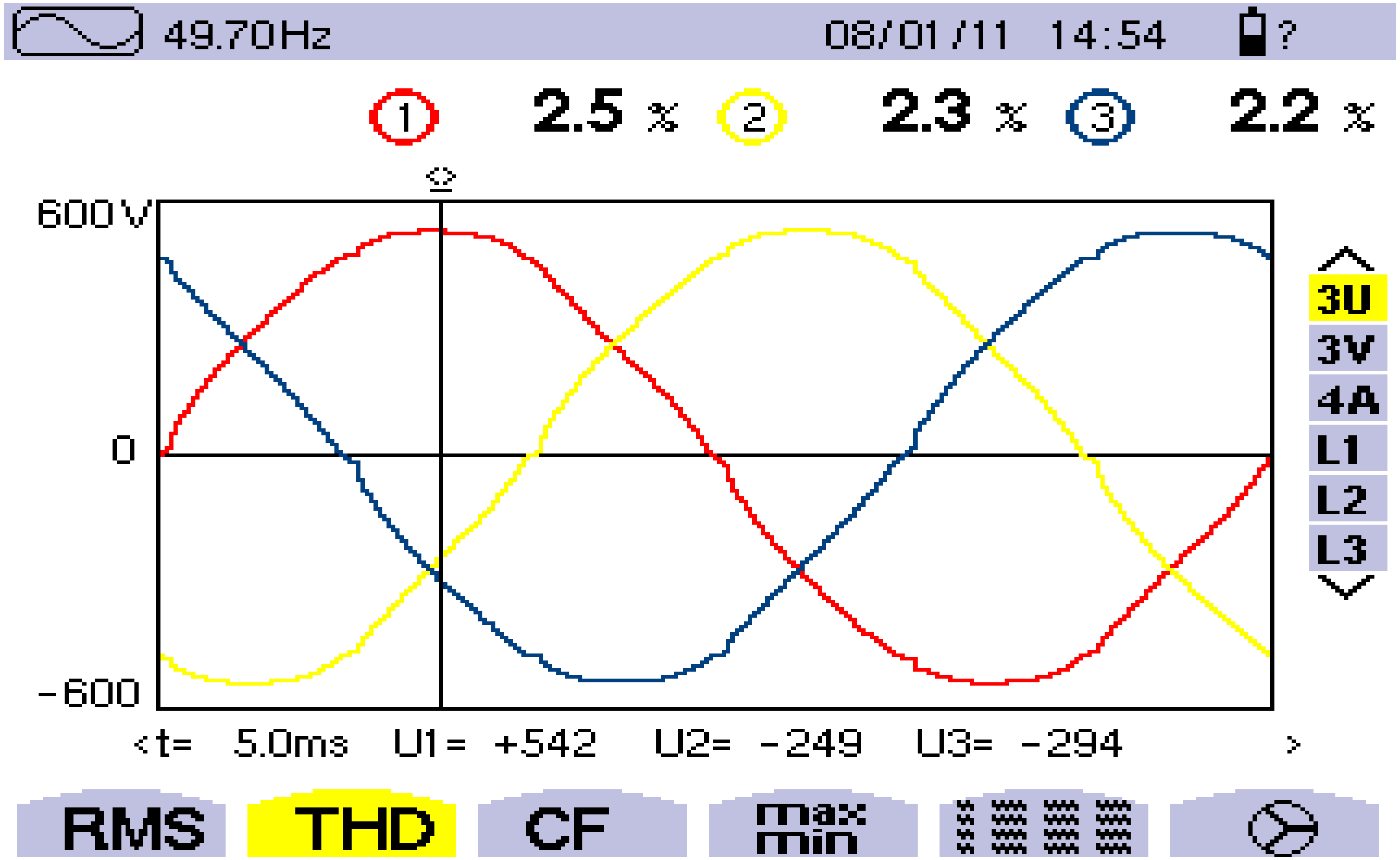
# LED LIGHT 60 W



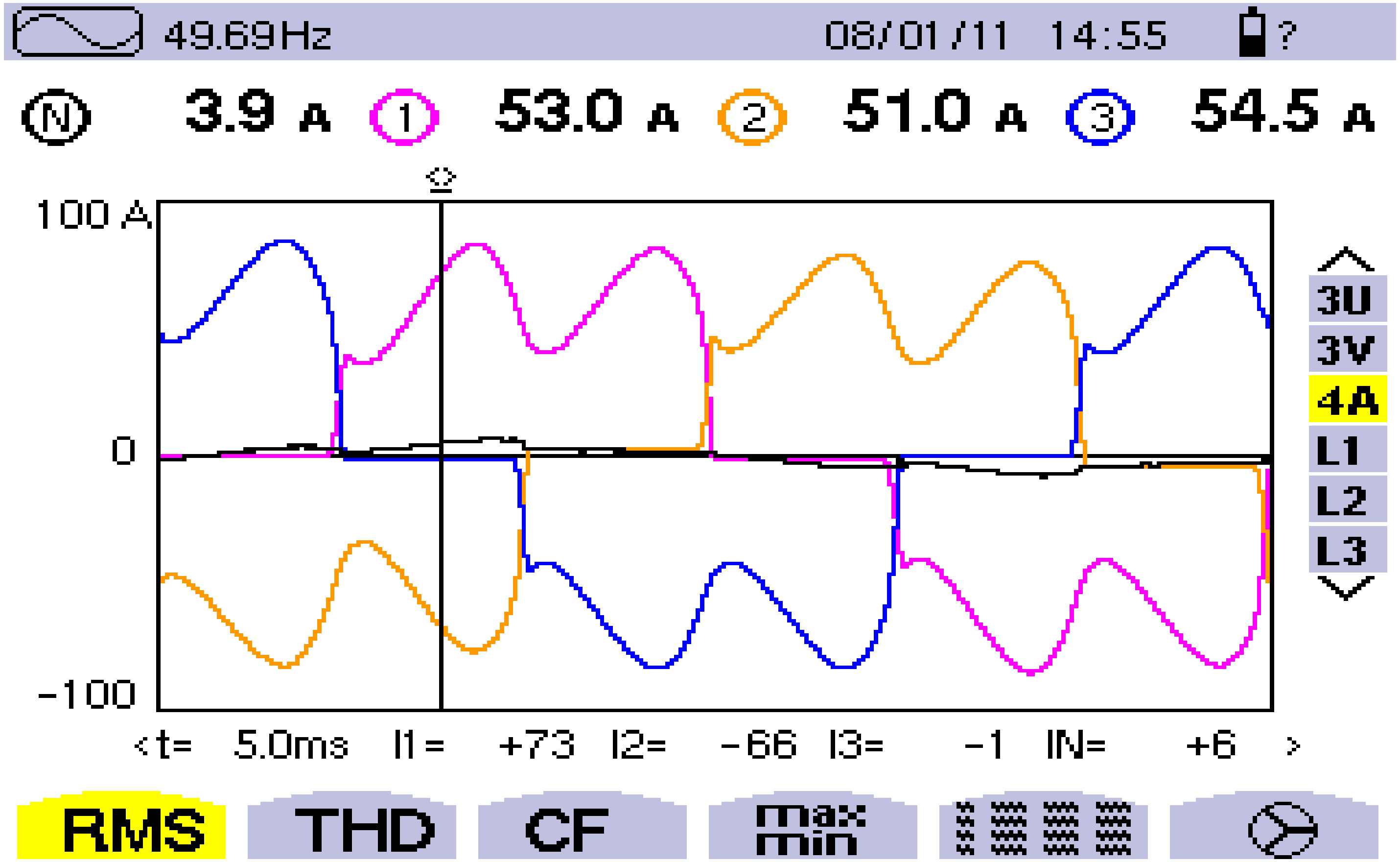
# LED LIGHT 60 W



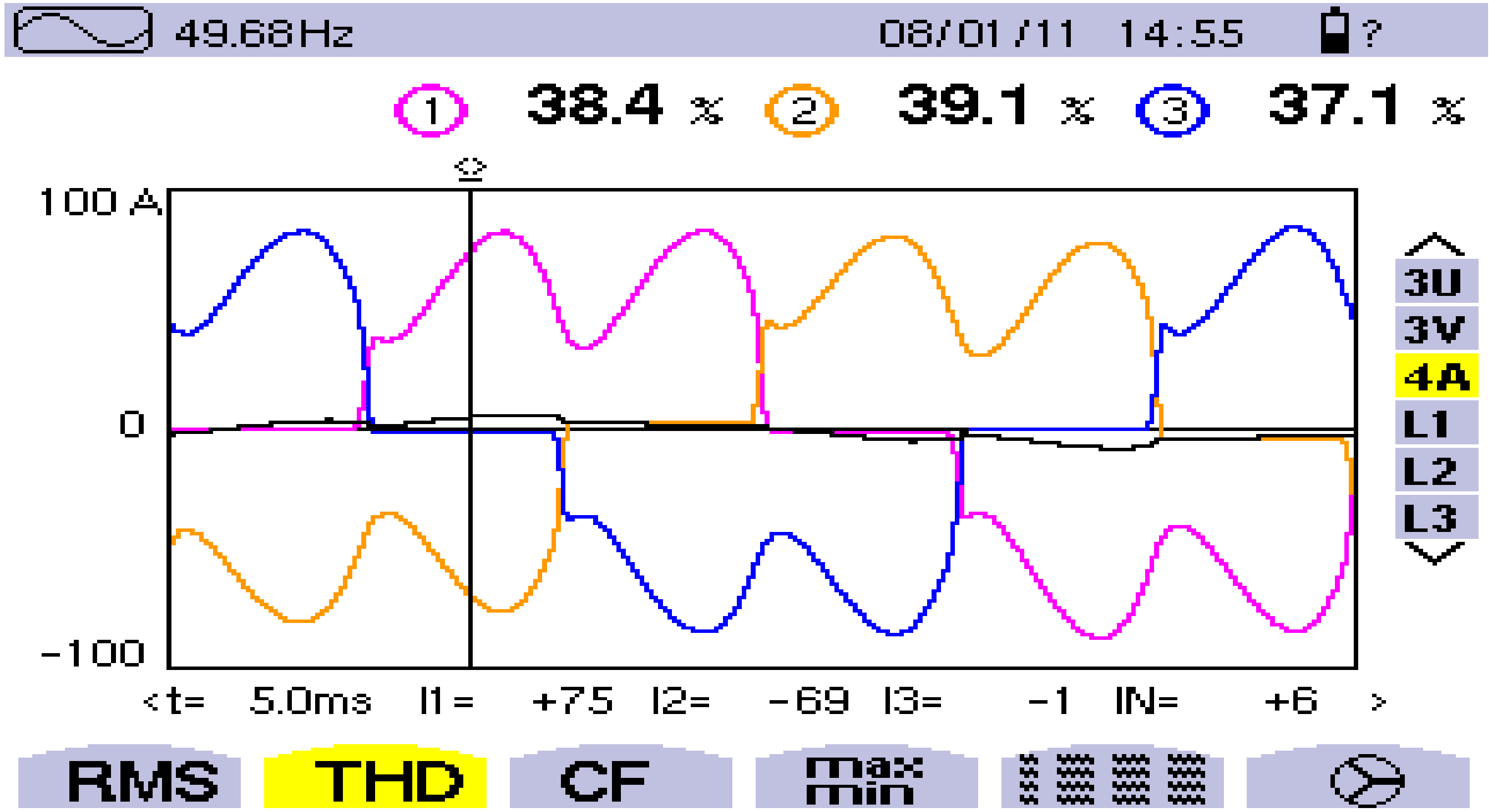
