LNCT GROUP OF COLLEGES

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Topic: Insulators

Insulators

Electrical Insulator must be used in electrical system to prevent unwanted flow of current to the earth from its supporting points. The insulator plays a vital role in electrical system. Electrical Insulator is a very high resistive path through which practically no current can flow. In transmission and distribution system, the overhead conductors are generally supported by supporting towers or poles. The towers and poles both are properly grounded. So there must be insulator between tower or pole body and current carrying conductors to prevent the flow of current from conductor to earth through the grounded supporting towers or poles.

Insulating Material

The main cause of failure of overhead line insulator, is flash over, occurs in between line and earth during abnormal over voltage in the system. During this flash over, the huge heat produced by arcing, causes puncher in insulator body. Viewing this phenomenon the materials used for electrical insulator, has to posses some specific properties.

Properties of Insulating Material

The materials generally used for insulating purpose is called **insulating material**. For successful utilization, this material should have some specific properties as listed below-

1. It must be mechanically strong enough to carry tension and weight of conductors.
2. It must have very high dielectric strength to withstand the voltage stresses in High Voltage system.
3. It must possesses high Insulation Resistance to prevent leakage current to the earth.
4. The **insulating material** must be free from unwanted impurities.
5. It should not be porous.
6. There must not be any entrance on the surface of electrical insulator so that the moisture or gases can enter in it.
7. There physical as well as electrical properties must be less affected by changing temperature.

There are mainly three **types of insulator** used as **overhead insulator** likewise

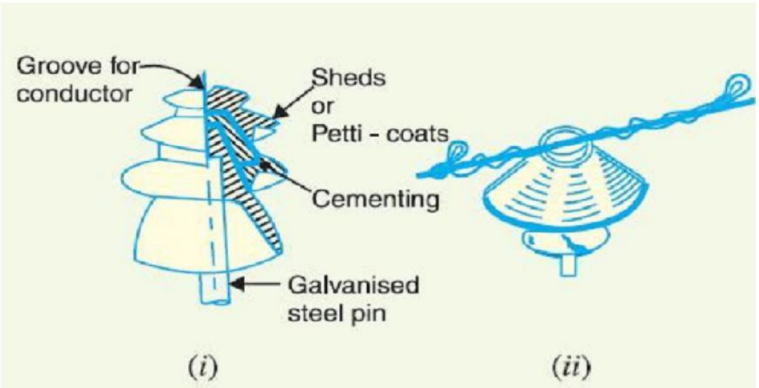
1. Pin Insulator
2. Suspension Insulator
3. Strain Insulator

In addition to that there are other two types of electrical insulator available mainly for low voltage application i.e. Stray Insulator and Shackle Insulator.

Pin Insulator

Pin Insulator is earliest developed **overhead insulator**, but still popularly used in power network up to 33KV system. Pin type insulator can be one part, two parts or three parts type, depending upon application voltage. In 11KV system we generally use one part type insulator where whole pin insulator is one piece of properly shaped porcelain or glass. As the leakage path

of insulator is through its surface, it is desirable to increase the vertical length of the insulator surface area for lengthening leakage path. In order to obtain lengthy leakage path, one, tower or more rain sheds or petticoats are provided on the insulator body. In addition to that rain shed or petticoats on an insulator serve another purpose. These rain sheds or petticoats are so designed, that during raining the outer surface of the rain shed becomes wet but the inner surface remains dry and non-conductive. So there will be discontinuations of conducting path through the wet pin insulator surface.



Pin Insulator

In higher **voltage** like 33KV and 66KV manufacturing of one part porcelain pin insulator becomes difficult. Because in higher voltage, the thickness of the insulator become more and a

quite thick single piece porcelain insulator cannot manufactured practically. In this case we use multiple part pin insulator, where a number of properly designed porcelain shells are fixed together by Portland cement to form one complete insulator unit. For 33KV tow parts and for 66KV three parts pin insulator are generally used.

