Overview of CIGRE TB 913

CIGRE UK SC C4 Technical Event – 21st January 2025

Presented by:

Kiran Munji

Grid Services Manager at SPR

For power system expertise

Table of Contents

For power system expertise

Temporary Overvoltage

Definition

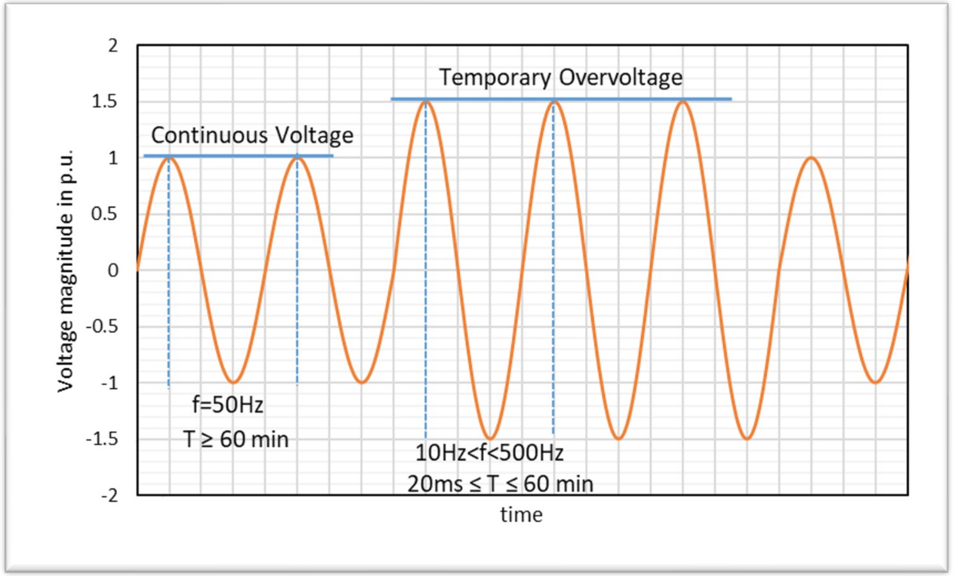
IEC 60071-1 (2019) defines temporary overvoltage as a power-frequency overvoltage of relatively long duration, that may be undamped or weakly damped. Its frequency may be several times smaller or higher than power frequency.

Continuous voltage:

- Characteristics: continuous sinusoidal
- Frequency: 50Hz or 60Hz
- Duration: ≥ 60min

Temporary overvoltage (TOV):

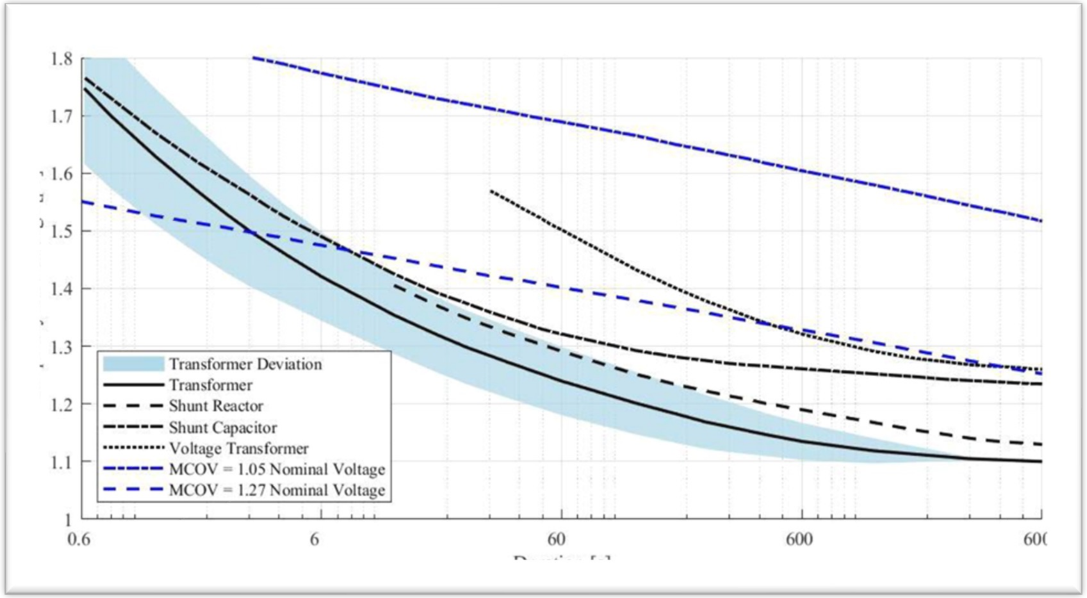
- Characteristics: undamped or weekly damped
- Frequency: 10Hz ≤ f ≤ 500Hz
- Duration: 20ms ≤ T ≤ 60min



