# List of Figures

<table>
<thead>
<tr>
<th>No</th>
<th>Name of the Figure</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Electric Circuit for explaining re-strikes</td>
<td>18</td>
</tr>
<tr>
<td>1.2</td>
<td>Voltage of the open-ended GIS side of the Isolator</td>
<td>19</td>
</tr>
<tr>
<td>1.3</td>
<td>Load side voltage waveform during opening of disconnect switch</td>
<td>25</td>
</tr>
<tr>
<td>1.4</td>
<td>waveform of over voltage with current chopping</td>
<td>27</td>
</tr>
<tr>
<td>3.1</td>
<td>Single-line diagram of 245kV GIS</td>
<td>76</td>
</tr>
<tr>
<td>3.2</td>
<td>Cross section of typical GIS System</td>
<td>83</td>
</tr>
<tr>
<td>3.3</td>
<td>Single line diagram of typical section of segregated-phase 245kV GIS system</td>
<td>87</td>
</tr>
<tr>
<td>3.4</td>
<td>EMTP-RV model of the section of 245kV GIS system</td>
<td>91</td>
</tr>
<tr>
<td>3.5</td>
<td>The Electrical equivalent network of the GIS system during disconnector switch 1 closing with fixed arc resistance.</td>
<td>92</td>
</tr>
<tr>
<td>3.6</td>
<td>The Electrical equivalent network of the GIS system during disconnector switch 1 closing with variable arc resistance</td>
<td>93</td>
</tr>
<tr>
<td>3.7</td>
<td>The Electrical equivalent network of the GIS system during disconnector switch 1 opening with fixed arc resistance.</td>
<td>93</td>
</tr>
<tr>
<td>3.8</td>
<td>The Electrical equivalent networks of the GIS system during disconnector switch 1 opening with variable arc resistance</td>
<td>94</td>
</tr>
</tbody>
</table>
3.9 The Electrical equivalent network of the GIS system during opening operation of disconnector switch 1 with -0.1 p.u. trapped charge

3.10 The Electrical equivalent network of the GIS system during opening operation of disconnector switch 1 with -0.2 p.u. trapped charge

3.11 The Electrical equivalent network of the GIS system during opening operation of disconnector switch 1 with -0.3 p.u. trapped charge

3.12 The Electrical equivalent network of the GIS system during opening operation of disconnector switch 1 with -0.4 p.u. trapped charge

3.13 The Electrical equivalent network of the GIS system during opening operation of disconnector switch 1 with -0.5 p.u. trapped charge

3.14 The Electrical equivalent network of the GIS system during opening operation of disconnector switch 1 with -0.6 p.u. trapped charge

3.15 The Electrical equivalent network of the GIS system during opening operation of disconnector switch 1 with -0.7 p.u. trapped charge

3.16 The Electrical equivalent network of the GIS system during opening operation of disconnector switch 1 with -0.8 p.u. trapped charge

3.17 The Electrical equivalent network of the GIS system during opening operation of disconnector switch 1 with -0.9 p.u. trapped charge

3.18 The Electrical equivalent network of the GIS system during opening operation of disconnector switch 1 with -1 p.u. trapped charge

3.19 The EMTP-RV equivalent network of the GIS system during closing operation of disconnector switch 2 with -1pu trapped charge.

3.20 VFTO at Air-to-SF6 bushing during the opening operation of the DS1 with fixed arc resistance
3.21 VFTO at Air-to-SF6 bushing during the opening operation of the DS1 with variable arc resistance.