Designing Consideration of Electrical Insulator

The live conductor attached to the top of the pin insulator is at a potential and bottom of the insulator fixed to supporting structure of earth potential. The insulator has to withstand the potential stresses between conductor and earth. The shortest distance between conductor and earth, surrounding the insulator body, along which electrical discharge may take place through air, is known as flash over distance.

1. When insulator is wet, its outer surface becomes almost conducting. Hence the flash over distance of insulator is decreased. The design of an electrical insulator should be such that the decrease of flash over distance is minimum when the insulator is wet. That is why the upper most petticoat of a pin insulator has umbrella type designed so that it can protect, the rest lower part of the insulator from rain. The upper surface of top most petticoat is inclined as less as possible to maintain maximum flash over voltage during raining.

2. To keep the inner side of the insulator dry, the rain sheds are made in order that these rain sheds should not disturb the voltage distribution they are so designed that their subsurface at right angle to the electromagnetic lines of force.

Suspension Insulator

In higher voltage, beyond 33KV, it becomes uneconomical to use pin insulator because size, weight of the insulator become more. Handling and replacing bigger size single unit insulator are quite difficult task. For overcoming these difficulties, **suspension insulator** was developed.
In **suspension insulator** numbers of insulators are connected in series to form a string and the line conductor is carried by the bottom most insulator. Each insulator of a suspension string is called disc insulator because of their disc like shape.

Advantages of Suspension Insulator

(i) Suspension type insulators are cheaper than pin type insulators for voltages beyond 33 kV.

(ii) Each unit or disc of suspension type insulator is designed for low voltage,usually 11 kV. Depending upon the working voltage, the desired number of discs can be connected in series.

(iii) If any one disc is damaged, the whole string does not become useless because the damaged disc can be replaced by the sound one.

(iv) The suspension arrangement provides greater flexibility to the line. The connection at the cross arm is such that insulator string is free to swing in any direction and can take up the position where mechanical stresses are minimum.

(v) In case of increased demand on the transmission line, it is found more satisfactory to supply the greater demand by raising the line voltage than to provide another set of conductors. The additional insulation required for the raised voltage can be easily obtained in the suspension arrangement by adding the desired number of discs.

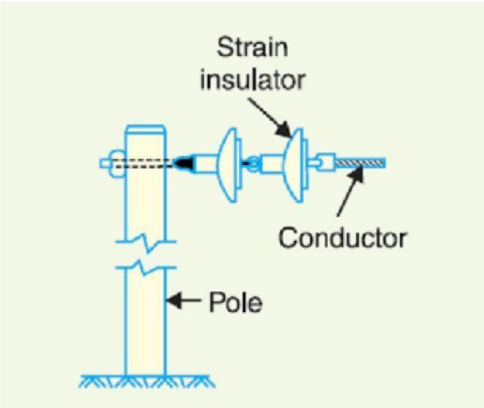
(vi) The suspension type insulators are generally used with steel towers. As the conductors run below the earthed cross-arm of the tower, therefore, this arrangement provides partial protection from lightning.

Disadvantages of Suspension Insulator

1. Suspension insulator string costlier than pin and post type insulator.
2. Suspension string requires more height of supporting structure than that for pin or post insulator to maintain same ground clearance of current conductor.
3. The amplitude of free swing of conductors is larger in suspension insulator system, hence, more spacing between conductors should be provided.

Strain Insulator

When suspension string is used to sustain extraordinary tensile load of conductor it is referred as **string insulator**. When there is a dead end or there is a sharp corner in transmission line, the line has to sustain a great tensile load of conductor or strain. A **strain insulator** must have considerable mechanical strength as well as the necessary electrical insulating properties.