Significance of WG C4.46

Ref 913

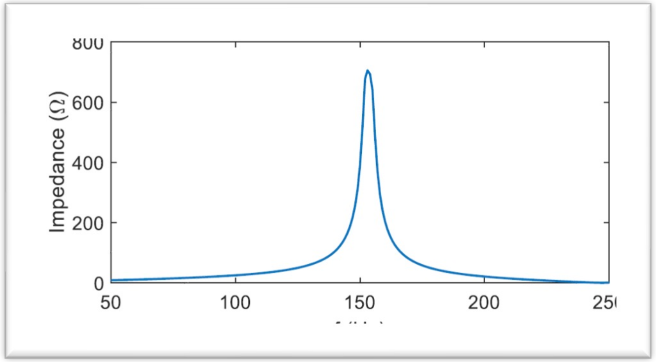
- IEC 60071-1 specifies a short duration power frequency test withstand voltage (SDPF) on a basis of 1-min value.
  - ✓ **(e.g. for the equipment rated at highest voltage (Um) of 245kV, a SDPF voltage of 460kV is applied for 60s)**
- CIGRE C33.10-1998 specifies the withstand curves based on duration of voltage application and only applicable for power frequencies and voltages higher than 345kV.
- Both the IEC standard and the CIGRE publication did not address the impact on insulation with respect to harmonically distorted TOV's.
- There are no methods to evaluate these kind of overvoltages. Instead, they strongly recommend that TOVs due to harmonic resonance conditions should be either avoided or properly limited by means of mitigation measures, which might not always be possible due to the resonances occurring at lower frequencies.



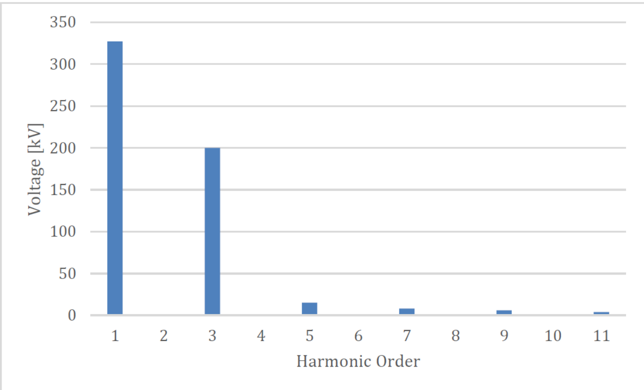
Shortfalls of past literature

- There are instances when the duration of overvoltage is less than 60s and comparing with 1-min value is quite conservative and leads to oversizing of the equipment as per IEC.
- If the overvoltages are undamped and for long duration, then it might lead to premature ageing and failure of the insulation.
- The CIGRE publication did not cover the withstand requirement for overvoltages below 600ms.
- No detailed information on equipment's capabilities in withstanding TOVs due to harmonic resonances is presented. Harmonic content may be amplified due to resonances and therefore, it is not fully correct to compare the voltage shape to the curves.

Sources of TOV



Impedance scan of a network showing parallel resonance around 150Hz.