# VARIABLE FREQUENCY DRIVE



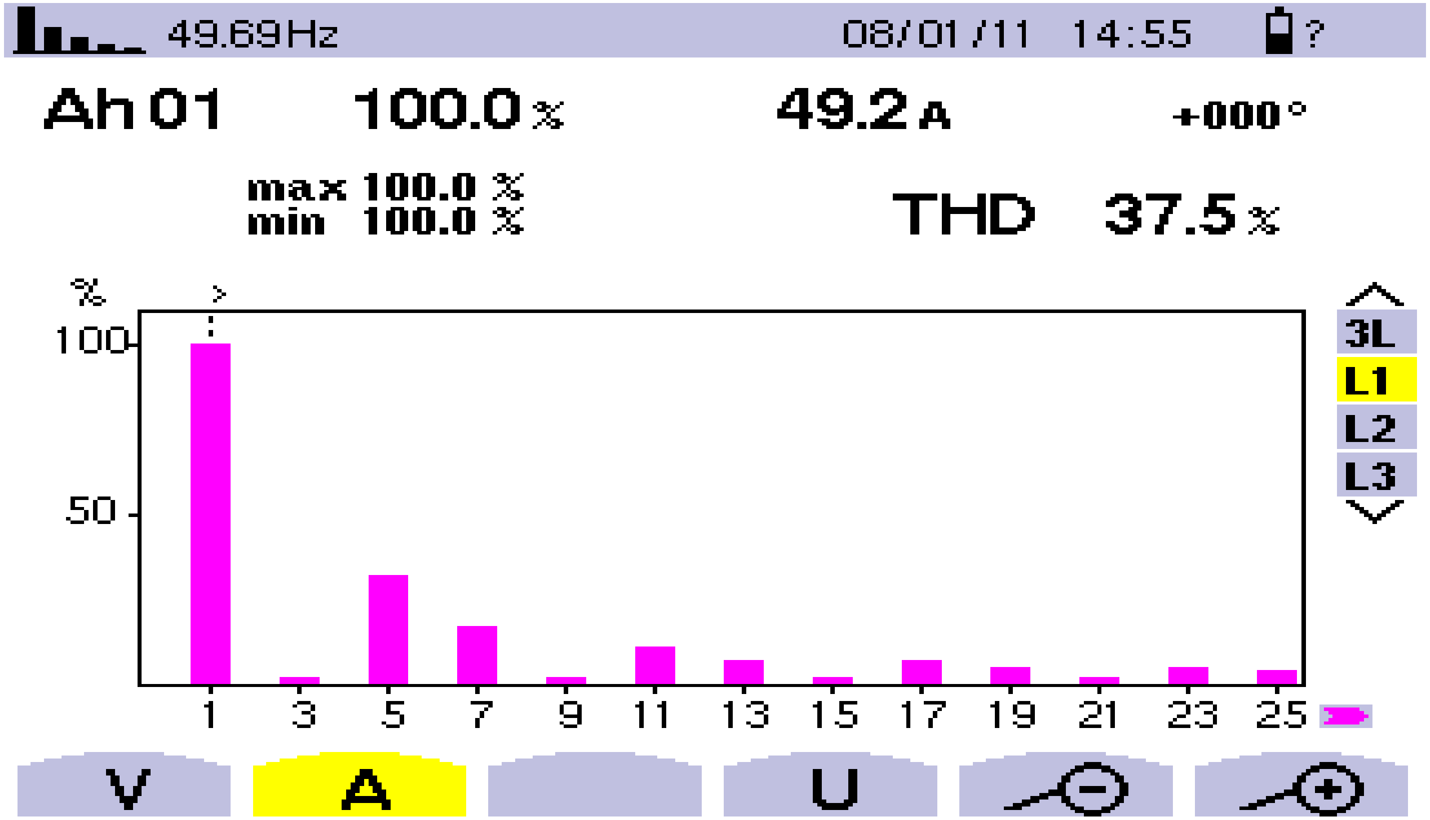
# VFD CURRENT WAVE FORM



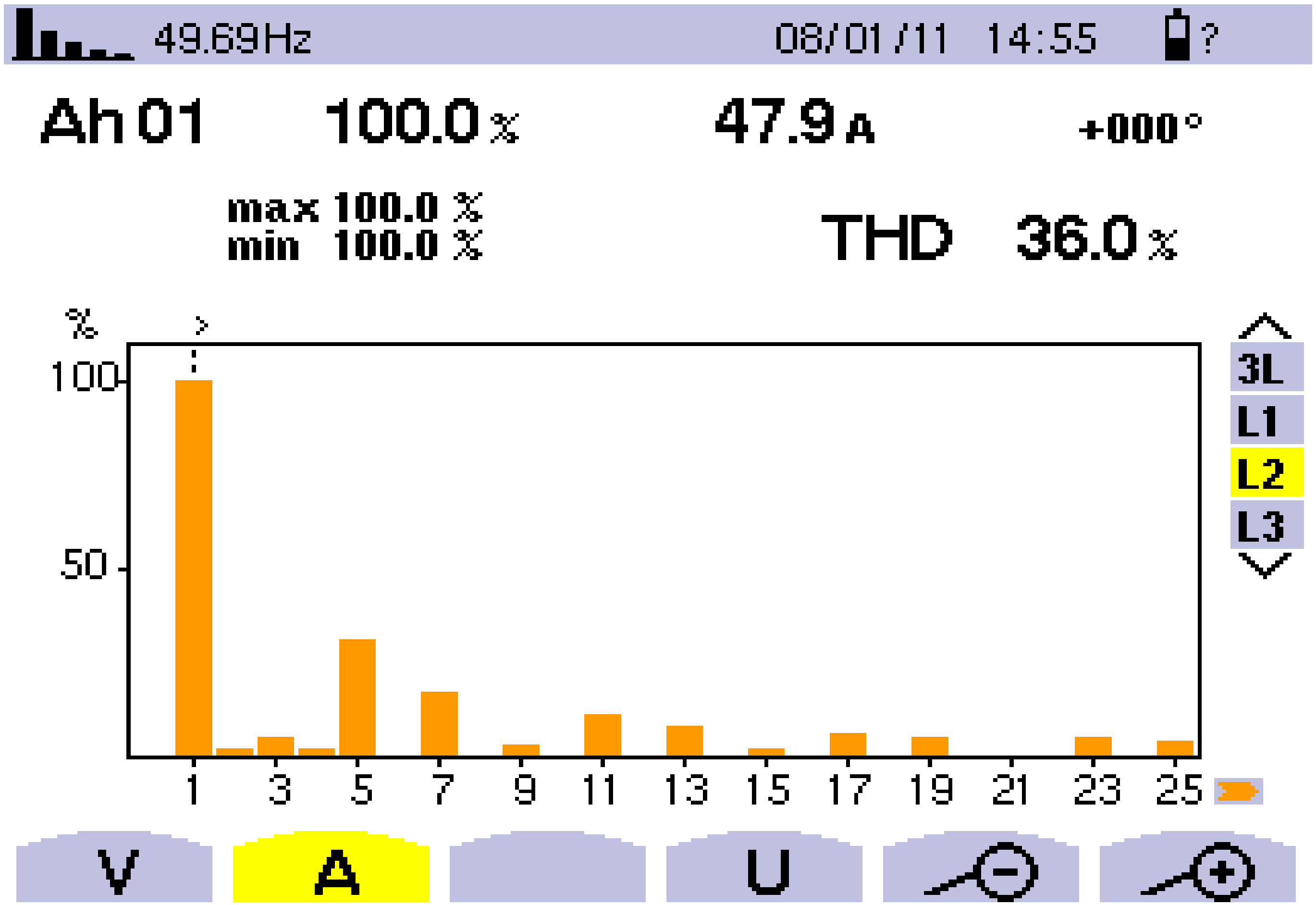