Strain Insulator

Shackle Insulator or Spool Insulator

The **shackle insulator** or **spool insulator** is usually used in low voltage distribution network. It can be used both in horizontal and vertical position. The use of such insulator has decreased recently after increasing the using of underground cable for distribution purpose. The tapered hole of the **spool insulator** distributes the load more evenly and minimizes the possibility of breakage when heavily loaded. The conductor in the groove of **shackle insulator** is fixed with the help of soft binding wire.

POTENTIAL DISTRIBUTION OVERA STRING OF SUSPENSION INSULATORS:

A string of suspension insulators consists of a number of porcelain discs connected in series through metallic links. Fig. 2.3(i) shows 3-disc string of suspension insulators. The porcelain portion of each disc is in between two metal links. Therefore, each disc forms a capacitor C as shown in Fig.2.3(ii). This is known as mutual capacitance or self-capacitance. If there were mutual capacitance alone, then charging current would have been the same through all the discs and consequently voltage across each unit would have been the same i.e., V/3 as shown in Fig. 2.3(ii). However, in actual practice, capacitance also exists between metal fitting of each disc and tower or earth. This is known as shunt capacitance C1. Due to shunt capacitance, charging current is not the same through all the discs of the string [See Fig 2.3(iii)]. Therefore, voltage across each disc will be different. Obviously, the disc nearest to the line conductor will have the maximum voltage. Thus referring to Fig 2.3(iii), V_3 will be much more than V_2 or V_1.

The following points may be noted regarding the potential distribution over a string of suspension insulators:

(i) The voltage impressed on a string of suspension insulators does not distribute itself uniformly across the individual discs due to the presence of shunt capacitance.

(ii) The disc nearest to the conductor has maximum voltage across it. As we move towards the cross-arm, the voltage across each disc goes on decreasing.

(iii) The unit nearest to the conductor is under maximum electrical stress and is likely to be punctured. Therefore, means must be provided to equalize the potential across each unit.

(iv) The presence of stray capacitance causes unequal potential distribution over the string. The end unit of the string (which is the closest to the line) takes maximum potential difference and the upper units have a gradually decreased potential difference until the uppermost unit which has the lowest potential difference. The next proof illustrates this concept.

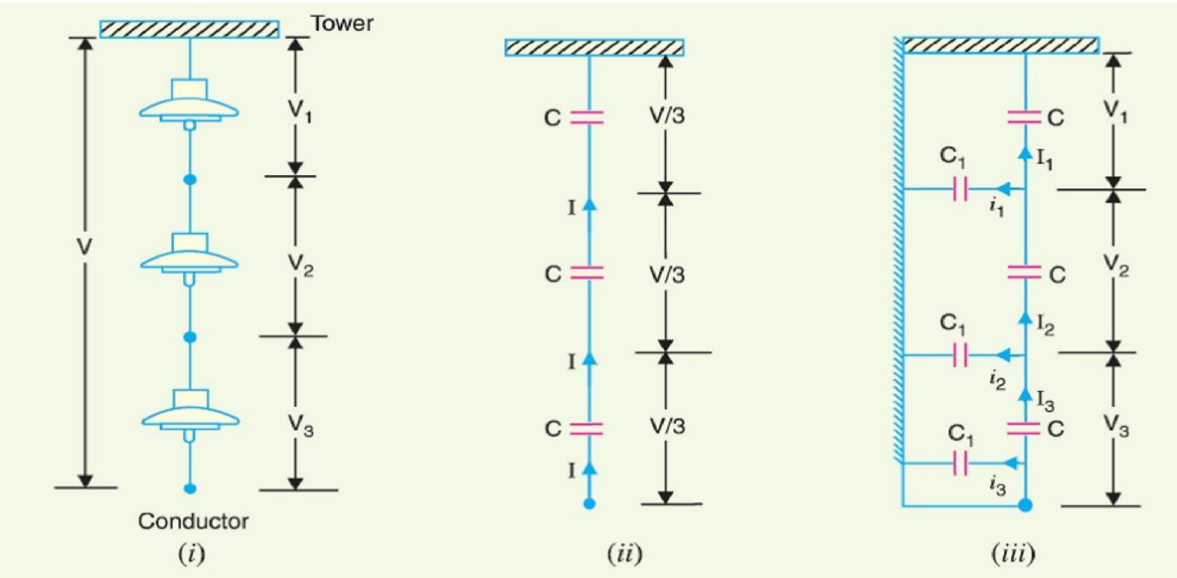


Fig 2.3- Suspension Insulator string

String Efficiency:

