CHAPTER 5

FTOs ACROSS INSULATING FLANGE OF GIS

5.0 INTRODUCTION

In the present study, modeling and analysis are confined to a section of the GIS bay illustrated in Fig. 5.6. The section chosen consists of an air/SF₆ bushing (through which an external circuit such as a transmission line is connected), insulating spacers, disconnector switch module and a bus bar. Fast transient over voltage waveforms generated between closing and opening operation of disconnector have been considered for calculation.

All the distributed parameters of lines are considered in the internal mode (conductor-enclosure) only and the external enclosure is considered to be connected to flange through insulators at high frequencies earth connectors by assuming significant reactance value.

The coaxial bus duct is modeled as a series of pi-networks. The Inductance of a bus duct is calculated from the diameters of the conductor and enclosure. Capacitances are calculated on the basis of actual diameters of inner and outer cylinder of central copper conductor and outer enclosure.

The capacitance on the source side (sum of the capacitance of SF₆-air bushing and capacitance of the transformer) is assumed as 2000 pF and used in the calculation. Spark resistance is simulated by a constant value of 2 ohms.
Any desired configuration is represented by an equivalent circuit of the main components of the GIS after calculation of the parameters. A trapped charge is assumed to be left on the floating section of the switchgear due to a previous opening operation of the disconnector or circuit breaker. This is simulated by a voltage of certain value on the bus on one side of the switch.

5.1 CALCULATION OF R, L, AND C

5.1.1 Calculation of Resistance

When DC current flows through the conductor, there will be uniform distribution of current. But when AC current flows through it, a non-uniform distribution occurs i.e., more current concentrates on the surface. Due to this there is a slight increase in resistance.

\[ R = \frac{\rho \times L}{A} \]

The average value of resistance = 238.46 \( \mu \Omega /m \)

\[ = 0.238 \text{ m}\Omega/m \]

The calculation value of specific resistance is \( 1.3189 \times 10^{-8} \Omega \cdot m \)

5.1.2 Calculation of Inductance

Outer and inner diameter of bus duct is 800-850 mm and 150 mm respectively.

Fig 5.1 Cross section of a typical GIS system
The coaxial inner and outer conductor of a coaxial GIS is shown in Fig. 5.1. The calculated value of inductance is 0.2295 μH per meter of bus length.

5.1.3 Calculation of Capacitance

5.1.3.1 Capacitance of Bus Duct

The capacitance is calculated with the assumption that the conductors are cylindrical as shown in Fig. 5.2 and calculated by the using the standard formula given below;

\[
(C = 2 \pi \varepsilon_0 \varepsilon_r l/2.303 \ln (r_2/r_3))
\]

Where \((\varepsilon_0 = 8.854 \times 10^{-12} \text{ F/m})\)

Fig 5.2 Inner conductor and outer enclosure of GIS

Outer radius of the bus bar is \(r_2\); Length of the bus bar is \(l\) meter

Inner radius of the outer enclosure is \(r_3\)

The calculated value of capacitance is 51.22 pF per meter.
5.1.3.2 Spacer Capacitance Calculation

Spacers are used for supporting the inner conductor with reference to the outer enclosure. They are made with Alumina filled epoxy material whose relative permittivity is 4. The thickness of the space is assumed to be the length of the capacitance for calculation.

By using the above data, the spacer capacitance calculation is calculated as follows

\[ \text{Capacitance of each spacer per meter length} = 51.22 \times 0.0155 \times 4 = 3.073 \text{pF} \]

Total capacitance of GIS bus bar per meter length is calculated as

\[ 51.22 + 3 \times 3.073 = 60.44 \text{F/m} \]

5.2. ESTIMATION OF TRANSIENT OVER VOLTAGES DURING SWITCHING OPERATION OF DISCONNECTOR

The capacitance per unit length of Gas insulated bus is a very high (of the value of 70 pF per meter length). Owing to this high capacitance switching of disconnector is analogous to that of capacitance switching.

5.2.1 Capacitance Switching

The operation like disconnecting of capacitor banks and the dropping of unloaded overhead lines or cables can be considered as potentially hazardous conditions and have traditionally been a source of considerable charge in to switchgear engineers. Problems tend to arise if the switching operation is unsuccessful, that is, if the switch reignites or restrikes in the course of opening. The chance of this happening is slight,
but cannot be ignored since capacitor switching operations are quite frequent occurrences.