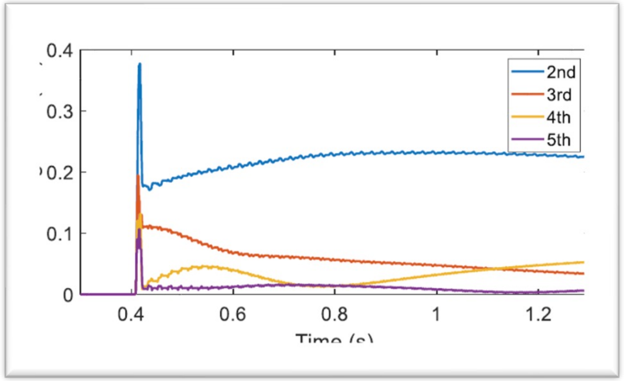
FFT of a voltage waveform during transformer energisation.

Introduction

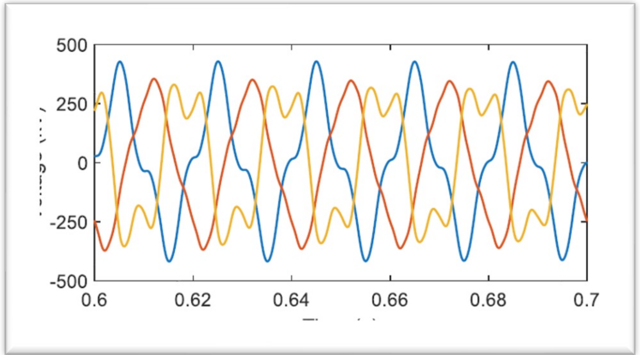
- Series and parallel resonance in a network containing inductive and capacitive elements
  - ✓ **(e.g. network with long cable network introducing resonance at lower orders).**
- Weak networks with long cables or transmission lines leading to ineffective damping of the overvoltages.
- Network events that can generate and inject harmonic currents in the system, resulting in the excitation of these resonances.
  - ✓ **(energisation of transformer connected to long HV cable)**
- The impedance scan of a network and the resultant FFT of a voltage waveform showing high magnitude of 3rd order harmonics.

Sources of TOV

Transformer Energisation



FFT of inrush current during transformer energisation.



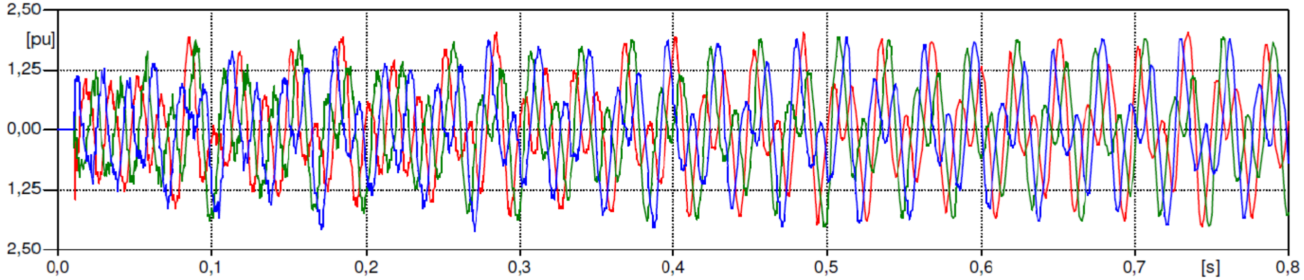
Overvoltage following transformer energisation.

- The inrush currents of the transformer contain harmonics due to the nonlinearity of its magnetizing inductance.
- These harmonics excite the resonance of the network seen from the transformer. The resulting voltage contains the excited harmonics, which is the cause of the temporary overvoltage.
- lightly loaded networks with low resonant frequencies are the most problematic in terms of resonance related TOVs.