# VFD CURRENT WAVEFORM AND THD



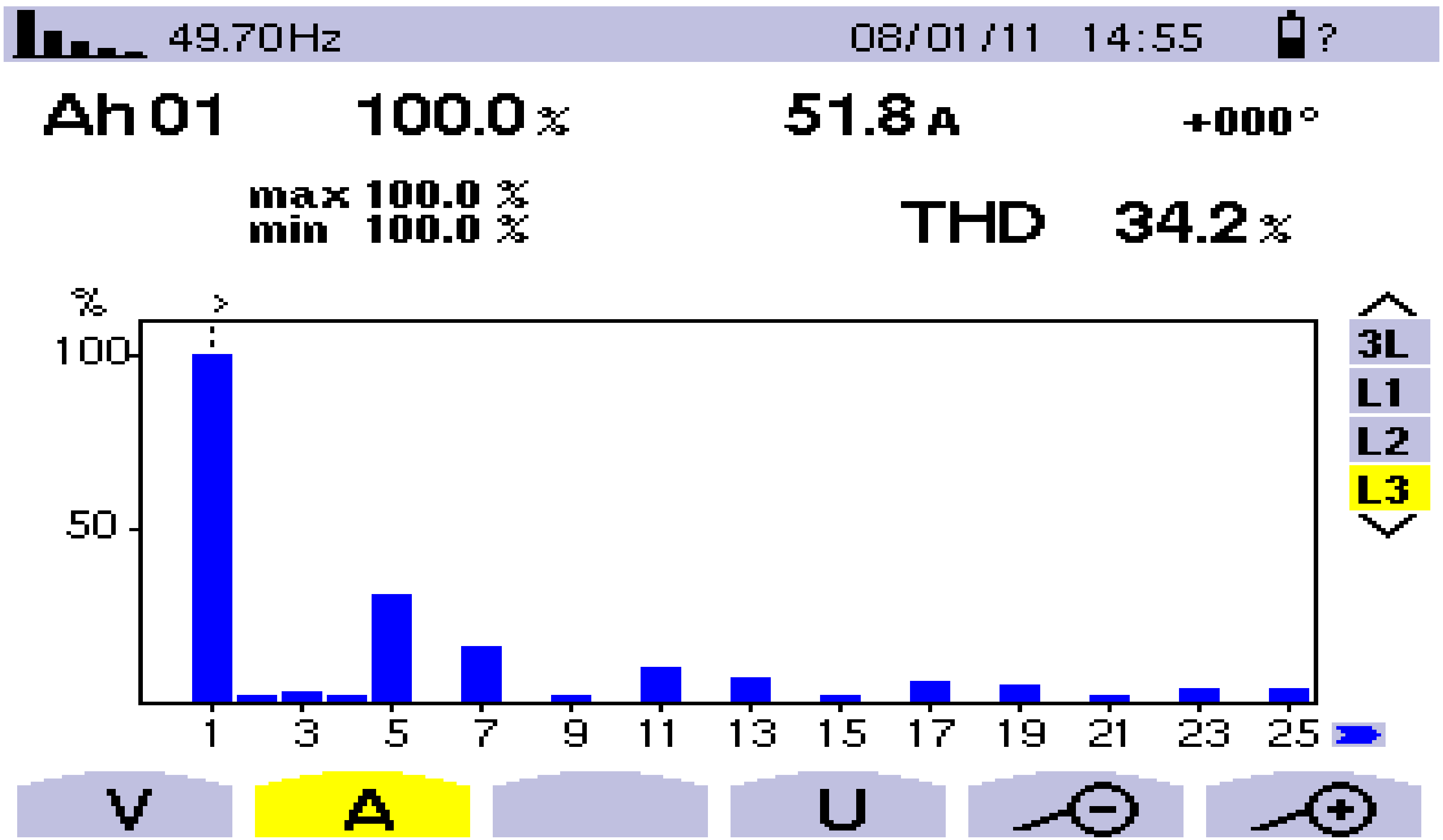
# CURRENT HARMONICS



# CURRENT HARMONICS



# CURRENT HARMONICS