Because of the relative phase of current and voltage (current leads the voltage by approximately 90 degree), the capacitor is fully charged to maximum voltage when the switch interrupts. The capacitance now isolated from the source and charge retains on it. As a consequence of this trapping its charge, it can be seen that half a cycle after current becomes zero and the voltage across the switch reaches a peak value of 2V, which is potentially dangerous.

Let us suppose that a restrike takes place precisely when the voltage reaches its peak, which is tantamount to reclosing the switch at that instant. This is an LC circuit, so the expectation would be to respond to this sudden disturbance by going into an oscillation at its natural frequency which is given by the following formula.

\[
\text{Frequency} = \frac{1}{2\pi \sqrt{LC}}
\]

Where L is the inductance of the supply and C is the capacitance of the bank. By considering the restriking operation with a trapped charge of 1 p.u, the restrike current will be the instantaneous voltage across the switch divide by the circuit surge impedance.

**5.2.2 Trapped Charge**

When a disconnect switch is opened on a floating section of switchgear, which is a common mode of operation, a trapped charge may
be left on the floating section. The potential caused by trapped charge will normally decay very slowly as a result of leakage through spacers.

Due to traveling nature of the transients the modeling of GIS makes use of electrical equivalent circuits composed by lumped elements and especially by distributed parameter lines defined by surge impedances and traveling times. The equivalent circuits can be derived from the manufacture’s drawings and from the internal arrangement. The transients are transmitted to the secondary lines-floating part of GIS by stray capacitances which result of the construction of the protection electrode in GIS.

5.3 CALCULATION OF INSULATING FLANGE INDUCTANCE AND CAPACITANCE

5.3.1 Calculation of Inductance of Insulating Flange

The inductance of insulating flange is calculated for 1-phase with the use of the following standard formula given below

\[ L = \left(\frac{\mu_0}{2\pi}\right) \ln \left(\frac{2h}{a}\right) \text{ Henry/meter} \]

Where \( h \) = height of the flange in meters (\( h=1\text{m}, 2\text{m}, 3\text{m} \))

\( a \) = Diameter of the flange (which is equal to 0.8 meter)

- \( h=1\text{m}; a=0.8\text{m} \) \( L = 0.183 \mu\text{H/m} \)
- \( h=2\text{m}; a=0.8\text{m} \) \( L = 0.322 \mu\text{H/m} \)
- \( h=3\text{m}; a=0.8\text{m} \) \( L = 0.403 \mu\text{H/m} \)

5.3.2 Calculation of capacitance of insulating flange

The capacitance of insulating flange is calculated for 1-phase with the use of the following standard formula given below
\[ C = 2\pi \varepsilon_0 / \ln (2h/a) \text{ Farad/meter} \]

Where \( h \) = height of the flange in meters (h=1m, 2m, 3m)
\( a \) = Diameter of the flange (which is equal to 0.8 meter)

\[
\begin{align*}
\text{h=1m; } a & = 0.8m & C & = 60.71 \text{pF/m} \\
\text{h=2m; } a & = 0.8m & C & = 34.56 \text{pF/m} \\
\text{h=3m; } a & = 0.8m & C & = 25.61 \text{pF/m} \\
\end{align*}
\]

**5.3.3 VFTO suppression elements**

Generally the following four techniques used across insulating flange as well as across enclosure with its electrical equivalents to suppress VFTOS.

1. Capacitors with values 0.001 \( \mu \text{F} \) to 0.003 \( \mu \text{F} \).
2. Shunting bar or copper strip with values 0.1 \( \mu \text{H} \) to 0.5 \( \mu \text{H} \).
3. Zno elements are nonlinear resistors with value of \( 10^6 \Omega \) of each element.
4. Metal oxide varistor (MOV) with 1 or 2 \( \Omega \) resistor with 200 pF capacitor in each unit.

In present study, only the first two methods have been implemented for VFTOS suppression.

Suppression of VFTOS across an insulating flange and across enclosure decreased with increase the number of suppression components. VFTOS suppressed by capacitors are more effective than shunting bar across the equivalent circuit of insulating flange shown in Fig. 5.3
Fig 5.3 Equivalent circuit of insulating flange

The line feeder E15 bay with insulating flange and it’s geometrical Structure is shown in Fig. 5.4

Fig 5.4 Fig. of the analyzed line feeder bay = E15.