As stated above, the voltage applied across the string of suspension insulators is not uniformly distributed across various units or discs. The disc nearest to the conductor has much higher potential than the other discs. This unequal potential distribution is undesirable and is usually expressed in terms of string efficiency.

The ratio of voltage across the whole string to the product of number of discs and the voltage across the disc nearest to the conductor is known as string efficiency i.e.

$$\text{String efficiency} = \frac{\text{Voltage across the string}}{n \times \text{Voltage across disc near to conductor}}$$

Where n is the no. of discs in the string.

String efficiency is an important consideration since it decides the potential distribution along the string. The greater the string efficiency, the more uniform is the voltage distribution. Thus 100%

string efficiency is an ideal case for which the voltage across each disc will be exactly the same. Although it is impossible to achieve 100% string efficiency, yet efforts should be made to improve it as close to this value as possible.

Mathematicalexpression. Fig. 2.3(iii) shows the equivalent circuit for a 3-disc string. Let us suppose that self capacitance of each disc is C. Let us further assume that shunt capacitance C1 is some fraction K of self capacitance i.e., C1 = KC. Starting from the cross-arm or tower, the voltage across each unit is V1,V2 and V3 respectively as shown.

Applying kirchoff's current law to node A

$$I_2 = I_1 + i_1$$
$$V_2 \omega C = V_1 \omega C + \omega V_1 C_1$$
$$V_2 = V_1(1 + K)$$

Applying kirchoff's current law to node B

$$I_3 = I_2 + i_2$$
$$V_3 = V_1(1 + 3K + K^2)$$
$$\%string\ efficiency = \frac{V_1}{3 \times V_3} \times 100$$

The following points may be noted from the above mathematical analysis:

(i) If K = 0·2 (Say), then we get, V_2 = 1·2 V_1 and V_3 = 1·64 V_1. This clearly shows that disc nearest to the conductor has maximum voltage across it; the voltage across other discs decreasing progressively as the cross-arm in approached.

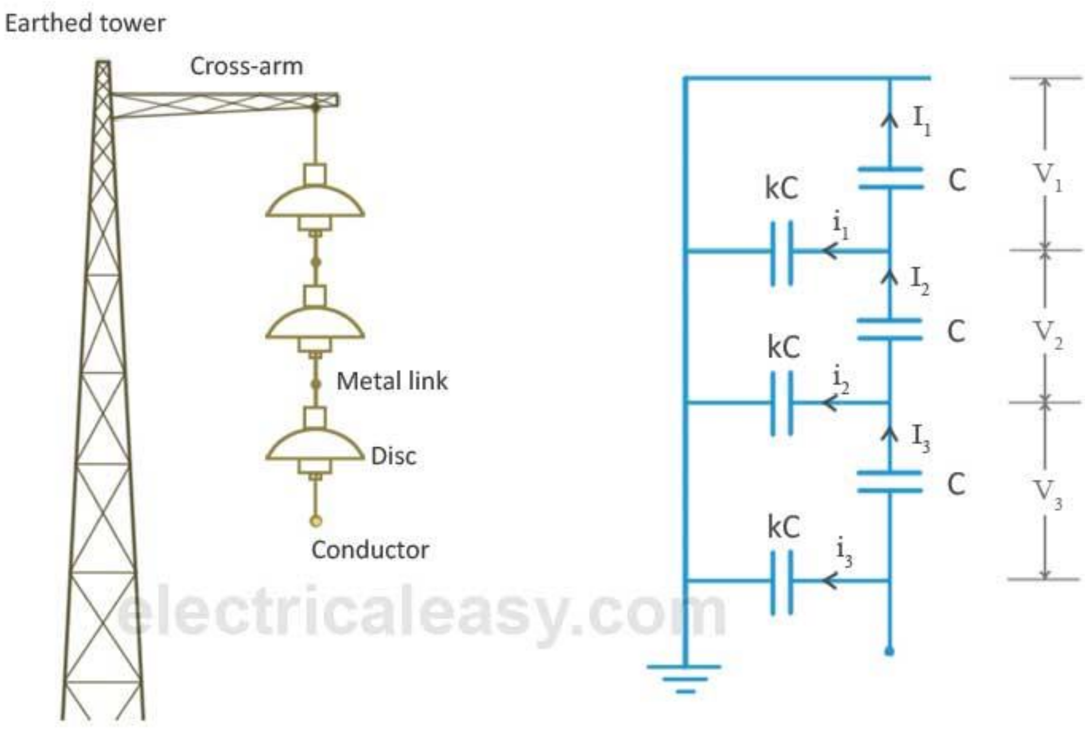
(ii) The greater the value of K (= C1/C), the more non-uniform is the potential across the discs and lesser is the string efficiency.