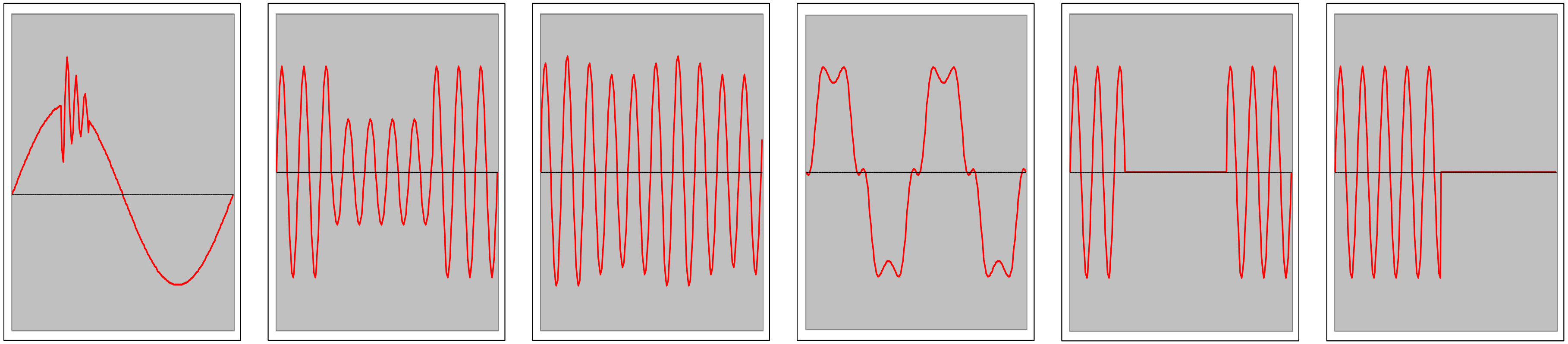
IEM Power Systems™

# Rotabloc® RBT

## Rotary UPS systems

# Introduction - Power Quality

What is it not ?