Sources of TOV

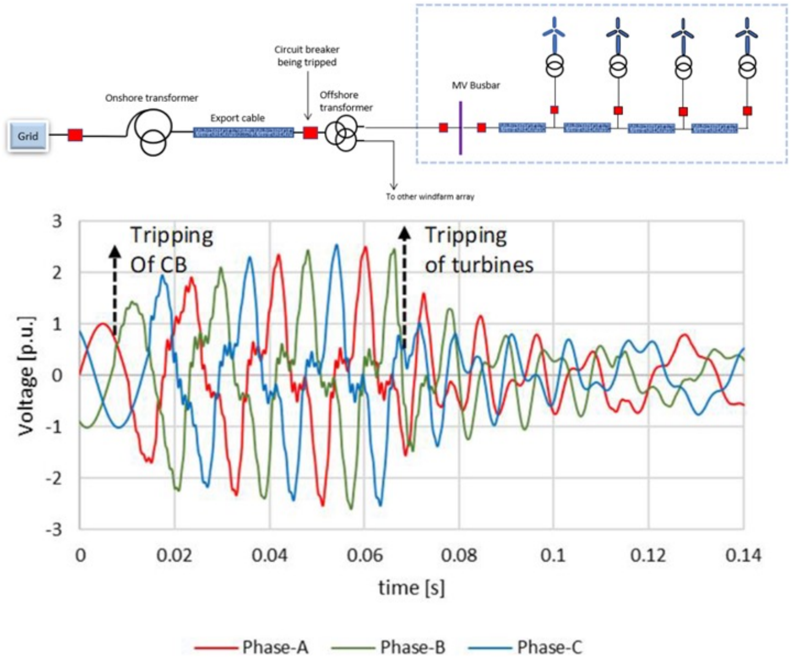
Ferroresonance

- Ferroresonance can be defined as a non-linear oscillation arising from the interaction between an iron core inductance and a capacitor. Ferroresonant circuits can be either series or parallel.
- Power transformers, inductive voltage transformers (VTs) and reactors are examples of nonlinear inductances. Long lines, cables, capacitive VTs, series and shunt capacitors, and power circuit breaker grading capacitors represent capacitances usually found in power system networks.
- when an extreme change in the system operating point takes place, triggering a ferroresonant state. if a layout prone to ferroresonance occurrence is anticipated, a sensitivity analysis should be carried out to investigate the impact of circuit parameterson ferroresonance phenomenon.



Overvoltage due to Ferroresonance.

Sources of TOV



Overvoltage during islanding of a windfarm.