3.22 VFTO at Air-to-SF6 bushing during the closing operation of the DS1 with fixed arc resistance.

3.23 VFTO at Air-to-SF6 bushing during the closing operation of the DS1 with variable arc resistance.

3.24 VFTO at source side of DS1 with variable arc resistance and trapped charge of - 0.1p.u.

3.25 VFTO at load side of DS1 with variable arc resistance and trapped charge of - 0.1p.u.

3.26 VFTO at source side of DS1 with variable arc resistance and trapped charge of - 0.2p.u.

3.27 VFTO at load side of DS1 with variable arc resistance and trapped charge of - 0.2p.u.

3.28 VFTO at source side of DS1 with variable arc resistance and trapped charge of - 0.3p.u.

3.29 VFTO at load side of DS1 with variable arc resistance and trapped charge of - 0.3p.u.

3.30 VFTO at source side of DS1 with variable arc resistance and trapped charge of - 0.4p.u.

3.31 VFTO at load side of DS1 with variable arc resistance and trapped charge of - 0.4p.u.

3.32 VFTO at source side of DS1 with variable arc resistance and trapped charge of - 0.5p.u.

3.33 VFTO at source side of DS1 with variable arc resistance and trapped charge of - 0.5p.u.

3.34 VFTO at source side of DS1 with variable arc resistance and trapped charge of - 0.6p.u.

3.35 VFTO at load side of DS1 with variable arc resistance and trapped charge of - 0.6p.u.
3.36 VFTO at source side of DS1 with variable arc resistance and trapped charge of 0.7 p.u.  

3.37 VFTO at load side of DS1 with variable arc resistance and trapped charge of 0.7 p.u.  

3.38 VFTO at source side of DS1 with variable arc resistance and trapped charge of 0.8 p.u.  

3.39 VFTO at load side of DS1 with variable arc resistance and trapped charge of 0.8 p.u.  

3.40 VFTO at source side of DS1 with variable arc resistance and trapped charge of 0.9 p.u.  

3.41 VFTO at load side of DS1 with variable arc resistance and trapped charge of 0.9 p.u.  

3.42 VFTO at source side of DS1 with variable arc resistance and trapped charge of 1 p.u.  

3.43 VFTO at load side of DS1 with variable arc resistance and trapped charge of 1 p.u.  

3.44 VFTO at SF₆ – to – XLPE cable termination during opening of DS2 With variable arc resistance and trapped charge of -1 p.u.  

3.45 Frequency spectrum of VFTO at Air-to-SF6 bushing during the opening operation of the DS1 with fixed arc resistance  

3.46 Frequency spectrum of VFTO at Air-to-SF6 bushing during the opening operation of the DS1 with variable arc resistance  

3.47 Frequency spectrum of VFTO at Air-to-SF6 bushing during the closing operation of the DS1 with fixed arc resistance
3.48 Frequency spectrum of VFTO at Air-to-SF6 bushing during the closing operation of the DS1 with variable arc resistance 124

3.49 Frequency spectrum of VFTO at source side of DS1 with variable arc resistance and trapped charge of -0.1p.u. 124

3.50 Frequency spectrum of VFTO at load side of DS1 with variable arc resistance and trapped charge of -0.1p.u. 125

3.51 Frequency spectrum of VFTO at source side of DS1 with variable arc resistance and trapped charge of -0.2p.u. 125

3.52 Frequency spectrum of VFTO at load side of DS1 with variable arc resistance and trapped charge of -0.2p.u. 126

3.53 Frequency spectrum of VFTO at source side of DS1 with variable arc resistance and trapped charge of -0.3p.u. 126

3.54 Frequency spectrum of VFTO at load side of DS1 with variable arc resistance and trapped charge of -0.3p.u. 127

3.55 Frequency spectrum of VFTO at source side of DS1 with variable arc resistance and trapped charge of -0.4p.u. 127

3.56 Frequency spectrum of VFTO at load side of DS1 with variable arc resistance and trapped charge of -0.4p.u. 128

3.57 Frequency spectrum of VFTO at source side of DS1 with variable arc resistance and trapped charge of -0.5p.u. 128

3.58 Frequency spectrum of VFTO at load side of DS1 with variable arc resistance and trapped charge of -0.5p.u. 129

3.59 Frequency spectrum of VFTO at source side of DS1 with variable arc resistance and trapped charge of -0.6p.u. 129
3.60 Frequency spectrum of VFTO at load side of DS1 with variable arc resistance and trapped charge of -0.6p.u.

