CHAPTER 3

EXPERIMENTAL EQUIPMENT AND PROCEDURE

This chapter describes the equipment, procedure and standard waveshape which are used to determine flashover voltage under atmospheric conditions of high voltage laboratory.

3.1 Impulse Voltage Tests

The impulse voltage is usually generated by an impulse generator consisting essentially of a number of capacitors that are charge in parallel from a direct voltage source and then discharged in series into a circuit that includes the test object and measuring system. This research used eight stages impulse generator as shown in figure 3.1.

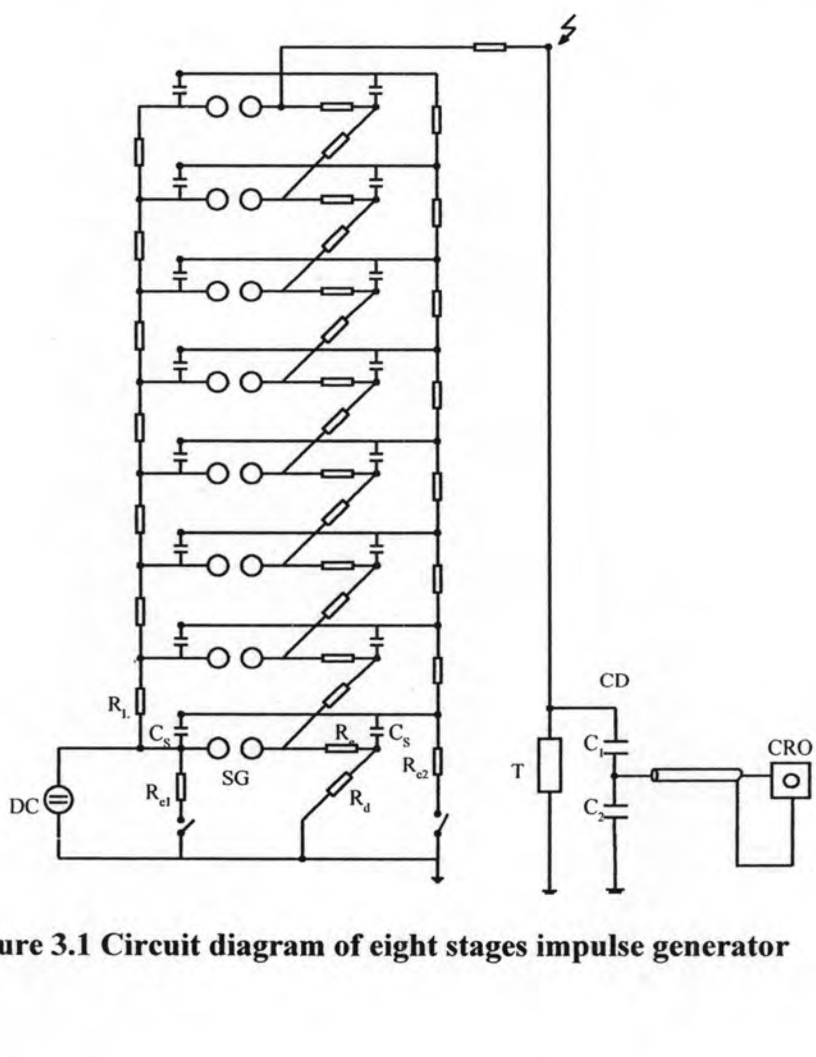


Figure 3.1 Circuit diagram of eight stages impulse generator

Where: **DC** is Dc source

C_S is capacitance of the generator

R_L is charging resistors

SG is spark gap

R_d is front wave shaping resistor

R_e, R_{e1}, R_{e2} are the tail wave shaping resistors

T is test object

CD is capacitive divider for impulse voltage measurement

CRO is oscilloscope or peak-volt meter

Figure 3.2 shows the picture of lightning impulse test set up that is used to determine flashover voltage under natural atmospheric conditions of high voltage laboratory, Chulalongkorn University.