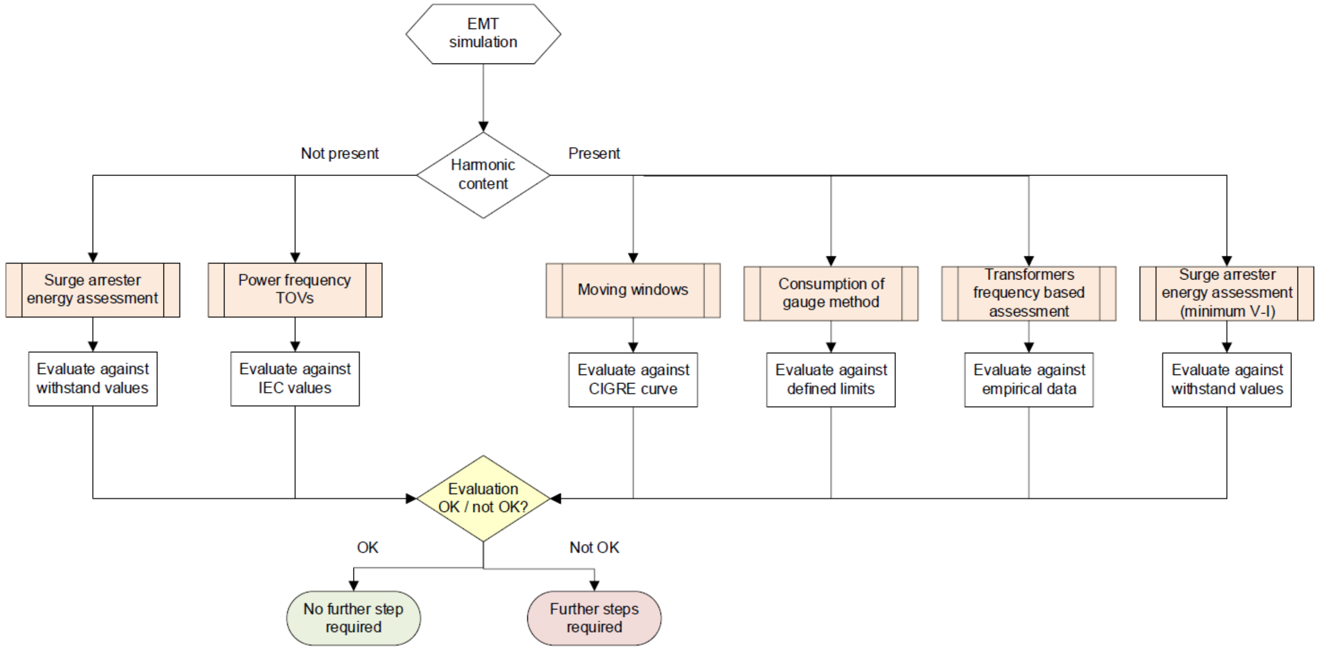
Network Islanding

- Fault clearing can cause TOV conditions due to islanding in a part of the network. This occurs due to huge mismatch of generation and demand after breaker tripping.
- During this operation, the complete windfarm array is disconnected. In this case, the voltage rises to 2.5pu for a duration of 50 ms before the wind turbines are tripped by the respective protection system.
- In case there is no anti-islanding protection scheme applied, or if the scheme fails to properly operate, an unintentional islanding condition may occur, which could impose serious TOV concerns to the system.
- Load rejection are also in this category to cause TOV concerns.

TOV assessment

Flow chart

- The assessment method is applicable for waveforms with harmonic distortion and for varying amplitudes in time. This can also be adapted for TOVs without harmonic content.



Flowchart for TOV assessment

Internal Use

TOV assessment

Methods

Energy based assessment

- For overvoltages without harmonics the energy can be verified with respect to the withstand limits of surge arrester.
- For overvoltages with harmonic content the V-I characteristics derived based on interpolation must be used.

Voltage based assessment

- For overvoltages without harmonics, the maximum of all absolute peak values of the waveform for a TOV situation from 20 ms after any change of state of the network (e.g., switching) is assumed to be the relevant TOV peak value. Generally, this value divided by $\sqrt{2}$ can be compared to the component RMS withstand limits. For range-2 voltages these voltage need to be converted to switching impulse with a necessary safety factor of the equipment.
- For TOV's with harmonic content the methods shown in the flow chart to be used. The equipment with minimum withstand are transformers and surge arresters.
  - ✓ **Moving window method**
  - ✓ **Consumption of gauge method**
  - ✓ **Transformer frequency-based assessment**
  - ✓ **Surge arrester energy assessment**

TOV assessment

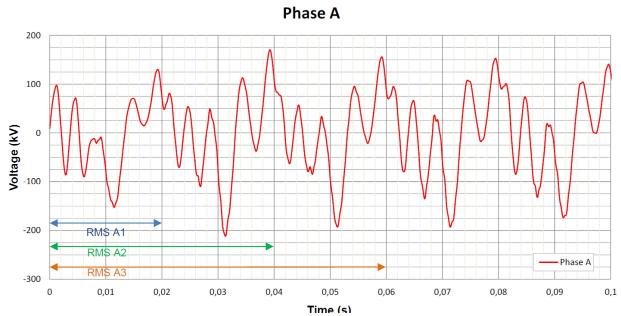
Moving window method

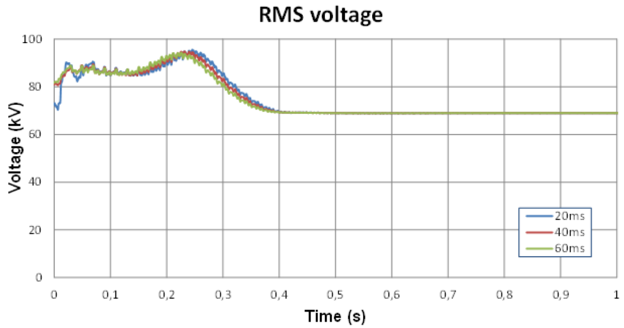
- The method involves calculating the RMS voltages for the voltage-time signal by a series of time windows.
- The calculation windows represent the duration that the overvoltage is sustained for. Hence, the windows are varied in size for a full evaluation of the TOV.
- This continues until the RMS calculation window has been shifted through the entire voltage time signal.
- From all the RMS values calculated in this process, the maximum value is stored