(iii) The inequality in voltage distribution increases with the increase of number of discs in the string. Therefore, shorter string has more efficiency than the larger one

A suspension type string insulator consists of a number of porcelain discs connected in series through metallic links. Suspension insulators or string insulators are very widely used in electrical overhead transmission system. However, there is a significant thing to be considered in case of these string insulators, known as **string efficiency**.

Potential distribution over a suspension insulator string

The figure below shows a 3-disc string of suspension insulator. As each porcelain disc lies in between two metal links, it forms a capacitor. This capacitance is known as *self-capacitance* or *mutual capacitance*. Moreover, air capacitance is also present between metal links and the earthed tower. This is known as *shunt capacitance*. The figure below illustrates the **equivalent circuit of a 3-disc suspension insulator** (assuming that shunt capacitance is some fraction of self-capacitance i.e shunt capacitance = k * self-capacitance).



(a) 3-disc string insulator (b) equivalent circuit

If there were only mutual capacitances, then the charging current would have been the same through all the discs. In this case, the voltage would have been uniformly distributed across the string, i.e. voltage across each disc would have been the same. But, due to the shut capacitances, charging current is not the same through all the discs.

From the above equivalent circuit, applying Kirchoff's current law to node A,

$I_2 = I_1 + i_1$
$V_2\omega C = V_1\omega C + V_1\omega kC$
$V_2 = V1 + V_1k$
$V_2 = (1 + k)V_1$ ...... eq.(i)

applying Kirchoff's current law to node B,

$I3 = I2 + i2$
$V3\omega C = V2\omega C + (V_2 + V_1)\omega kC$
$V_3 = V_2 + (V_1 + V_2)k$
$V_3 = kV1 + (1 + k)\ V_2$
$V_3 = kV1 + (1 + k)^2\ V_1$ ...... from eq.(i)
$V_3 = V_1\ [k + (1 + k)^2]$
$V_3 = V_1\ [k + 1 + 2k + k^2]$
$V_3 = V_1\ (1 + 3k + k^2)$ ...... eq.(ii)

Now, voltage between the conductor and the earther tower is,

$V = V_1 + V_2 + V_3$
$V = V_1 + (1 + k)V_1 + V_1\ (1 + 3k + k^2)$
$V = V_1\ (3 + 4k + k^2)$ ...... eq.(iii)

from the above equations (i), (ii) & (iii), it is clear that the voltage across the top disc is minimum while voltage across the disc nearest to the conductor is maximum, i.e. V3 = V1 (1 + 3k + k2). As we move towards the cross arm, voltage across the disc goes on decreasing. Due to this non-uniform voltage distribution across the string, the unit nearest to the conductor is under maximum electrical stress and is likely to be punctured.

