Switching surge generation setup for experimental studies

Switching surge generators of different types are needed for the study of the impact of oscillating switching surge in power systems. This chapter deals with the details of the various types of switching impulse voltage generators, that is, standard switching impulse voltage generator, unipolar-damped OSS generator and damped OSS generator. To generate the oscillating switching impulse voltage, Marx type impulse generator is used. The impulses are, alternatively UDOSS or DOSS, and the frequency and decay rate can be controlled by varying the resistances, capacitances and inductance of the impulse generator circuit.

3.2 Generation of standard switching surges

A 3 MV, 50 kJ impulse voltage generator has been used to obtain the standard switching surges (250/2500μs). It is a fifteen stage Marx type impulse voltage generator, out of which five stages are used to get a maximum output voltage of 1000000 volts. Each stage has two 0.33μF capacitors in series and it employs a resistive wave shaping circuit. The Marx generator capacitors are charged using a voltage doubler circuit. The dc voltage to the circuit can be varied smoothly from 0 to 100 kV using a motor driven auto-transformer in the input side of the rectifier circuit.
Fig. 3.1 Experimental setup for generating standard switching impulse voltage (3 MV, 50 kJ)

1. Impulse generator  
2. Front resistance  
3. Tail resistance  
4. Load capacitance  
5. Insulators  
6. Rod - rod gap

Fig. 3.2 Standard switching impulse voltage waveform
A 500 kV, 6.25 kJ impulse voltage generator is also used to obtain the standard switching surge (250/2500 µs). It is a ten stage Marx type generator with a capacitance of 0.5 µF per stage and a resistive wave shaping circuit. The Marx circuit is fed from a voltage doubler circuit. The dc voltage can be varied smoothly from 0 to 50 kV by an auto-transformer in the input side of the rectifier circuit.

The following components of Marx impulse voltage generator are designed using the simulation of impulse voltage generator described in chapter 2.

a) For 3 million volt generator

i. Wave front resistor \( R_f \) of magnitude 7.0 kΩ. It consists of five tubular resistors connected in series.

ii. Wave tail resistors \( R_t \) consist of five tubular resistors connected in series having a total magnitude of 114.1 kΩ.

iii. The load capacitor \( C_L \) consists of four 0.1 µF capacitors connected in series

b) For 500 kV generator

i. Wave front resistor \( R_f \) of magnitude 15 kΩ. This consists of a number of tubular resistors connected in series.

ii. The wave tail resistors \( R_t \) consists of tubular resistors, connected in series and having a resistance of 79 kΩ.

iii. The load capacitor \( C_L \) consists of two capacitors of 9.0 nF and 1.07 nF connected in parallel.
Fig. 3.1 shows the setup for generating standard switching impulse voltage and Fig 3.2 shows the generated waveform. The generator developed switching impulse voltage of waveshape 250/2500 µs.

3.3 Generation of oscillating switching surges

Oscillating switching impulse voltage of either polarity is obtained using the Marx type generator with a modified wave shaping circuit using inductances. A detailed design of the circuits used to generate unipolar-damped and damped oscillating surges have been presented by the author [78]. Hence, they are very briefly dealt with in this section.

3.3.1 Unipolar- damped oscillating switching surge generator

Using the simulation study described in chapter 2, the values of $R_r, R_1, L$ and $C_L$ for different frequencies are obtained. The components are then designed as per the method followed in [78].

The components used for frequencies 4 kHz, 14 kHz, 20 kHz, 30 kHz, and 40 kHz has given in table 3.1 and table 3.2. Figure 3.3 shows the experimental setup for the generation of unipolar-damped OSS. Figure 3.4 shows typical voltage waveform generated.
Table 3.1
Circuit parameters for unipolar- damped OSS generator

<table>
<thead>
<tr>
<th>Circuit parameters</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impulse generator Capacitance ($C_g$)</td>
<td>33.0 nF</td>
</tr>
<tr>
<td>Load Capacitance ($C_L$)</td>
<td>20.0 nF</td>
</tr>
<tr>
<td>Front Resistance ($R_f$)</td>
<td>300Ω</td>
</tr>
<tr>
<td>Tail Resistance ($R_t$)</td>
<td>114.1 kΩ</td>
</tr>
</tbody>
</table>