Overvoltage / Surge — Voltage dip / Brown-out — Voltage fluctuation — Harmonics / Distortion — Microcut / short cut — Power failure / Black-out

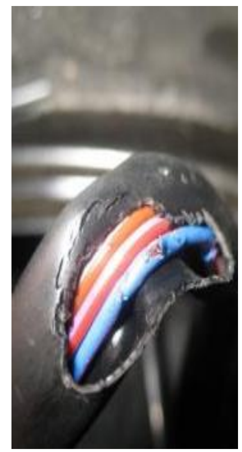
Uninterrupted power ≠ High Quality power !

# Introduction - Power Quality

## What affects Power Quality ?

External causes ( mains side )

- Lightning
- Fault on transport or distribution lines
- Transformer failure
- Surrounding users
- …



Internal causes ( load side )

- Load step, peak current…
- Short-circuit, fault, transient
- Current distortion, harmonics
- …

High Quality Power Supply = Protection against <u>mains</u> disturbances + Capacity to handle <u>load</u> disturbances

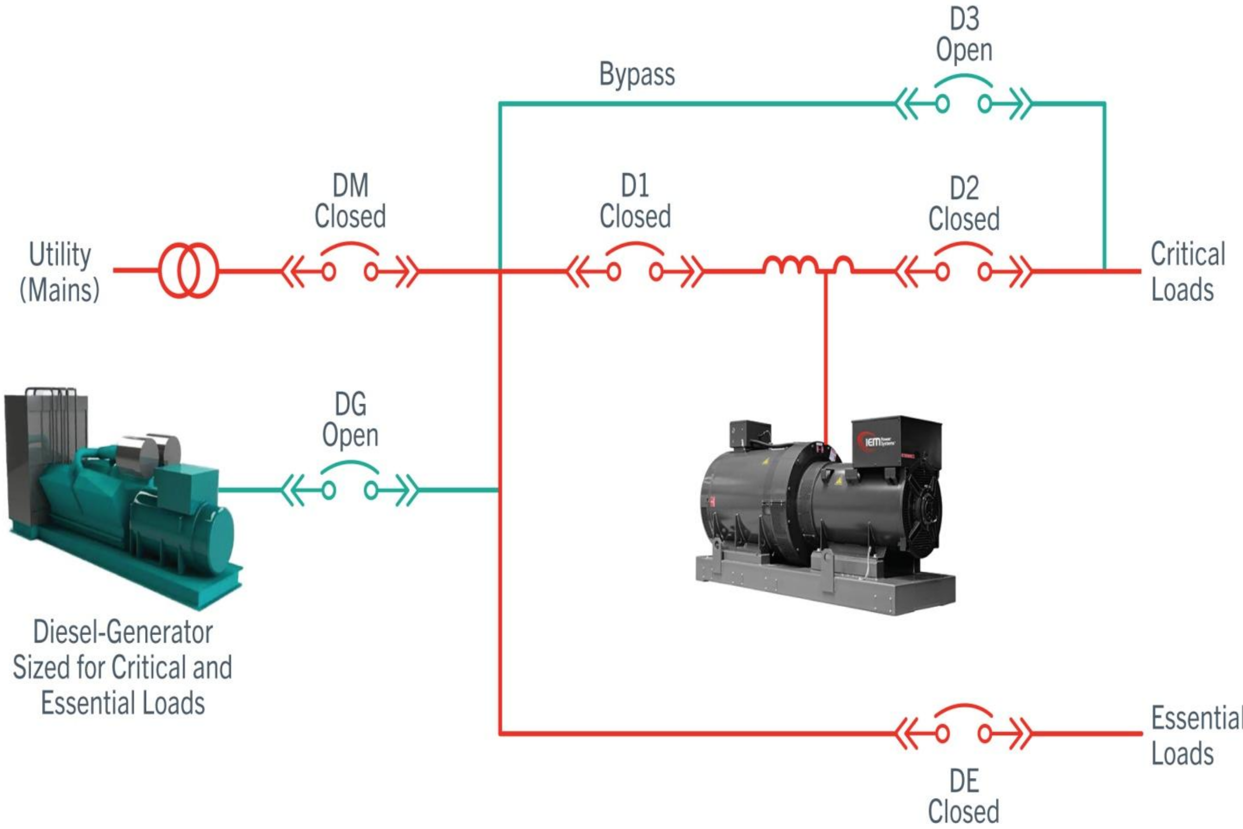
# Product: Rotary UPS

- 400kVA upto 2MVA
- Low Voltage and Medium Voltage
- Voltage and Power Conditioning
- High efficiency
- High short-circuit power
- Low Maintenance
- Low TCO
- 50 $^{o}$C Rated

- ROTABLOCK

# System Operation 1 – Normal Operation

In **Normal Operation**, the Rotabloc (RB) filters the supply to the Critical Loads (No Break) via the UPS choke and regulates the power factor at the Utility service input.