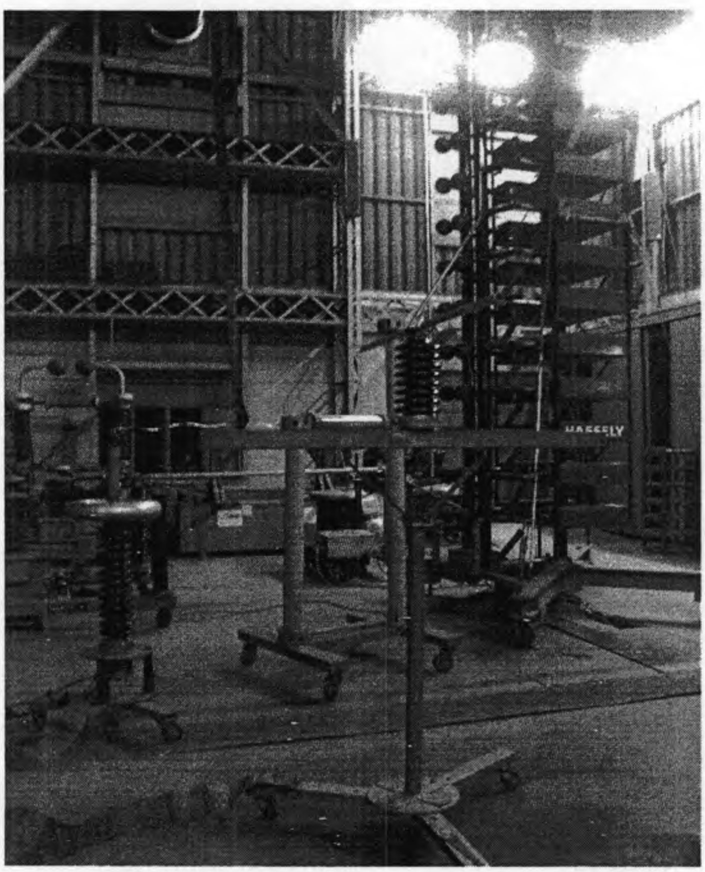


Figure 3.2 Lightning impulse tests of line-post porcelain insulator Class 57-3

3.1.1 Standard Impulse Waveshapes

The general lightning impulse waveshapes are illustrated in figure 3.3 and is described by their time to crest and their time to half value of the tail. The time to crest is determined by first constructing a line between two points: the points at which the voltage is equal to 30% and 90% of its crest value. The point at which this line intersects the origin or zero voltage is called the virtual origin and all times are measured from this point. Next, a horizontal line is drawn at the crest value so as to intersect the other line drawn through the 30% and 90% points. The time from the virtual origin to this intersection point is denoted as the time to crest or as the virtual time to crest t_f. The time to half value is simply the time between the virtual origin and the point at which the voltage decreases to 50% of the crest value, t_T. In general, the waveshape is denoted as a t_f/t_T impulse.

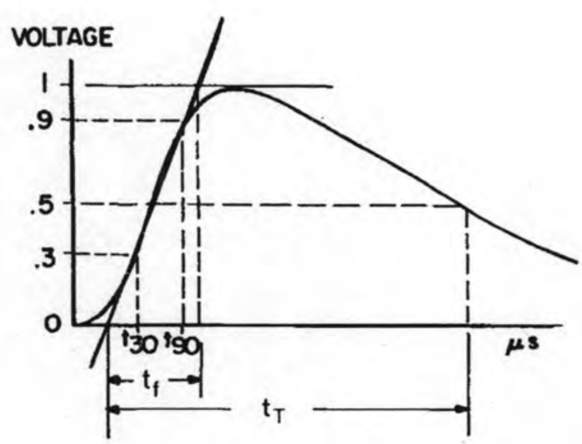


Figure 3.3 Lightning impulse wave shape

Table 3.1 Standard Impulse Wave Shape and Tolerances

Impulse Type	Nominal wave shape	Tolerances	
		Front	Tail
Lightning	1.2/50μs	±30%	±20%

3.1.2 Data Recorded

The lightning impulse disruptive discharge voltage, $U_{50\%}$, is determined by using up - down test method with 20 voltages application, for both polarities. The $U_{50\%}$ is the prospective voltage value which has a 50% probability of producing a disruptive discharge. In up – down method test provides an estimate of $U_{50\%}$, is given by:

$$U_{50\%} = \sum \frac{k_i U_i}{n} \tag{3.1}$$

Where k_i is the number of groups of stresses applied at the voltage level U_i

3.1.3 Test Procedure

Before tests, porcelain insulator should be clean and dry, as an effect of dust or condenses water deposition on insulation surface may reduced the flashover voltage. In the up-down method, the voltage is initially raised in steps of a fixed amplitude Δu, from an initially value u_0 at which certainty no breakdown occurs, until the first breakdown at a voltage u_1 as shows in figure 3.4. The voltage is then reduced by Δu. If no breakdown occurs at voltage $u_2 = u_1 - \Delta u$, the test voltage should again be raised through Δu, otherwise be reduced by Δu. The process is repeated until a predetermined number n of voltage values u_1, u_2, ...u_n are obtained. Particularly with a large sample n, the arithmetic mean of these voltages in itself provides a preliminary estimate of the 50% breakdown voltage being sought. Usually the value of Δu recommended by international standard is equal to $\pm 3\,\%$.