3.61 Frequency spectrum of VFTO at source side of DS1 with variable arc resistance and trapped charge of -0.7p.u.

3.62 Frequency spectrum of VFTO at load side of DS1 with variable arc resistance and trapped charge of -0.7p.u.

3.63 Frequency spectrum of VFTO at source side of DS1 with variable arc resistance and trapped charge of -0.8p.u.

3.64 Frequency spectrum of VFTO at load side of DS1 with variable arc resistance and trapped charge of -0.8p.u.

3.65 Frequency spectrum of VFTO at source side of DS1 with variable arc resistance and trapped charge of -0.9p.u.

3.66 Frequency spectrum of VFTO at load side of DS1 with variable arc resistance and trapped charge of -0.9p.u.

3.67 Frequency spectrum of VFTO at source side of DS1 with variable arc resistance and trapped charge of -1p.u.

3.68 Frequency spectrum of VFTO at load side of DS1 with variable arc resistance and trapped charge of -1p.u.

3.69 Frequency spectrum of VFTO at at SF₆ – to – XLPE cable termination during opening of DS2 with variable arc resistance and trapped charge of -1 p.u.

3.70(a) DS1 opening operation with variable arc resistance and with -0.1p.u trapped charge and resistance Switching

3.70(b) DS1 closing operation with variable arc resistance and with -0.1p.u trapped charge and resistance Switching
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.70(c)</td>
<td>DS1 opening operation with variable arc resistance and with -0.5p.u trapped charge and resistance Switching</td>
</tr>
<tr>
<td>3.70(d)</td>
<td>DS1 closing operation with variable arc resistance and with -0.5p.u trapped charge and resistance Switching</td>
</tr>
<tr>
<td>3.70(e)</td>
<td>DS1 opening operation with variable arc resistance and with -1p.u trapped charge and resistance Switching</td>
</tr>
<tr>
<td>3.70(f)</td>
<td>DS1 closing operation with variable arc resistance and with -1p.u trapped charge and resistance Switching</td>
</tr>
<tr>
<td>3.71(a)</td>
<td>VFTO at source side of the DS1 opening operation with variable arc resistance and trapped charge of -0.1p.u and switching resistance across DS</td>
</tr>
<tr>
<td>3.71(b)</td>
<td>FFT of VFTO waveform during opening of DS1 with variable arc resistance and trapped charge of -0.1p.u with resistance switching</td>
</tr>
<tr>
<td>3.71(c)</td>
<td>VFTO at source side of the DS1 closing operation variable arc resistance and trapped charge of -0.1p.u and switching resistance across DS</td>
</tr>
<tr>
<td>3.71(d)</td>
<td>FFT of VFTO waveform during closing of DS1 with variable arc resistance and trapped charge of -0.1p.u with resistance switching</td>
</tr>
<tr>
<td>3.71(e)</td>
<td>VFTO at source side of the DS1 opening operation with variable arc resistance and trapped charge of -1p.u and switching resistance across DS</td>
</tr>
<tr>
<td>3.71(f)</td>
<td>FFT of VFTO waveform during opening of DS1 with variable arc resistance and trapped charge of -1p.u with resistance switching</td>
</tr>
<tr>
<td>3.71(g)</td>
<td>VFTO at source side of the DS1 closing operation with variable arc resistance and trapped charge of -1p.u and switching resistance across DS</td>
</tr>
</tbody>
</table>
3.71(h) FFT of VFTO waveform during closing of DS1 with variable arc resistance and trapped charge of -1p.u with resistance switching

3.71(i) VFTO at source side of the DS1 opening operation variable arc Resistance and trapped charge of -0.5p.u and switching resistance across DS

3.71(j) FFT of VFTO waveform during opening of DS1 with variable arc resistance and trapped charge of -0.5p.u with resistance switching

3.71(k) VFTO at source side of the DS1 closing operation with variable arc Resistance and trapped charge of -0.5p.u and switching resistance across DS

3.71(l) FFT of VFTO waveform during closing of DS1 with variable arc resistance and trapped charge of -0.5p.u with resistance switching

3.72(a) DS1 opening Operation with variable arc resistance and trapped charge of -0.1p.u and Ferrite rings

3.72(b) DS1 closing Operation with variable Arc Resistance and trapped charge of -0.1p.u. and Ferrite rings

3.72(c) DS1 opening Operation with variable Arc Resistance and trapped charge of - 0.5p.u. and Ferrite rings

3.72(d) DS1 closing Operation with variable Arc Resistance and trapped charge of - 0.5p.u. and Ferrite rings

3.73(a) VFTO at source side of the DS1 during opening operation with variable arc resistance, trapped charge -0.1p.u and ferrite rings.