Where,

Z1 : Source Impedance
Q8, Q51, Q52 : Earth Switch
Q9 : Outgoing Disconnector
T5 : Potential Transformer
T1 : Current Transformer
Q0 : Switch Gear
Q1, Q2, Q3, Q70 : Bulbar Disconnector

In order to predict the transient electromagnetic phenomena in the secondary circuits of voltage \( T_5 \) and current \( T_1 \) transformers, several network models of GIS – components and physical effects in the GIS have been developed the help of the models available. The simulations of transients in GIS due to disconnector operation have been carried out.

The simulations have been made for the analyzed bay E15 with insulating flange as shown in Fig 5.4, the bus bar disconnectors Q1, Q2, Q3 and Q70 as well as Q0 were switched off. The transients caused in between closing and opening operation of the outgoing disconnector Q9 of the line feeder bay E15, have been determined by applying the SIMULINK module of the MATLAB 5.0 software. In the basic circuit of the line feeder bay E15, AC voltage source applied 816.4KV \((1000/\sqrt{3})\sqrt{2}\) KV per phase), 50Hz with a source impedance \((z_1)\) of 10 micro Henry/m and line impedance \((z_l)\) of 0.212 micro Henry/m considered and the flange connected after breaker through line impedance. To make on/off the breaker with a specified timing, the timer is on at 2 micro sec and switched off at 4 micro sec. The breaker \((Q9)\) resistance at on is 0.001 ohm .The values Q0, Q1, Q70 and the open disconnector in the circuit considered as 50 PF and earth switches Q8, Q51, Q52 considered as 1nano Farad. With this basic circuit due to switching operation of Q9
breaker, the transient voltages across insulating flange and across enclosure have been analyzed as well as suppression of transient voltages by copper strips and capacitors have been implemented and analyzed.

5.4 RESULTS AND DISCUSSIONS

5.4.1 Case (I): (a) Effect of Height of the Insulating Flange

In the basic circuit by keeping all the values are fixed for 1m length and changing the height of the insulating flange to 1m, 2m, 3m by considering flange diameter 0.8 m and flange length 1m in each section (FL, FC per meter) with total length of flange is 8m and inner conductor (IL=0.212µH/m each one) with spacers (spacer capacitance=50PF/m each one) is 8m same as that of flange length.

The source impedance = z1 = 10 µH

Series line impedance = zl = 0.212 µH

Shunt capacitance = Q2 =Q3= 50 pF

Earth switch = Q8 =Q51 =Q52= 1nF

Bus bar disconnectors Q0= Q1=Q70 & open disconnector=50 pF

And height of flange h=1m,2m,3m as shown in simulink diagram 5.7, then flange inductance and capacitance are as follows

h=1m; a=0.8m
FL = 0.183µH/m
FC = 60.71pF /m

h=2m; a=0.8m
FL = 0.322 µH/m
FC =34.56 pF /m

h=3m; a=0.8m
FL = 0.403 µH/m
FC = 25.61 pF /m
The transient voltages across the insulating flange have been observed for different heights of flange for 1m, 2m and 3meters.

Table 5.1 Transient voltages across flange with increasing of flange height

<table>
<thead>
<tr>
<th>S.No</th>
<th>Description</th>
<th>Transient voltages across Insulating Flange</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Height of the insulating flange =1m</td>
<td>14KV</td>
</tr>
<tr>
<td>2</td>
<td>Height of the insulating flange =2m</td>
<td>14.5KV</td>
</tr>
<tr>
<td>3</td>
<td>Height of the insulating flange =3m</td>
<td>16KV</td>
</tr>
</tbody>
</table>

From Fig. 5.6 to 5.8 respectively and are tabulated in table 5.1. From these Fig. it has been observed that the transient voltages are increased as the height of the insulating flange increases.
Fig 5.5 Basic circuit with flange height variation (h=1m, 2m, 3m)

Fig 5.6 Transient voltages across flange with height of flange h=1m
5.4.2 Case (I) (b) Effect of length of Insulating Flange:

In the basic circuit by changing the length of the insulating flange to 0.5m, 1m and 2m with considering height of flange is 2m by keeping all the other values fixed for 1meter length, then flange inductance and capacitance & internal conductor inductance and capacitance of spacers respectively are as follows. The equivalent simulink diagram for change in length of insulating flange is shown in Fig. 5.11

\[
\begin{align*}
&l=0.5\text{m}; a=0.8\text{m} \quad FL = 0.161\mu\text{H}/0.5\text{m} \quad FC = 15.28\text{pF}/0.5\text{m} \\
&l=0.5\text{m}; a=0.8\text{m} \quad IL = 0.106\mu\text{H}/0.5\text{m} \quad sp = 25\text{pF}/0.5\text{m}
\end{align*}
\]
l=1m; a=0.8m FL = 0.322 µH/m FC = 34.56 PF /m
l=1m; a=0.8m IL = 0.212 µH/m sp = 50 PF /m
l=2m; a=0.8m FL = 0.644 µH/2m FC = 69.12 PF /2m
l=2m; a=0.8m IL = 0.424 µH/2m sp = 100 PF /2m