Table 3.2
Inductors for generation of UDOSS of different frequencies

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Frequency ($f$), kHz</th>
<th>Inductance ($L$), mH</th>
<th>Resistance of the inductor ($r$), Ω</th>
<th>Damping ratio of the voltage wave ($A_V/A_G$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>117</td>
<td>175</td>
<td>1.27</td>
</tr>
<tr>
<td>2</td>
<td>14</td>
<td>62</td>
<td>96</td>
<td>1.30</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>4.5</td>
<td>17.7</td>
<td>1.33</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>2.8</td>
<td>14.8</td>
<td>1.36</td>
</tr>
<tr>
<td>5</td>
<td>40</td>
<td>1.28</td>
<td>12.3</td>
<td>1.39</td>
</tr>
</tbody>
</table>

Switching surge generation setup
Fig. 3.3 Experimental setup for generating oscillating switching impulse voltages (3 MV, 50 kJ)

1. Impulse generator
2. Front resistance
3. Tail resistance
4. Load capacitance
5. Inductance
6. Insulators
7. Rod-rod gap

Fig. 3.4 Unipolar-damped OSS waveform, 4 kHz

TRIA: 0.50V, 200 μs
Fig. 3.5 Experimental setup for generation of OSS (500 kV, 6.25 kJ)

1. Impulse generator
2. Load capacitor
3. Damped capacitor divider
4. Control panel
5. Trigger circuit
6. Front resistor
7. Waveshaping inductor

TRIA: 0.50V: 50 μs

Fig. 3.6 Damped OSS waveform, 10 kHz
3.3.2 Damped oscillating switching surge generator

The same inductors that used for generating unipolar-damped OSS are employed for damped oscillating voltage also. It produces frequencies of 2 kHz, 4 kHz, 10 kHz, 20 kHz and 30 kHz. Table 3.3 and Table 3.4 give the value of the components used for the generation of damped oscillating switching impulse voltage. Fig. 3.5 shows experimental setup for the generation of DOSS. Figure 3.6 shows typical voltage waveform generated.

Table 3.3
Circuit parameters for damped OSS generator

<table>
<thead>
<tr>
<th>Circuit parameters</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impulse generator Capacitance ($C_G$)</td>
<td>33.0 nF</td>
</tr>
<tr>
<td>Load Capacitance ($C_L$)</td>
<td>20.0 nF</td>
</tr>
<tr>
<td>Front Resistance ($R_f$)</td>
<td>200Ω</td>
</tr>
<tr>
<td>Tail Resistance ($R_t$)</td>
<td>114.1 kΩ</td>
</tr>
</tbody>
</table>
Table 3.4

Inductors for generation of DOSS of different frequencies

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Frequency ((f), \text{kHz})</th>
<th>Inductance ((L), \text{mH})</th>
<th>Resistance of the inductor ((r), \Omega)</th>
<th>Damping ratio of the voltage wave ((A_1/A_2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.0</td>
<td>117</td>
<td>175</td>
<td>2.14</td>
</tr>
<tr>
<td>2</td>
<td>4.0</td>
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<td>96</td>
<td>2.19</td>
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<tr>
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<td>10</td>
<td>4.5</td>
<td>17.7</td>
<td>2.23</td>
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<tr>
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<td>20</td>
<td>2.8</td>
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<td>30</td>
<td>1.28</td>
<td>12.3</td>
<td>4.08</td>
</tr>
</tbody>
</table>

3.3.3 Voltage measurement and wave shape recording

The standard and oscillating switching impulse voltages produced by the Marx type generator are measured using a precision damped capacitance divider with a ratio of 424 and a peak voltmeter. The waveforms are studied using a 100 MHz Digital storage oscilloscope. Figure 3.7 shows the measuring arrangements.
Fig. 3.7 Control panel and measuring circuit

1. Impulse generator
2. Load capacitor
3. Damped capacitance divider
4. Peak voltmeter
5. Digital storage oscilloscope

6. Control panel
7. Trigger circuit
8. Front resistor
9. Wave tail resistor
10. Waveshaping inductor
3.3.4 Correction factors.

Air density correction factor ($\delta$) and humidity correction factor ($k$) are applied to positive polarity flashover voltages only as per the IEEE standard 4-1978 [6].

\[ \delta = \frac{0.386 P}{273 + t_d} \] ..........3.1

where,

$P =$ Atmospheric pressure in mm of mercury

and $t_d =$ Dry bulb temperature in degree centigrade

The humidity correction factor ($k$) is found from the dry and wet bulb temperatures using the curves given in the above standard.

\[ \text{corrected voltage} = \frac{(\text{measured voltage}) \times k}{\delta} \] ..........3.2

3.4 Conclusion

The surge generators capable of generating standard switching surge, oscillating switching surge of unipolar-damped and damped of both polarities having different frequencies are designed and assembled. The waveforms are plotted and measured using digital storage oscilloscope and peak voltmeter.