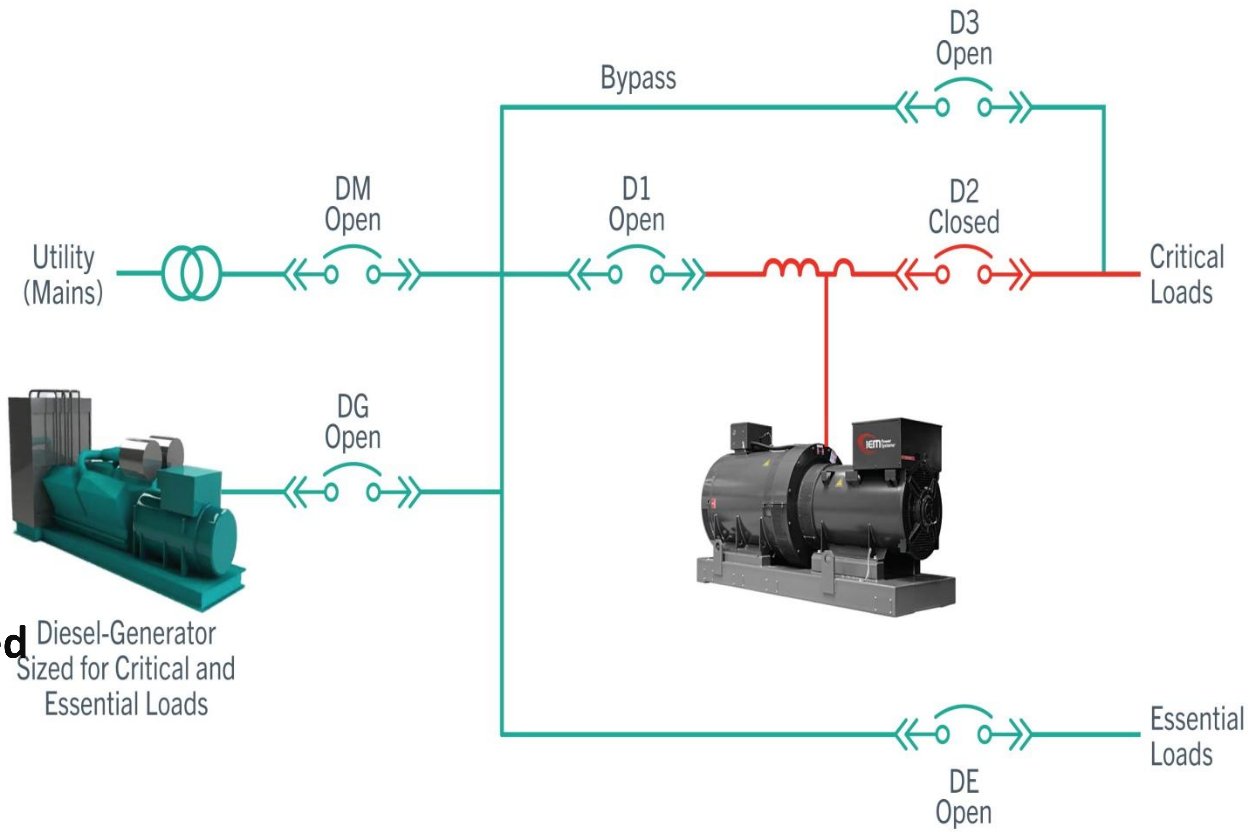
# System Operation 2 – Utility Failure

When the **Utility fails**
D1 opens and the Diesel Engine Generator (EG) is sent a start signal.

**During EG start the Rotabloc supplies the Critical Loads** and Essential Loads disconnected.

Once the Diesel is at speed, it syncs with the UPS and DG closes. The Critical Load is handed gradually to the Diesel Genset.

**<u>Critical Loads</u> are now supported by the Diesel.**



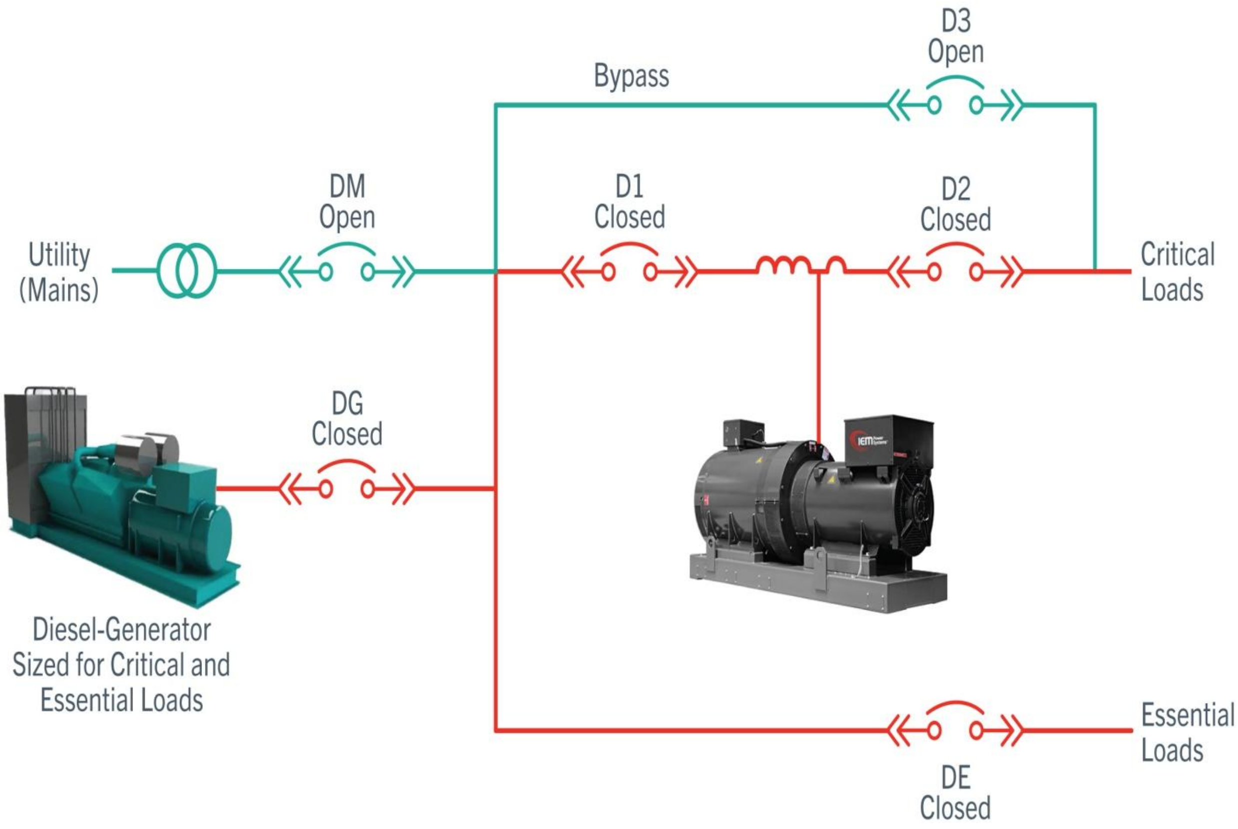

**All Critical Loads are maintained at all time.**

# System Operation 3 – Diesel Genset Operation

After a short period of supplying only the No Break Loads, the UPS breaker DE closes and reconnects the Short Break Loads.