3.73(b) FFT of VFTO waveform during opening of DS1 with variable arc resistance, trapped charge -0.1 and ferrite rings
3.73(c) VFTO at source side of the DS1 during closing operation with variable arc resistance, trapped charge -0.1p.u and ferrite rings

3.73(d) FFT of VFTO waveform during closing of DS1 with variable arc resistance, trapped charge -0.1p.u and ferrite rings

3.73(e) VFTO at source side of the DS1 during opening operation with variable arc resistance, trapped charge -1p.u and ferrite rings

3.73(f) FFT of VFTO waveform during closing of DS1 with variable arc resistance, trapped charge -1p.u and ferrite rings

3.73(g) VFTO at source side of the DS1 during closing operation with variable arc resistance, trapped charge -1p.u and ferrite rings

3.73(h) FFT of VFTO waveform during closing of DS1 with variable arc resistance, trapped charge -1p.u and ferrite rings

3.73(i) VFTO at source side of the DS1 during closing operation with variable arc resistance, trapped charge -0.5p.u and ferrite rings

3.73(j) FFT of VFTO waveform during closing of DS1 with variable arc resistance, trapped charge -0.5p.u and ferrite rings

3.73(k) VFTO at source side of the DS1 during opening operation with variable arc resistance, trapped charge -0.5p.u and ferrite rings

3.73(l) FFT of VFTO waveform during opening of DS1 with variable arc resistance, trapped charge -0.5p.u and ferrite rings

4.1 An experimental set up of 3.3kV GIS system for the estimation of VFTOs during DS operation

4.2 Principle of operation of capacitive surge sensor

4.3 High frequency capacitive surge sensor with pre-amplifier circuit
4.4 A 1-phase, 3.3kV GIS bus duct while carrying out the experiment 183

4.5 A complete experimental set of 1-phase, 3.3kV GIS bus duct 183

4.6 Capacitive surge sensor element and bus bar 184

4.7 Capacitive surge sensor placed 0.24m from the Disconnector switch and probe is terminated carefully from enclosure 184

4.8 Capacitive surge sensor element and an amplifier used in the experiment 185

4.9 The electrodes arrangement in a 1-phase Gas Insulated Bus duct. 185

4.10 Arc generation between the electrodes during opening of the disconnector switch in SF₆ chamber 185

4.11 High frequency probes used for VFTO Measurements 186

4.12 A complete experimental set up of a 1-phase, 3.3kV GIS bus duct with sensor and digital storage oscilloscope. 186

4.13 The captured VFTO during opening operation of disconnector switch 187

4.14 The captured VFTO’s during closing operation of disconnector switch 187

4.15 Ferrite rings(FT140A series)on fixed electrode of a disconnector switch 189

4.16 VFTO captured with out ferrite rings on bus bar 190

4.17 VFTO captured during opening operation of Disconnector switch with out trapped charge 192

4.18 VFTO captured during closing operation of Disconnector switch with out trapped charge 192

4.19 Very fast Transient over voltage recorded during Disconnector switch opening with speed of 6mm/sec 193
4.20 Frequency spectrum VFTO with DS speed 6mm/sec

4.21 Very fast Transient over voltage recorded during Disconnector switch opening with speed of 8mm/sec

4.22 Frequency spectrum VFTO with DS speed 8mm/sec

4.23 Very fast Transient over voltage recorded during Disconnector switch opening with speed of 10mm/sec

4.24 Frequency spectrum VFTO with DS speed 10mm/sec

4.25 Very fast Transient over voltage recorded during Disconnector switch opening with speed of 12mm/sec

4.26 Frequency spectrum VFTO with DS speed 12mm/sec

4.27 Very fast Transient over voltage recorded during Disconnector switch opening with speed of 14mm/sec

4.28 Frequency spectrum VFTO with DS speed 14mm/sec

4.29 Very fast Transient over voltage recorded during Disconnector switch opening with speed of 16mm/sec

4.30 Frequency spectrum VFTO with DS speed 16mm/sec

4.31 Very fast Transient over voltage recorded during Disconnector switch closing with speed of 6mm/sec and trapped charge of -0.2 p.u and with ferrite rings

