

HARMONIC FILTERS

Design for IEC 61000 compliance

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Overview

- **What is a filter**
- Types of harmonic filters
- What is harmonic compliance
- Designing for compliance
- Designing for reliability
- Other considerations

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Filter defined

- Device or combination of devices
- Intended to reduce harmonic voltage distortion
- Caused by non-linear loads in the network
- That may be otherwise result in costs, losses or damage to other equipment in the network

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Filter defined

- Device or combination of devices
 - Can be a single filter, or a combination of several
 - Can be located at a single node or be distributed
 - Can be active or passive
 - Can be part of equipment selection (transformer impedance or vector arrangement)
- Intended to reduce harmonic voltage distortion
- Caused by non-linear loads in the network
- That may be otherwise result in costs, losses or damage to other equipment in the network

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Filter defined

- Device or combination of devices
- Intended to reduce harmonic voltage distortion
 - Australian power quality focuses on voltage distortion
 - Voltage distortion in the network is seen by all connected loads
- Caused by non-linear loads in the network
- That may be otherwise result in costs, losses or damage to other equipment in the network

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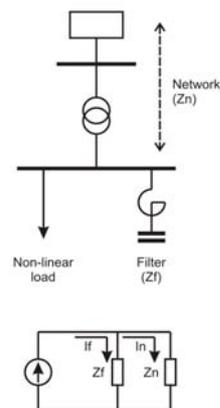


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Filter defined

- Passive filter presents a lower impedance path for harmonic current than the rest of the system
- The amount of harmonic absorption is a function of the filter configuration and the network impedance
- Filter impedance can be designed to reduce network voltage distortion



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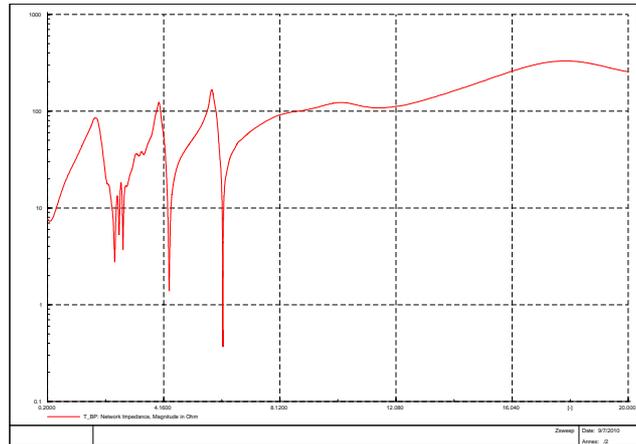


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Filter defined

- Network impedance generally has multiple poles and zeroes



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Types of harmonic filter

- Single tuned
- C-type
- Damped single tuned
- Double (and more) tuned

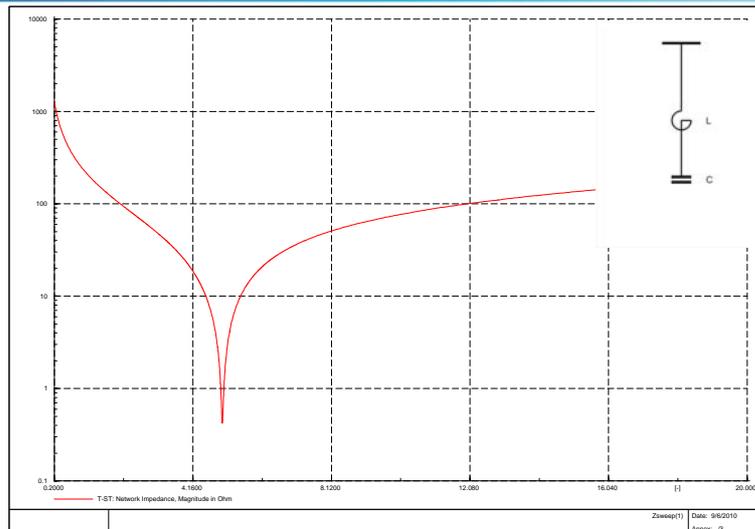
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Types of harmonic filter – Single tuned



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Types of harmonic filter – Single tuned