The VFD maintains the UPS speed and will use any excess diesel generator power to recharge the UPS so that it is ready to manage another Utility failure.

**At this stage all loads are served by the Diesel Engine Genset**

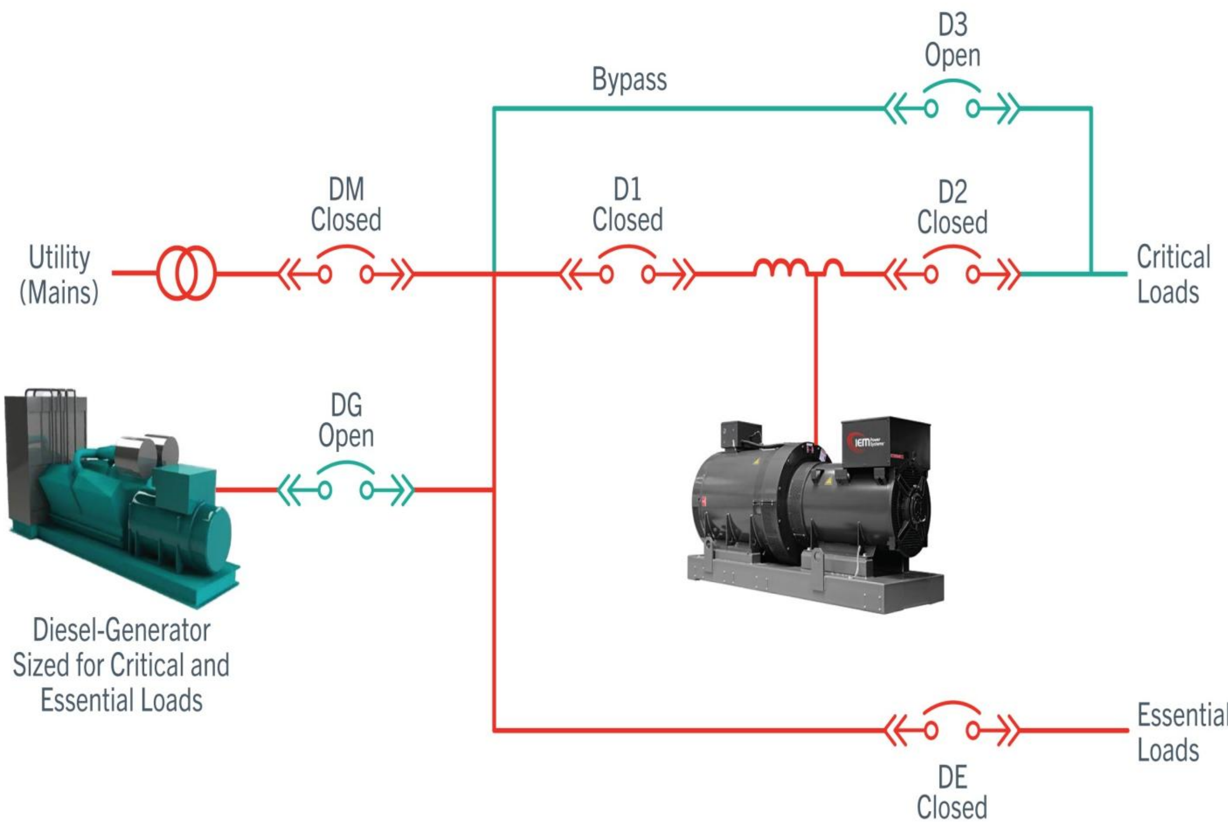


# System Operation 4 – Return to Utility Power

When the Utility supply returns, the VFD ensures that the Rotabloc is fully recharged before it signals that a return to Utility can begin.

The Utility breaker DM closes and the Loads are gradually transferred to Utility power.

DG is opened and the Diesel disconnected.