FL= flange Inductance ,FC=Flange capacitance,SP=spacer capacitance
IL=internal conductor inductance

The transient voltages across the insulating flange have been observed for different lengths of 0.5m, 1m and 2 meters from Fig. 5.10 to 5.12 respectively and are tabulated in table 5.2.

Table 5.2 Transient voltages across flange with decreasing of flange length

<table>
<thead>
<tr>
<th>S.No</th>
<th>Description</th>
<th>Transient voltages across insulating Flange</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>length of insulating flange l=2m</td>
<td>180KV</td>
</tr>
<tr>
<td>2</td>
<td>Length of insulating flange l=1m</td>
<td>15KV</td>
</tr>
<tr>
<td>3</td>
<td>Length of insulating flange l=0.5m</td>
<td>4KV</td>
</tr>
</tbody>
</table>

From this, it is observed that the transient voltages across the insulating flange decreases abnormally as the length of the insulating flange decreases.
Fig 5.9 Basic circuit with flange length variation (L=0.5m, 1m, 2m)

Fig 5.10 Transient voltages across flange with length of flange l=0.5m
5.4.3 Case (ii): Effect of suppression of VFTOS across Insulating Flange by Shunting bars (copper strips) connected across flange

By considering the flange length as 0.5m and height of the flange 2m, by keeping all the values are fixed in the basic circuit shown in Fig.5.15 for 1m, then the inductance and capacitance of flange each one as well as inductance of inner conductor and capacitance of spacers are as follows. Total eight sections flange length is 4m and inner conductor with spacers length also same as that of flange.
l=0.5m; a=0.8m \quad FL = 0.161\mu H/0.5m \quad FC = 15.28PF/0.5m \\
l=0.5m; a=0.8m \quad IL = 0.106\mu H/0.5m \quad sp = 25PF/0.5m

The transient voltages across insulating flange can be suppressed by connecting different values of copper strips (0.1\mu H to 0.5 \mu H) across insulating flange with different number of elements then. Suppression of VFTOS across flange has been observed from Fig. 5.14 to 5.17 for number of elements as well as inductance of the copper strip connected across it. The comparison of transient voltages across flange with and without copper strips across it is shown in Table 5.3

Table 5.3 Comparison of transient voltages across flange with and without copper strips

<table>
<thead>
<tr>
<th>S.No</th>
<th>Description</th>
<th>Transient voltages across Insulating Flange With copper strips</th>
<th>Transient voltages Across Insulating Flange Without suppression</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Two copper strips with 0.5 \mu H</td>
<td>1.50KV</td>
<td>4KV</td>
</tr>
<tr>
<td>2</td>
<td>Two copper strips with 0.1 \mu H</td>
<td>0.45KV</td>
<td>4KV</td>
</tr>
<tr>
<td>3</td>
<td>Four copper strips with 0.5 \mu H</td>
<td>0.90KV</td>
<td>4KV</td>
</tr>
<tr>
<td>4</td>
<td>Four copper strips with 0.1 \mu H</td>
<td>0.24KV</td>
<td>4KV</td>
</tr>
</tbody>
</table>

From the above study, it has been observed that the transient voltages across the flange are suppressed more effectively for a low value of copper strips connected across the flange.

Also, it has been observed that the transient voltages are suppressed more effectively by increasing the number of copper strips across the insulating flange.
Fig 5.13 Basic circuit with copper strips across flange

Fig 5.14 Suppression of Transient voltages across Flange with two Copper strips (0.5µH each)

Fig 5.15 Suppression of Transient voltages across Flange with two Copper strips (0.1µH each)
Fig 5.16 Suppression of Transient voltages across Flange with four Copper strips (0.5µH each)

Fig 5.17 Suppression of Transient voltages across Flange with four Copper strips (0.1µH each)