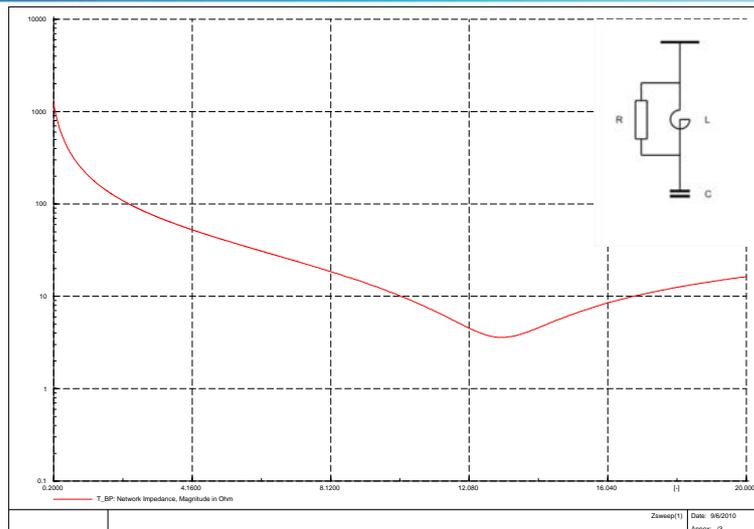
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Types of harmonic filter – Damped single tuned



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Types of harmonic filter – Damped single tuned



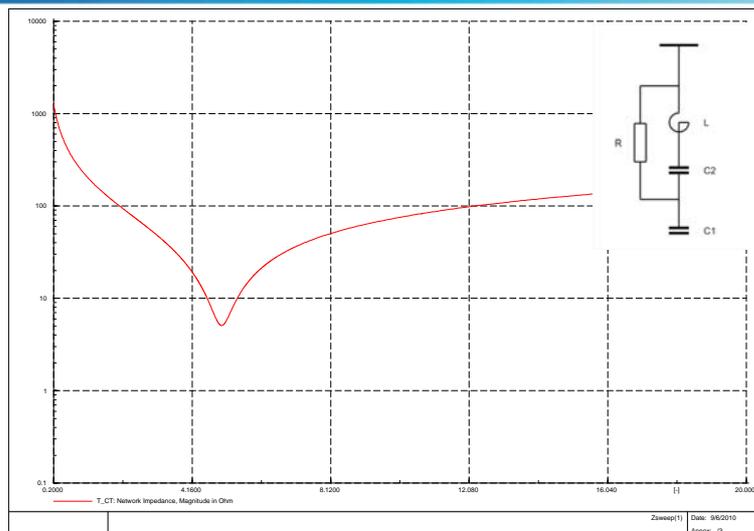
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Types of harmonic filter – C-type



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Types of harmonic filter – C-type



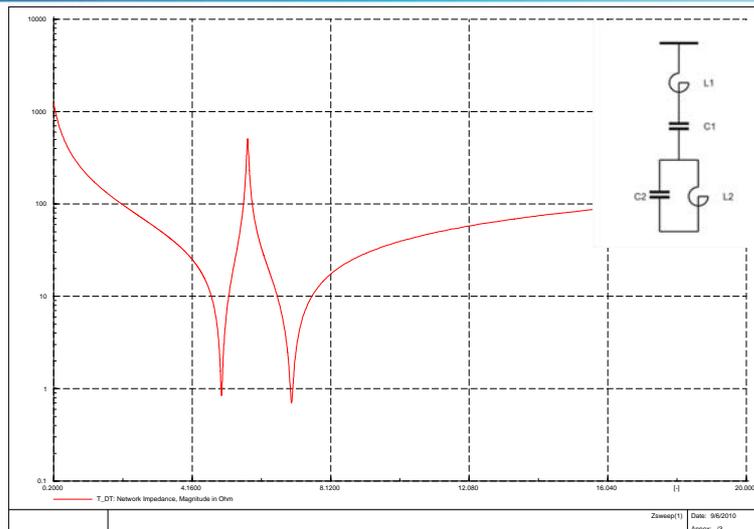
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Types of harmonic filter – Double tuned



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Types of harmonic filter – Double tuned