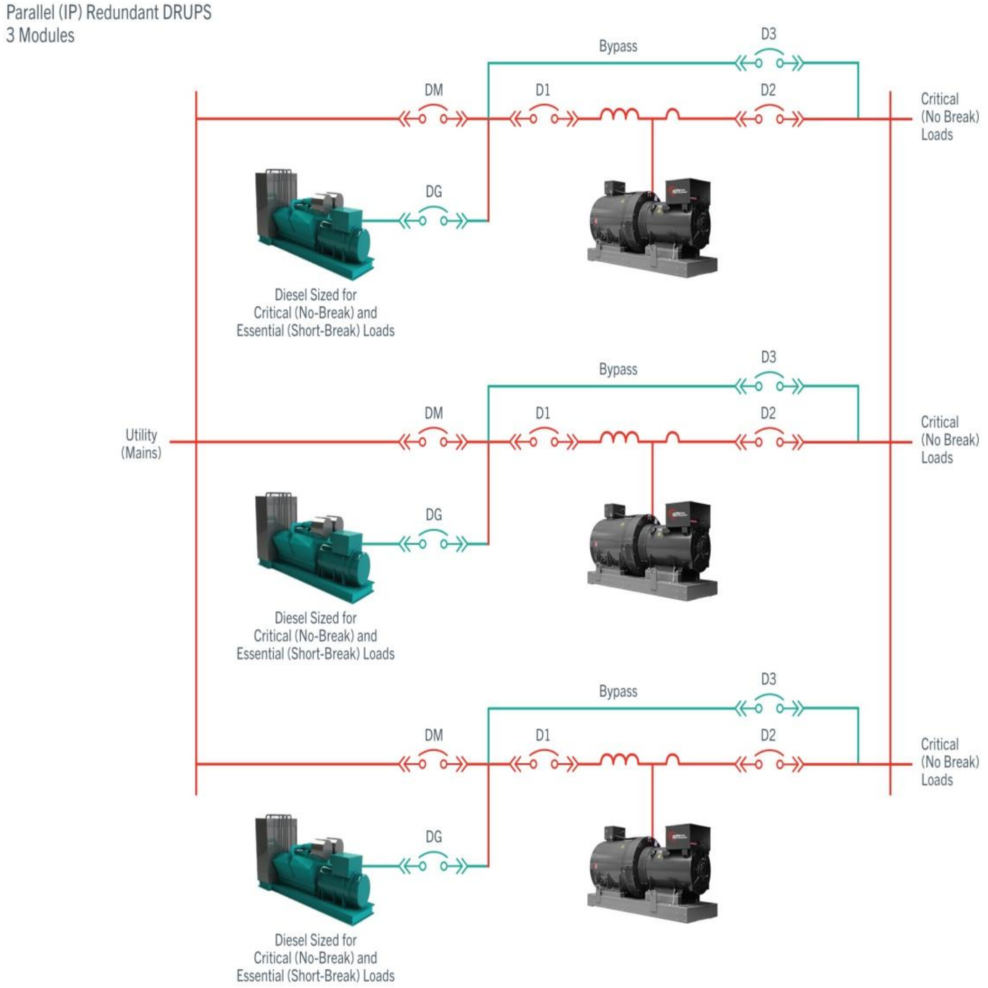



**During the transfer to Utility <u>all loads</u> are maintained without break.**

# System Configurations 3 – Parallel Redundant (LV)

Creating Redundancy in the UPS System ensures that even in cases of simultaneous multiple failures.

For example utility power fails while a diesel genset is being maintained – the Critical Load is always protected.



# References gallery


Trinidad & Tobago Telecom Services – Data Centre – 2 x 400 kVA (n+1)

# References gallery

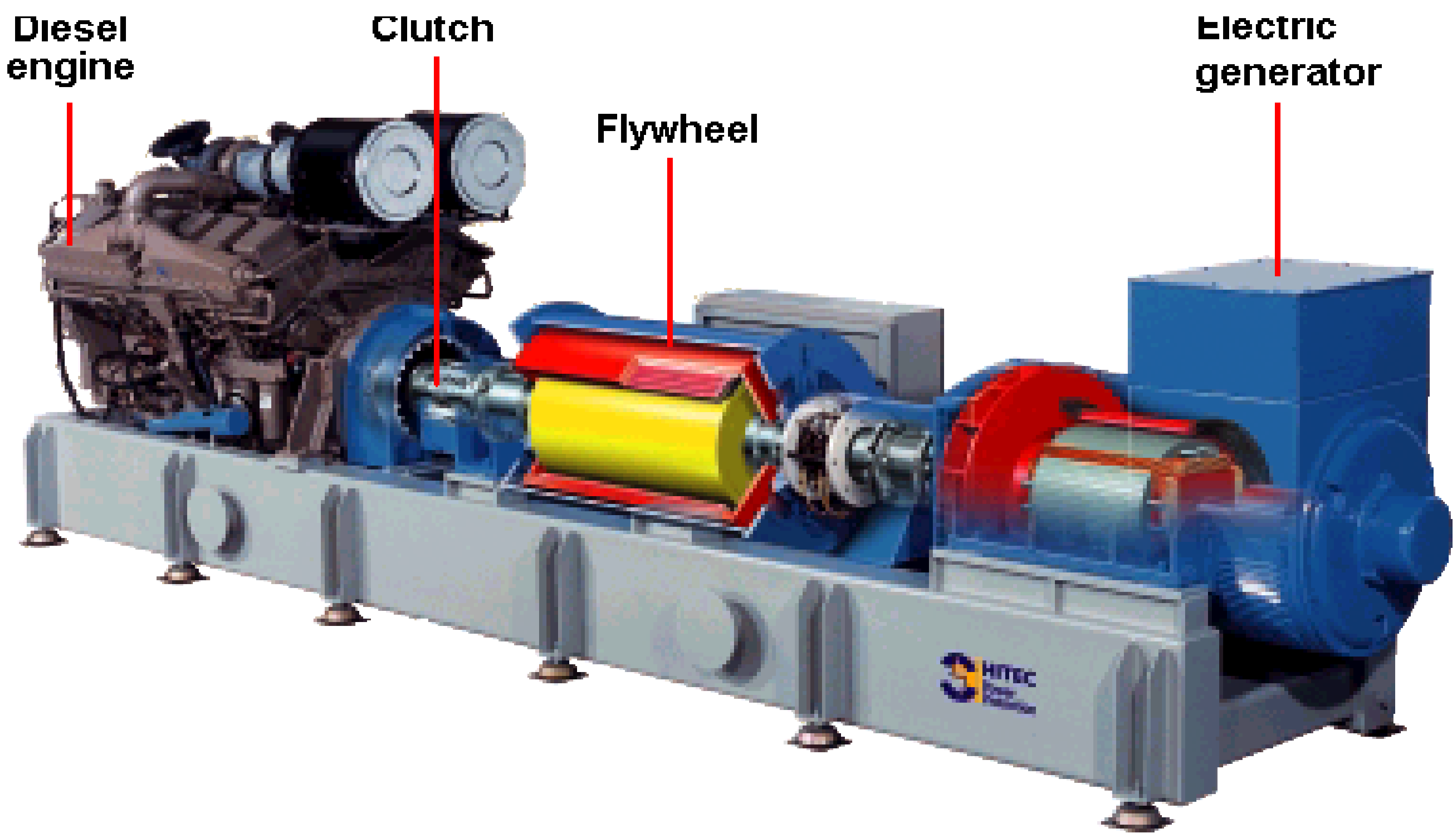

Co-op Bank Data Centre  2 x 500 kVA

Fujitsu Nova Data Centre 2 x 400 kVA

# References gallery


European Synchrotron Radiation Facilities 14 x 800 kVA @ 20kV

# CONTINUOUS POWER SYSTEM



# Thank You