String efficiency

As explained above, voltage is not uniformly distributed over a suspension insulator string. The disc nearest to the conductor has maximum voltage across it and, hence, it will be under maximum electrical stress. Due to this, the disc nearest to the conductor is likely to be punctured and subsequently, other discs may puncture successively. Therefore, this unequal voltage distribution is undesirable and usually expressed in terms of string efficiency.

The ratio of voltage across the whole string to the product of number of discs and the voltage across the disc nearest to the conductor is called as **string efficiency**

String efficiency = Voltage across the string / (number of discs X voltage across the disc nearest to the conductor).

Greater the string efficiency, more uniform is the voltage distribution. String efficiency becomes 100% if the voltage across each disc is exactly the same, but this is an ideal case and impossible in practical scenario. However, for DC voltages, insulator capacitances are ineffective and voltage across each unit would be the same. This is **why string efficiency for DC system is 100%**.

Inequality in voltage distribution increases with the increase in the number of discs in a string. Therefore, shorter strings are more efficient than longer string insulators.

Methods of improving string efficiency

(i) Using longer cross arms

It is clear from the above mathematical expression of string efficiency that the value of string efficiency depends upon the value of *k*. Lesser the value of *k*, the greater is the string efficiency. As the value of *k* approaches to zero, the string efficiency approaches to 100%. The value of *k* can be decreased by reducing the shunt capacitance. In order to decrease the shunt capacitance, the distance between the insulator string and the tower should be increased, i.e. longer cross-arms should be used. However, there is a limit in increasing the length of cross-arms due to economic considerations.

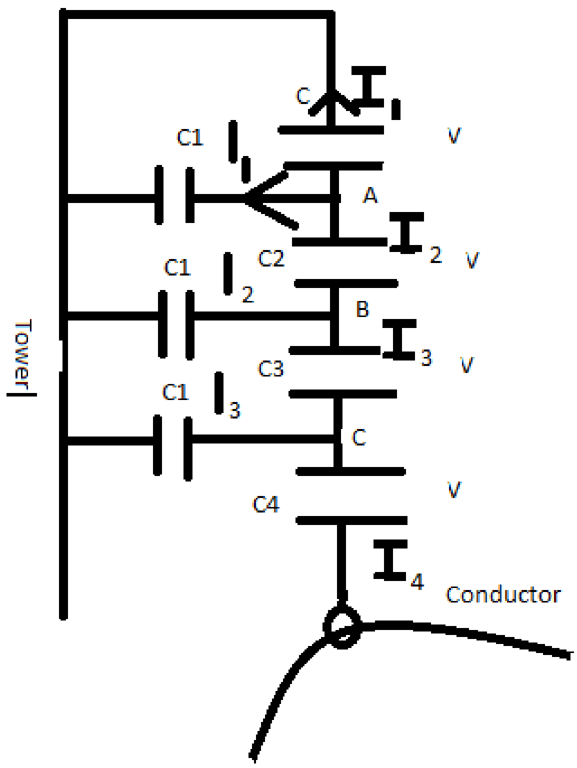
(ii) Grading of insulator discs

In this method, voltage across each disc can be equailized by using discs with different capacitances. For equalizing the voltage distribution, the top unit of the string must have minimum capacitance, while the disc nearest to the conductor must have maximum capacitance. The insulator discs of different dimensions are so chosen that the each disc has a different capacitance. They are arranged in such a way that the capacitance increases progressively towards the bottom. As voltage is inversely proportional to capacitance, this method tends to equalize the voltage distribution across each disc.

(iii) By using a guard or grading ring

A guard ring or grading ring is basically a metal ring which is electrically connected to the conductor surrounding the bottom unit of the string insulator. The guard ring introduces capacitance between metal links and the line conductor which tends to cancel out the shunt capacitance. As a result, nearly same charging current flows through each disc and, hence, improving the string efficiency.