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Types of harmonic filter – Comparison

| | Single tuned | Damped | C-type |
|----------------------------------|--------------------|---------------|--------------------|
| Performance as a harmonic filter | Best (Green) | Good (Yellow) | Good (Light Green) |
| Complexity of electrical design | Good (Yellow) | Worst (Red) | Worst (Red) |
| Mechanical complexity | Good (Light Green) | Good (Yellow) | Worst (Red) |
| Required footprint | Good (Light Green) | Good (Yellow) | Worst (Red) |
| Susceptible to variation | Worst (Red) | Best (Green) | Best (Green) |
| Audible noise | Good (Yellow) | Worst (Red) | Worst (Red) |
| Losses | Best (Green) | Worst (Red) | Good (Yellow) |
| Cost of capital | Good (Light Green) | Good (Yellow) | Worst (Red) |
| Cost of installation | Good (Light Green) | Good (Yellow) | Good (Yellow) |
| Operating cost | Best (Green) | Worst (Red) | Good (Yellow) |

Best ■ ■ ■ ■ Worst

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Harmonic compliance

- AS/NZS 61000-3-6

Table 2 – Indicative values of planning levels for harmonic voltage (in percent of the nominal voltage) in MV, HV and EHV power systems ¹⁾

| Order h | Odd harmonics non multiple of 3 | | Odd harmonics multiple of 3 | | | Even harmonics | | |
|------------|------------------------------------|-------------------|--------------------------------|--------------------------|--------|----------------|--------------------------|--------|
| | Harmonic voltage % | | Order h | Harmonic voltage % | | Order h | Harmonic voltage % | |
| | MV | HV-EHV | | MV | HV-EHV | | MV | HV-EHV |
| 5 | 5 | 2 | 3 | 4 | 2 | 2 | 1.6 | 1.5 |
| 7 | 4 | 2 | 9 | 1.2 | 1 | 4 | 1 | 1 |
| 11 | 3 | 1.5 | 15 | 0.3 | 0.3 | 6 | 0.5 | 0.5 |
| 13 | 2.5 | 1.5 | 21 | 0.2 | 0.2 | 8 | 0.4 | 0.4 |
| 17 | 1.6 | 1 | >21 | 0.2 | 0.2 | 10 | 0.4 | 0.4 |
| 19 | 1.2 | 1 | | | | 12 | 0.2 | 0.2 |
| 23 | 1.2 | 0.7 | | | | >12 | 0.2 | 0.2 |
| 25 | 1.2 | 0.7 | | | | | | |
| >25 | 0.2 + 0.5 h | 0.2 + 0.5 h | | | | | | |

NOTE – Total harmonic distortion (THD): 6.5% in MV networks; 3% in HV networks.

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Harmonic compliance

- The table is the beginning, not the end of the story
- Network owners must set their own planning limits
- Emission limits must then be calculated according to the procedures in the standard for every new load to ensure planning levels are not exceeded
- These emission limits are the compliance limits
- They are always lower than the planning limits
- Emission limits are generally stated as voltage distortion at a busbar in the absence of other loads or background distortion

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Harmonic compliance

Typical emissions limit table:

| Harmonic | Allocated % of Fundamental Voltage | Harmonic | Allocated % of Fundamental Voltage |
|----------|------------------------------------|----------|------------------------------------|
| 2 | 0.55 | 27 | 0.11 |
| 3 | 0.66 | 28 | 0.10 |
| 4 | 0.33 | 29 | 0.28 |
| 5 | 0.66 | 30 | 0.10 |
| 6 | 0.16 | 31 | 0.20 |
| 7 | 0.66 | 32 | 0.10 |
| 8 | 0.13 | 33 | 0.10 |
| 9 | 0.33 | 34 | 0.10 |
| 10 | 0.16 | 35 | 0.20 |
| 11 | 0.60 | 36 | 0.10 |
| 12 | 0.11 | 37 | 0.24 |
| 13 | 0.60 | 38 | 0.10 |
| 14 | 0.10 | 39 | 0.10 |
| 15 | 0.15 | 40 | 0.10 |
| 16 | 0.10 | 41 | 0.27 |

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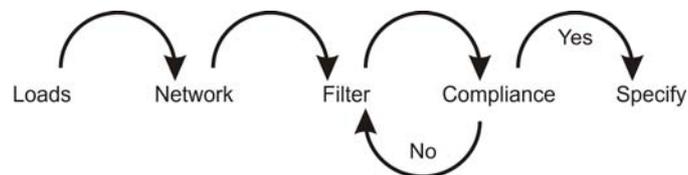


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Design for harmonic compliance

- Similar approach for compliance and reliability
- Compliance looks at the network
- Reliability looks at the filter components



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Design for harmonic compliance

➤ Loads

- If at all possible, measure existing loads or at least voltage distortion
- Familiar with conditions on site
- Can be used to calibrate the model
- Take care of AS/NZS 61000-4-7
- Can be scaled for load changes
- Many variations / combinations are possible
- Determine harmonic current emission to be used