4.32 Frequency spectrum of VFTO with DS speed 6mm/sec. and with ferrite rings.

4.33 Very fast Transient over voltage recorded during Disconnector switch closing with speed of 8mm/sec and trapped charge of -0.4 p.u and with ferrite rings

4.34 Frequency spectrum of VFTO with DS speed 8mm/sec. and with ferrite rings

4.35 Very fast Transient over voltage recorded during Disconnector switch closing with speed of 10mm/sec and trapped charge of -0.6 p.u and with ferrite rings

4.36 Frequency spectrum of VFTO with DS speed 10mm/sec. and with ferrite rings.
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.37</td>
<td>Very fast Transient over voltage recorded during Disconnector switch closing with speed of 12mm/sec and trapped charge of -0.8 p.u and with ferrite rings</td>
<td>202</td>
</tr>
<tr>
<td>4.38</td>
<td>Frequency spectrum of VFTO with DS speed 12mm/sec. and with ferrite rings.</td>
<td>202</td>
</tr>
<tr>
<td>4.39</td>
<td>Very fast Transient over voltage recorded during Disconnector switch closing with speed of 14mm/sec and trapped charge of -1 p.u and with ferrite rings</td>
<td>203</td>
</tr>
<tr>
<td>4.40</td>
<td>Frequency spectrum of VFTO with DS speed 14mm/sec. and with ferrite rings.</td>
<td>203</td>
</tr>
<tr>
<td>4.41</td>
<td>Very fast Transient over voltage recorded during Disconnector switch closing with speed of 16mm/sec and trapped charge of -1 p.u and with ferrite rings</td>
<td>204</td>
</tr>
<tr>
<td>4.42</td>
<td>Frequency spectrum of VFTO with DS speed 16mm/sec. and with ferrite rings.</td>
<td>204</td>
</tr>
<tr>
<td>4.43</td>
<td>Very fast Transient over voltage recorded during Disconnector switch closing with speed of 6mm/sec and trapped charge of -0.2 p.u</td>
<td>207</td>
</tr>
<tr>
<td>4.44</td>
<td>Frequency spectrum of VFTO with DS speed 6mm/sec</td>
<td>207</td>
</tr>
<tr>
<td>4.45</td>
<td>Very fast Transient over voltage recorded during Disconnector switch closing with speed of 8mm/sec and trapped charge of -0.4 p.u</td>
<td>208</td>
</tr>
<tr>
<td>4.46</td>
<td>Frequency spectrum VFTO with DS speed 8mm/sec</td>
<td>208</td>
</tr>
<tr>
<td>4.47</td>
<td>Very fast Transient over voltage recorded during Disconnector switch closing with speed of 10mm/sec and trapped charge of -0.6 p.u</td>
<td>209</td>
</tr>
<tr>
<td>4.48</td>
<td>Frequency spectrum VFTO with DS speed 10mm/sec</td>
<td>209</td>
</tr>
<tr>
<td>4.49</td>
<td>Very fast Transient over voltage recorded during Disconnector switch closing with speed of 12mm/sec and trapped charge of -0.8 p.u</td>
<td>210</td>
</tr>
</tbody>
</table>
4.50 Frequency spectrum VFTO with DS speed 12mm/sec

4.51 Very fast Transient over voltage recorded during Disconnector switch closing with speed of 14mm/sec and trapped charge of -1 p.u

4.52 Frequency spectrum VFTO with DS speed 14mm/sec

4.53 Very fast Transient over voltage recorded during Disconnector switch closing with speed of 16mm/sec and trapped charge of -1 p.u

4.54 Frequency spectrum VFTO with DS speed 16mm/sec

4.55 Very fast Transient over voltage recorded during Disconnector switch closing with speed of 6mm/sec and trapped charge of -0.2p.u and with ferrite rings

4.56 Frequency spectrum of VFTO with DS speed 6mm/sec. and with ferrite rings.

4.57 Very fast Transient over voltage recorded during Disconnector switch closing with speed of 8mm/sec and trapped charge of -0.4p.u and with ferrite rings

