Ac harmonic filters
HVDC Main Components
AC Harmonic Filters
Filter Design Objectives

- Limit voltage distortion
- Minimise reactive power imbalance
- Minimise losses
- Improve system performance

Types of Harmonic

- Idealised harmonic currents
- Practical harmonic currents
  - Characteristic harmonics
  - Theoretically cancelled harmonics
  - Non-characteristic harmonics
Types of Harmonic

- Idealised harmonic currents
- Practical harmonic currents
  - Characteristic harmonics
  - Theoretically cancelled harmonics
  - Non-characteristic harmonics
Idealised Current Waveforms....
Combined Waveform.....
Practical Harmonic Currents....
Fourier Analysis

\[ I = \frac{2\sqrt{3}}{\pi} I_D \left( \cos \omega t - \frac{1}{5} \cos 5\omega t + \frac{1}{7} \cos 7\omega t - \frac{1}{11} \cos 11\omega t + \frac{1}{13} \cos 13\omega t \ldots \right) \]

\[ I = \frac{2\sqrt{3}}{\pi} I_D \left( \cos \omega t + \frac{1}{5} \cos 5\omega t - \frac{1}{7} \cos 7\omega t + \frac{1}{11} \cos 11\omega t - \frac{1}{13} \cos 13\omega t \ldots \right) \]
Fourier Analysis

\[
I = \frac{4 \sqrt{3}}{\pi} I_D \left( \cos \omega t - \frac{1}{11} \cos 11 \omega t + \frac{1}{13} \cos 13 \omega t - \frac{1}{23} \cos 23 \omega t + \frac{1}{25} \cos 25 \omega t \ldots \right)
\]
11th Harmonic as a Percentage of Fundamental
Characteristic Harmonic Generation

- 11th Harmonic
- 13th Harmonic

Graph showing harmonic line current % of rated fundamental vs transmitted power (PU).
Theoretically Cancelled Harmonic Generation

Harmonic line current % of rated fundamental

Transmitted Power (PU)

5th
7th
Typical Spectrum...
Non - Characteristic Harmonics

- Orders $n = 1, 2, 3, 4$ etc.
  - AC system unbalance (NPS)
  - Transformer reactance phase unbalance
  - Pre-existing distortion
  - Firing angle jitter
Filter $Z_{fn}$

System $Z_{Sn}$

$I_{cn}$

$I_{fn}$

$I_{Sn}$

$V_{Sn}$
400kV System Harmonic Impedance
Sasaram Filters

400kV

Double Damped Filter

400kV

Double Tuned Filter
AC Filter Layouts...

- Components mounted on the ground
- Insulation and magnetic clearances
- Two types of harmonic filter
  - Double damped filter
  - Double tuned filter
- Key Interlocking System for safety - to permit access only when filter is de-energised and earthed.
AC Filter Layouts Double Damped Filter
3/13th Double-Frequency Filter

Admittance vs frequency for 400kV 112Mvar 3/13 double frequency filter

Admittance

Harmonic
Admittance vs frequency for 400kV 112Mvar 11/25 double frequency filter

11/25th Double-Frequency Filter
Types of Filter

- Single frequency tuned filter
- 2nd Order broadband damped filter
- 3rd Order broadband damped filter
- ‘C’ Type broadband damped filter
Single Tuned

- Advantages
  - Maximum attenuation at single harmonic
  - Low loss

- Disadvantages
  - May be de-tuned
  - Off-circuit adjustment
Effect of De-tuning
2nd Order Damped

- Advantages
  - Attenuation over a spectrum of harmonics
  - Less sensitive to de-tuning

- Disadvantages
  - Needs higher Mvar to achieve same performance as single tuned
  - Additional losses in resistor
Tuned / Damped Filters

Filter admittance

Tuned filter

Damped filter

f1 f0 f2 Frequency
Types of Filter

1. Single frequency tuned filter
2. 2nd Order broadband damped filter
3. 3rd Order broadband damped filter
4. ‘C’ Type broadband damped filter
3rd Order Damped

- Advantages
  - Lower losses in resistor

- Disadvantages
  - Poorer performance than 2nd order
  - Additional cost of capacitor
C - Type

- Advantages
  - lower losses in resistor
  - Better performance than 3rd order
- Disadvantages
  - Poorer performance than 2nd order
  - Additional cost of capacitor
  - May require off-circuit adjustment
Multiple Tuned Filters

- Advantages
  - Only one HV capacitor bank
  - Only one reactor subject to HV tests
  - Reduced number of filter arms
  - No minimum size
  - Improved redundancy
  - Low fundamental losses (double tuned)
Double Tuned Filters

Double Tuned

Double Tuned
Admittance Characteristic
(G = conductance, B = susceptance)
Main Capacitor

- Corona Rings
- Base Insulators
- Horizontal Mounted Cans
- HV Terminal
- LV Terminal
Auxiliary Capacitor

HV terminal

LV terminal

Base Insulators

Steel Frames
Reactors

- Spiders
- Terminal
- Coil
- Base
- Insulators
- Pedestals
Resistors

- **Roof**
- **Bushings**
- **Base Insulators**
Thank You