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Design for harmonic compliance

➤ Network

- Existing model may be available
- Many "topology" variations are possible: fault level, loading, generation, lines connected
- Documented and agreed topology scenarios
- Many "network" variations are possible: voltage deviations, unbalance, frequency deviations
- Documented and agreed network variations
- Network model without knowledge of frequency dependency is useless
- Unbalanced harmonic load flow generally required
- Wherever possible, calibrate the model from measurements and explain any deviations

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Design for harmonic compliance

➤ Filters

- Select a filter configuration that is feasible in terms of design and impact on the network
- Obtain as realistic as possible model for components: resistance of reactors, manufacturing tolerances of components, sensitivity to aging, temperature
- Document the range of variations in L, C and R
- General guideline is to keep it as simple as possible: minimum steps, minimum components

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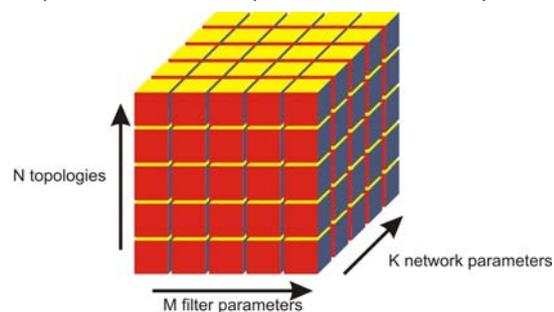
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Design for harmonic compliance

➤ Compliance test

- N possible topologies, K network parameters, and M filter parameters that can change $N \times K \times M$ can easily result in thousands of discrete scenarios
- Each scenario produces sets of harmonic spectra at multiple busbars
- Compliance reached with optimal cost solution – capital and lifetime



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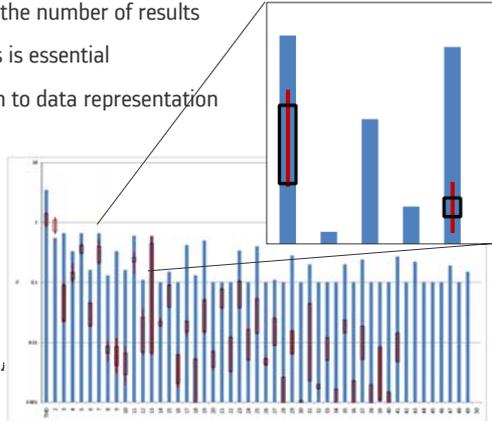
Design for harmonic compliance

➤ Compliance test

- Common sense can reduce the number of results
- Automated analysis process is essential
- Sensible, compact approach to data representation
- Box and whisker

```
oMatrix.Set(H, 6, MaxRef); !Set MaxRef
}

oMatrix.Set(H, 1, H); !Set Harmonic order
CaseNumber.Execute(CaseName);
!CaseNr=CaseNumber:CaseNr;
IAvg= ((IAvg*(Iter-1) +IAvg)/Iter;
printf(' HDxAvg=%f---HDnew=%f---iter=%i', IAvg, HDnew, Iter);
oMatrix.Set(H, 4, IAvg); !Set Avg
}
```



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Design for reliability

- Equipment to be rated to ensure reliable operation
- Ratings according to manufacturing standards
- IEC 60871 for capacitor units
- AS/NZS 1028 (or IEC 60076-6) for reactors
- Worst case expected continuous and short time ratings determined from modelling

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Design for reliability

- IEC 60871 for capacitor units

Addition to 3.11:

In the case of filter capacitors, U_N is defined as the arithmetic sum of the r.m.s. voltages arising from the fundamental voltage and the harmonic voltage, or as the voltage calculated from rated output (see addition to 3.10) and capacitor reactance at rated frequency, whichever value is the greater.

- AS/NZS 1028 for reactors

29.1 Rated current or voltage quantities

Depending on whether the tuning reactor is intended to be connected in a series or a parallel configuration, it has rated values of power-frequency and tuning-frequency current or voltage, as applicable.

The values of these rated quantities shall be selected at least equal to the expected values in normal operation of the filter circuits in the system.

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Other considerations

- Protection and control
- Acceptable sound emissions
- Insulation coordination / Impulse withstand
- Switching transients
- Seismic and wind loading
- Standardisation

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