(ii) CPACITANCE GRADING



Applying KCL at A

$I_2 = i_1 + I_1$

$C_2 = C_1 + C$

Since C_1 is ratio of Capacitance with tower and self capacitance which is denoted by k

That why $C_2 = kC + C$

$C_2 = C(1 + k)$ ……………………….. (1)

Applying KCL at B

$I_3 = i_2 + I_2$

$\acute{\omega}C_3V = \acute{\omega}C_1(V+V) + \acute{\omega}C_2V$

$C_3 = 2C_1 + C_2$

$C_3 = k2C + C(1 + k)$

$C_3 = C(1 + 3k)$ …………………………………….(2)

Applying KCL at C

$I_4 = i_3 + I_3$

$\acute{\omega}C_4V = \acute{\omega}C_1(V+V+V) + \acute{\omega}C_3V$

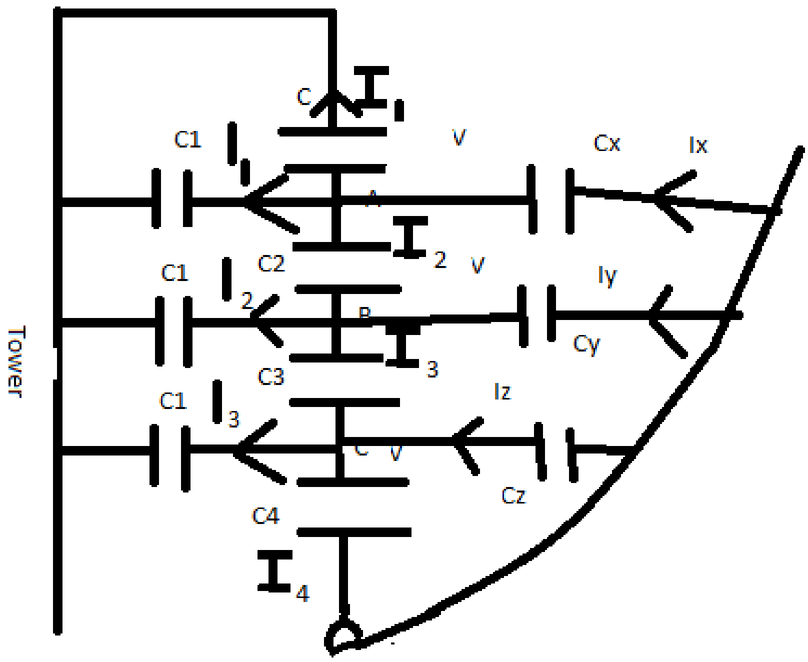
$C_4 = 3C_1 + C_3$

$C_4 = 3kC + C(1 + 3k)$

$C_4 = C(1 + 6k)$ ……………………………………..(3)

By using Discs of different capacitance Voltage distribution becomes equal and String efficiency will be 1 or 100%.

By use of Guard Ring



Applying kcl at A

$I_2 + I_x = i_1 + I_1$

$V_2\omega C + \omega C_x 3V = V_1\omega C + V_1\omega kC$

For equal distribution of Voltage $I_1 = I_2$

$I_x = i_1$

$\omega C_x 3V = V\omega kC$
$C_x = kC / 3$ ……………………………………………(1)

Applying KCL at B

$I_3 + I_y = i_2 + I_2$

$\omega C_y 2V = 2V\omega kC$
$C_y = 2kC$ ……………………………………………(2)

Applying KCL at C

$I_4 + I_z = i_3 + I_3$

If $I_4 = I_3$
$I_z = i_3$

$\omega C_z V = 3V\omega kC$

$C_z = 3kC$ ……………………………………………(3)

By using values of C_x , C_y and C_z equal distribution of Voltages across each unit can be achieved.