4.58 Frequency spectrum of VFTO with DS speed 8mm/sec. and with ferrite rings.

4.59 Very fast Transient over voltage recorded during Disconnector switch closing with speed of 10mm/sec and trapped charge of -0.6p.u and with ferrite rings

4.60 Frequency spectrum of VFTO with DS speed 10mm/sec. and with ferrite rings.

4.61 Very fast Transient over voltage recorded during Disconnector switch closing with speed of 12mm/sec and trapped charge of -0.8p.u and with ferrite rings

4.62 Frequency spectrum of VFTO with DS speed 12mm/sec. and with ferrite rings.

4.63 Very fast Transient over voltage recorded during Disconnector switch closing with speed of 14mm/sec and trapped charge of -1p.u and with ferrite rings

4.64 Frequency spectrum of VFTO with DS speed 14mm/sec. and with ferrite rings.

4.65 Very fast Transient over voltage recorded during Disconnector switch closing with speed of 16mm/sec and trapped charge of -1p.u and with ferrite rings
4.66 Frequency spectrum of VFTO with DS speed 16mm/sec. and with ferrite rings.

5.1 ELECNET Simulation model of a 245kV Gas Insulated system (Siemens-8DN9 Type) for the estimation of Electric fields

5.2 OPERA-Simulation model of a 245kV Gas Insulated system (Siemens-8DN9 Type) with all live parts are energized with 245kV, 50Hz supply.

5.3 ELECNET simulation model of 245kV GIS system

5.4 ELECNET solution FEM mesh of 245kV GIS system

5.5 Close up view of Electric field plot at Disconnector switch immediately after Opening operation of 245kV GIS system

5.6 Electric field plot at C.T position of 245kV GIS System

5.7 Electric field plot at XLPE cable termination of 245kV GIS System

5.8 Electric field plot at SF₆ gas –air bushing of 245kV GIS System

5.9 Electric field plot at bus link position of 245kV GIS system

5.9(a) Magnetic field plot of 245kv GIS system

5.10 The 245kV- GIS at CARNAC substation

5.11 Measured plot of transient electric field at bus link position

5.12 Measured plot of transient electric field at C.T position

5.13 Measured plot of transient electric field at XLPE cable termination

5.14 Measured plot of transient electric field at SF₆-Air bushing

5.15 Measured plot of transient Magnetic field at bus link position

5.16 Measured plot of transient Magnetic field at C.T position

5.17 Measured plot of transient Magnetic field at XLPE cable termination
5.18 Measured plot of transient Magnetic field at SF₆-Air bushing

6.1 Single Line Diagram of a 245 kV GIS section

6.2 EMTP-RV model of a 245kV GIS system with travelling times

6.3(a) VFTC Waveform at P.T from EMTP-RV simulation

6.3(b) Frequency Spectrum of VFTC at P.T

6.4(a) Gabor mother wavelet at σ² = 4

6.4(b) Gabor mother wavelet at σ² = 64

6.5(a-h) Validation of the wavelet model for an arbitrary transient signal

6.6(a) VFTC waveform at Air-SF₆ bushing

6.6(b) Frequency spectrum of VFTC waveform at Air-SF₆ bushing

6.7(a) Frequency less than 4MHz and its time-frequency spectrum at Air-SF₆ bushing

6.7(b) Frequency equal to 7.5 MHz and its time-frequency spectrum at Air-SF₆ bushing

6.7(c) Frequency equal to 13 MHz and its time-frequency spectrum at Air-SF₆ bushing

6.7(d) Frequency equal to 29.5 MHz and its time-frequency spectrum at Air-SF₆ bushing

6.7(e) Frequency equal to or less than 51 MHz and its time-frequency spectrum at Air-SF₆ bushing

6.7(f) Time-frequency spectrum at Air-SF₆ bushing

6.8(a-i) Time-frequency spectrum with frequency range (0-300 MHz)

6.8(J) VFTC waveform and its frequency spectrum using wavelet transform at DS1

6.9 Variation of peak amplitude of the transient current with frequency
6.10 Variation of transient current magnitude with distance for different frequencies of the VFTC