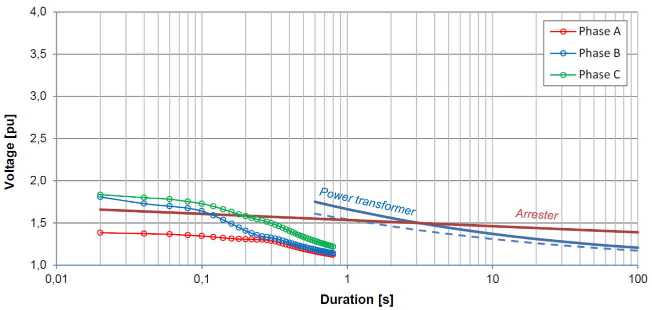
First Window Data points = time period (20ms)/time step	→	N number of data points used for first RMS value	→	window is then shifted by a half power cycle (10ms for 50Hz)	→	The second RMS value is then calculated by the data points in the shifted window
$N = \frac{t_{period}}{t_{step}}$		$RMS_1 = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(u(t_i)^2)}$		$N_{shift} = \frac{t_{period}}{2t_{step}}$		$RMS_2 = \sqrt{\frac{1}{N}\sum_{i=N_{shift}}^{N+N_{shift}}(u(t_i)^2)}$

For power system expertise

TOV assessment







Moving window method

- Then, the window N is increased to two power cycles (i.e., 40 ms for a 50 Hz system), and the calculation process is repeated, maintaining the window shift to a half power cycle. The maximum value calculated with the two-power cycle window is stored. The calculation process is then repeated with a calculation window of three power-cycles, four power-cycles, and so on, until the window covers the entire time signal.
- All maximum RMS values are then plotted together with the TOV capability characteristic of the installed surge arresters and the CIGRE withstand curve for maximum TOV of transformers

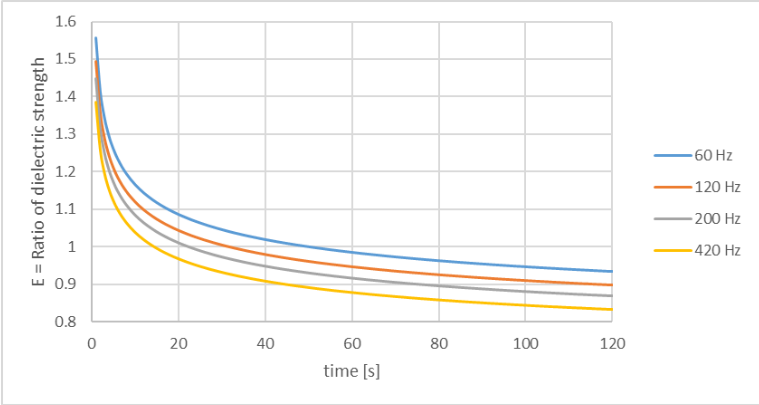
20ms	40ms	60ms	80ms	100ms
95.5	94.8	94.2	93.5	92.8

cigre
For power system expertise

TOV assessment

Power Transformers

- The breakdown strength of transformer insulation at low frequencies is influenced by the storage and dissipation of the heat in the material.
- When AC voltage is applied, the stress begins to generate hysteresis and dielectric losses.
- At first, all the loss is stored, and temperature starts to rise. As soon as the temperature rises the material starts to dissipate the heat. Until a state of equilibrium is reached (the heat dissipated is equal to the heat generated), the temperature continues to rise, the resistance of the insulation material decreases and the current increases.
- After the equilibrium state is reached, no further decrease in breakdown strength occurs with time.
- The effect of the time of voltage application and of the frequency on dielectric strength is obtained by the product of breakdown strength at power frequency and frequency of the voltage application.



$$E_b = E_{b\_pf} * E_{b_{vf}} = \left(a + \frac{1-a}{\sqrt[4]{t}}\right) * \left(\frac{K}{f^n}\right)$$

Material in oil	a
0.003in. untreated cable and kraft papers	0.85
0.012in. Varnished cambric (1 to 10 layers)	0.675
0.012in. Varnished bond paper (6 or 7 layers)	0.675
3/32in. Pressboard and 3/32in. oil duct in series	0.675
Pressboard at 75 and 100 deg C	0.675
Pressboard at 25 deg C	0.5