5.4.4 Case (iii): Effect of suppression of VFTOS across Insulating Flange by Capacitors connected across flange.

By considering the flange length as 0.5m and height of the flange 2m, by keeping all the values are fixed in the basic circuit shown in Fig. 5.18 for 1m, then the inductance and capacitance of flange as well as inductance of inner conductor and capacitance of spacers are as follows:

\[
\begin{align*}
& l = 0.5m; \ a = 0.8m \quad FL = 0.161\mu H/0.5m & FC = 15.28pF /0.5m \\
& l = 0.5m; \ a = 0.8m \quad IL = 0.106\mu H/0.5m \quad sp = 25pF /0.5m
\end{align*}
\]
The transient voltages are suppressed across insulating flange by connecting different values of capacitors (0.001µF to 0.005µF) across insulating flange with different number of elements. Suppression of VFTOS depends on number of elements as well as the value of capacitor connected across flange has been observed from Fig. 5.19 to 5.22. The comparison of transient voltages across flange with and without coppers across it, is shown in Table 5.4

Table 5.4 Comparison of transient voltages across flange with and without capacitors across flange

<table>
<thead>
<tr>
<th>S.No</th>
<th>Description</th>
<th>Transient voltages Across Insulating Flange With capacitors</th>
<th>Transient voltage Across Insulating Flange Without suppression</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>One capacitor with 0.001µF</td>
<td>0.9KV</td>
<td>4KV</td>
</tr>
<tr>
<td>2</td>
<td>One capacitor with 0.003µF</td>
<td>0.06KV</td>
<td>4KV</td>
</tr>
<tr>
<td>3</td>
<td>Two capacitors with 0.001µF</td>
<td>0.098KV</td>
<td>4KV</td>
</tr>
<tr>
<td>4</td>
<td>Two capacitors with 0.003µF</td>
<td>0.035KV</td>
<td>4KV</td>
</tr>
</tbody>
</table>

From the above study, it has been observed that the transient voltages across the flange are suppressed more effectively for a high value of capacitors connected across the flange than a low value of capacitors.

Also, it has been observed that the transient voltages are suppressed more effectively by increasing the number of capacitors connected across the insulating flange.
Fig 5.18 Basic circuit with capacitors across flange

Fig 5.19 Suppression of Transient voltages across Flange with capacitor of 0.001µF
Fig 5.20 Suppression of Transient voltages across Flange with capacitor 0.003µF

Fig 5.21 Suppression of Transient voltages across Flange with two capacitors (0.001µF each)
Fig 5.22 Suppression of Transient voltages across Flange with two capacitors (0.003µF each)

5.4.5 Case (IV):a) Effect of suppression of VFTOS across Insulating Flange and enclosure by Shunting bars (copper strips) connected across enclosure.

Table 5.5 Comparison of transient voltages across flange and enclosure with and without copper strips across them

<table>
<thead>
<tr>
<th>S.No</th>
<th>Description</th>
<th>Transient voltages across flange</th>
<th>Transient voltages across enclosure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With copper strips</td>
<td>With copper strips</td>
<td>Without suppression</td>
</tr>
<tr>
<td>1</td>
<td>Two copper strips with 0.3 µH</td>
<td>3.2KV</td>
<td>9KV</td>
</tr>
<tr>
<td>2</td>
<td>Two copper strips with 0.1 µH</td>
<td>2.4KV</td>
<td>3.8KV</td>
</tr>
<tr>
<td>3</td>
<td>Four copper strips with 0.3 µH</td>
<td>2.6KV</td>
<td>5.8KV</td>
</tr>
<tr>
<td>4</td>
<td>Four copper strips with 0.1 µH</td>
<td>1.3KV</td>
<td>3.5KV</td>
</tr>
</tbody>
</table>

Considering the flange length as 0.5m and height of the flange 2m in the
basic circuit shown in Fig. 5.23 by keeping all other values fixed for 1 meter, then the inductance and capacitance of flange as well as inductance of inner conductor and capacitance of spacers are as follows

\[
l = 0.5 \text{m}; a = 0.8 \text{m} \quad FL = 0.161 \mu \text{H} / 0.5 \text{m} \quad FC = 15.28 \text{pF} / 0.5 \text{m}
\]

\[
l = 0.5 \text{m}; a = 0.8 \text{m} \quad IL = 0.106 \mu \text{H} / 0.5 \text{m} \quad sp = 25 \text{pF} / 0.5 \text{m}
\]

The transient voltages across insulating flange and enclosure are suppressed by connecting different values of copper strips (0.1\( \mu \text{H} \) to 0.5 \( \mu \text{H} \)) across enclosure with different number of elements. The Suppression of VFTOS depends on number of elements as well as the value of copper strips has been observed from Fig. 5.24 to 5.31.