Material and arrangement	Temperature deg C	constant- a	constant- k	constant-n
Solid insulation	25	0.5	1.75	0.137
Solid pressboard	75-100	0.675	1.75	0.137
Equal distribution of pressboard and oil	75-100	0.675	1.75	0.137
Two 3/32in. pressboard seperated by one 3/16 in. oil duct	25	0.675	1.26	0.06
Two 3/32in. pressboard seperated by one 9/32 in. oil duct	25	0.675	1.22	0.05

t: duration of overvoltage in minutes
a, K, n: constants from above table
f: frequency of overvoltage in Hz

TOV assessment

Power Transformers: Example

Nominal voltage of system: 66 kV
Maximum voltage of system: 72.5 kV
Short duration power frequency withstand voltage: 140 kV (RMS)
Overvoltage measured: 143 kV (RMS)
Main resonance frequency: 500 Hz (obtained by performing an FFT)
Duration of overvoltage (t): 200ms

The required breakdown strength based on the 1-minute value is given by multiplying the maximum TOV value (143 kV) by a safety factor (1.15 for internal insulation, in this example). This corresponds to 164.45 kV, which is higher than the withstand voltage of 140kV.

- The breakdown strength based on the duration and frequency of the voltage is estimated using Equation. The following constants are selected for the evaluation:
  - ✓ **Duration of overvoltage (‘t’): 200 ms (0.0033 minutes)**
  - ✓ **Constant ‘a’, ‘K’, ‘n’ = 0.675, 1.75 and 0.137 respectively.**
- If information on the transformer insulation arrangement (pressboard thickness and oil duct thickness) is not available, the above constants can be chosen for a conservative approach.
- With the use of the above constants, the following ratios are obtained:
  - ✓ **Eb_pf = 2.028**
  - ✓ **Eb_vf = 0.747**
  - ✓ **Eb = 1.5145**
- Based on the above, the transformer insulation can withstand 212 kV (140 kV*1.5145) for a TOV of 143kV with a duration of 200 ms and a frequency of 500 Hz.

Mitigation of TOV's

Method	Applicability	Pros	Cons	Maturity
Operational constraints	Energization		N/A under fault clearing conditions	Mature
Controlled switching	Energization		N/A under fault clearing conditions	Mature
Pre-insertion resistor	Energization		N/A under fault clearing conditions	Mature
Filter	Energization Fault clearing	Works under fault clearing conditions	Additional substation space required Additional reactive power compensation might be required	Limited operational experience
Detuning by cable switching	Energization Fault clearing	No impact to system in normal operation	Limited to certain conditions (requires cables that can be disconnected to shift the resonance)	Recently proposed, no operational experience
Undervoltage protection/disconnection of saturated transformer	Energization Fault clearing		N/A to fault clearing depending on what is connected to the secondary side	Limited/no operational experience
Sacrificial arresters	Energization Fault clearing		Risk of repeated fault clearing	Well-known concept for power frequency TOVs

cigre
For power system expertise

Regards

TECHNICAL BROCHURE

Evaluation of Temporary Overvoltages in Power Systems due to Low Order Harmonic Resonances

WG C4.46

Members

F. FARIA DA SILVA, **Convenor**	DK	K. VELITSIKAKIS, **Secretary**	NL
O. LENNERHAG, **TF Leader**	SE	F. BARAKOU	NL
A. CRUZ	BR	J. MICHEL	FR
D. MILLS	UK	K. MUNJI	UK
J. PENG	UK	I. RAHIMI	CA
C. SKOVGAARD	DK	I. TANNEMAAT	NL

Reviewers

M. MARTINEZ DURO
S. RAMADHIN
M. VAL ESCUDERO

cigre
For power system expertise

Thank You!

For more information:
kmunji@scottishpower.com

Kiran Munji
Grid Services Manager at SPR

Disclaimer notice

“CIGRE gives no warranty or assurance about the contents of this publication, nor does it accept any responsibility, as to the accuracy or exhaustiveness of the information. All implied warranties and conditions are excluded to the maximum extent permitted by law”.