The comparison of transient voltages across flange and enclosure with and without copper strips across them, is shown in table 5.5

From the above study, it has been observed that the transient Voltages across flange & enclosure are suppressed effectively for low value of copper strips connected across the enclosure than the high value of copper strips.

Also, it is observed that the transient voltages are suppressed more effectively by increasing the number of copper strips across enclosure.
Fig 5.23 Basic circuit with copper strips across enclosure

Fig 5.24 Suppression of Transient voltages across Flange with two copper strips connected across enclosure (0.3µH each)

Fig 5.25 Suppression of Transient voltages across Flange with two copper strips connected across enclosure (0.1µH each)
Fig 5.26 Suppression of Transient voltages across Flange with four copper strips connected across enclosure (0.3 µH each)

Fig 5.27 Suppression of Transient voltages across Flange with four copper strips connected across enclosure (0.1 µH each)

Fig 5.28 Suppression of Transient voltages across enclosure with two copper strips connected across enclosure (0.1µH each)
Fig 5.29 Suppression of Transient voltages across enclosure with two copper strips connected across enclosure (0.1 µH each)

Fig 5.30 Suppression of Transient voltages across enclosure with four copper strips connected across enclosure (0.3 µH each)

Fig 5.31 Suppression of Transient voltages across enclosure with four copper strips connected across enclosure (0.1 µH each)
5.5.5 Case (IV) :a) Effect of suppression of VFTOS across Insulating Flange and enclosure by capacitors connected across enclosure.

Transient voltages are suppressed across insulating flange and also across enclosure by connecting different values of capacitors (0.001µF to 0.005µF) across enclosure with different number of elements as shown in Fig. 5.32. The suppression of VFTOS depends on number of elements as well as the value of capacitor has been observed from Fig. 5.33 to 5.40.

The comparison of transient voltages across flange and enclosure with and without capacitors across enclosure, is shown in table 5.6.

<table>
<thead>
<tr>
<th>S.N o</th>
<th>Description</th>
<th>Transient voltages across flange With Capacitors</th>
<th>Transient voltages across enclosure With capacitors</th>
<th>Transient voltages across flange Without suppression</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>One capacitor with 0.001µF</td>
<td>0.45KV</td>
<td>14KV</td>
<td>4KV</td>
</tr>
<tr>
<td>2</td>
<td>One capacitor with 0.003µF</td>
<td>0.16KV</td>
<td>3.6KV</td>
<td>4KV</td>
</tr>
<tr>
<td>3</td>
<td>Two capacitor with 0.001µF</td>
<td>0.25KV</td>
<td>6KV</td>
<td>4KV</td>
</tr>
<tr>
<td>4</td>
<td>Two capacitor with 0.003µF</td>
<td>0.09KV</td>
<td>1.8KV</td>
<td>4KV</td>
</tr>
</tbody>
</table>

From the above study, it has been observed that the transient voltages across the flange & across the enclosure are suppressed more effectively by a high value of capacitors connected across the enclosure than the low value of capacitors.
It is also observed that the transient voltages are suppressed more effectively across the flange & across the enclosure as the number of capacitors connected across the enclosure increases.

![Basic circuit with capacitors across enclosure](image1)

**Fig 5.32** Basic circuit with capacitors across enclosure

![Suppression of Transient voltages across flange with 0.001 µF capacitor connected across enclosure](image2)

**Fig 5.33** Suppression of Transient voltages across flange with 0.001 µF capacitor connected across enclosure
Fig 5.34 Suppression of Transient voltages across flange with 0.003 µF capacitor connected across enclosure

Fig 5.35 Suppression of Transient voltages across flange with two capacitors connected across enclosure (0.001 µF each)

Fig 5.36 Suppression of Transient voltages across flange with two capacitors connected across enclosure (0.003 µF each)
Fig 5.37 Suppression of Transient voltages across enclosure with 0.001 µF capacitor connected across enclosure

Fig 5.38 Suppression of Transient voltages across enclosure with 0.003 µF capacitor connected across enclosure

Fig 5.39 Suppression of Transient voltages across enclosure with two capacitors connected across enclosure (0.001 µF each)
Fig 5.40 Suppression of Transient voltages across enclosure with two capacitors connected across enclosure (0.003 μF each)