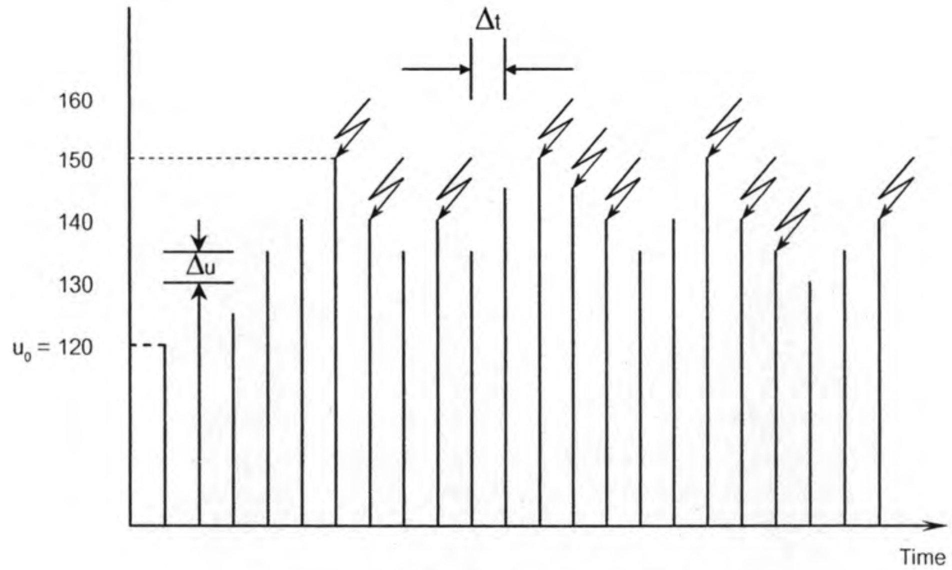


Figure 3.4 Up - Down test method

3.2 AC Voltage Tests

AC voltage tests for the determination of the disruptive discharge voltage U, calculated as the medium value of 6 disruptive voltage applications (the time interval between each application is greater than 1 minute).

3.2.1 Experiment arrangement

The experiment arrangement is shown in figure 3.5. For the 50 Hz AC test with voltage up to 200KV rms, a 0.2/200KV, 10 kVA cascade high voltage transformer was employed, and the experiments were carried out under atmospheric condition of HV laboratory.

AC voltage was measured by using the C-divider (ratio 1:2638.9, 200kV) and digital voltmeter (0.1% max. error).

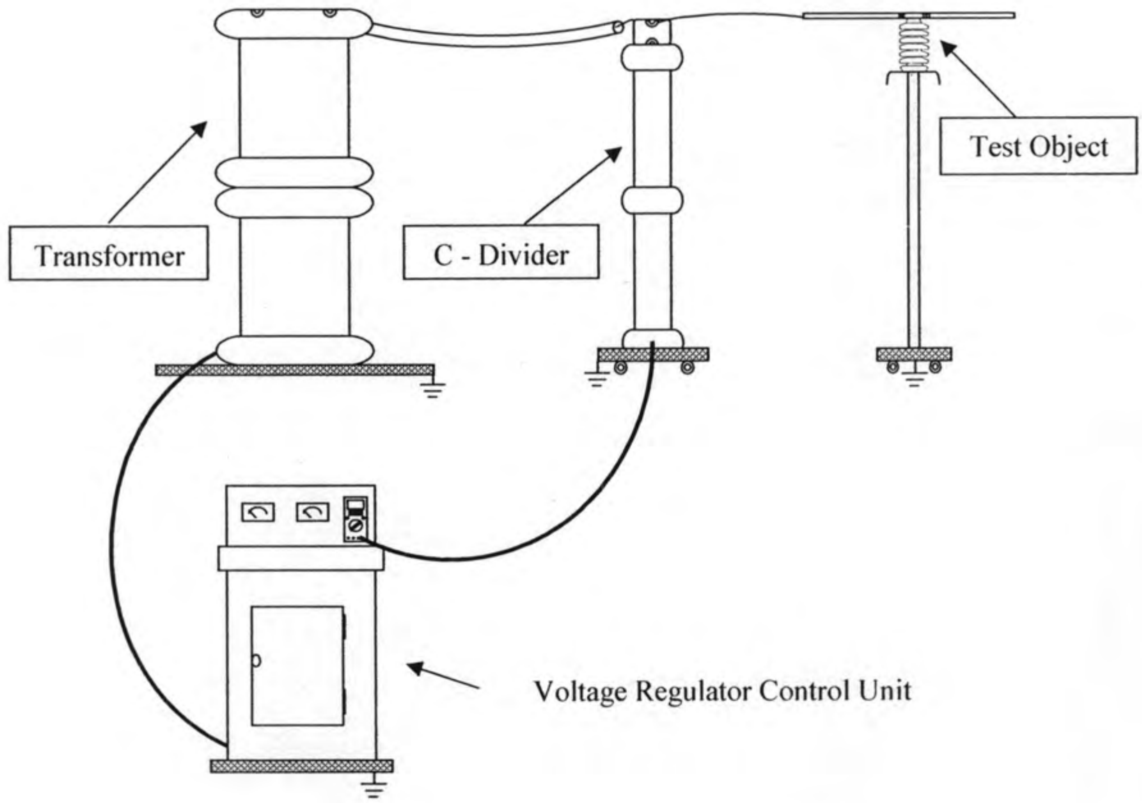


Figure 3.5 Circuit diagram of power frequency tests

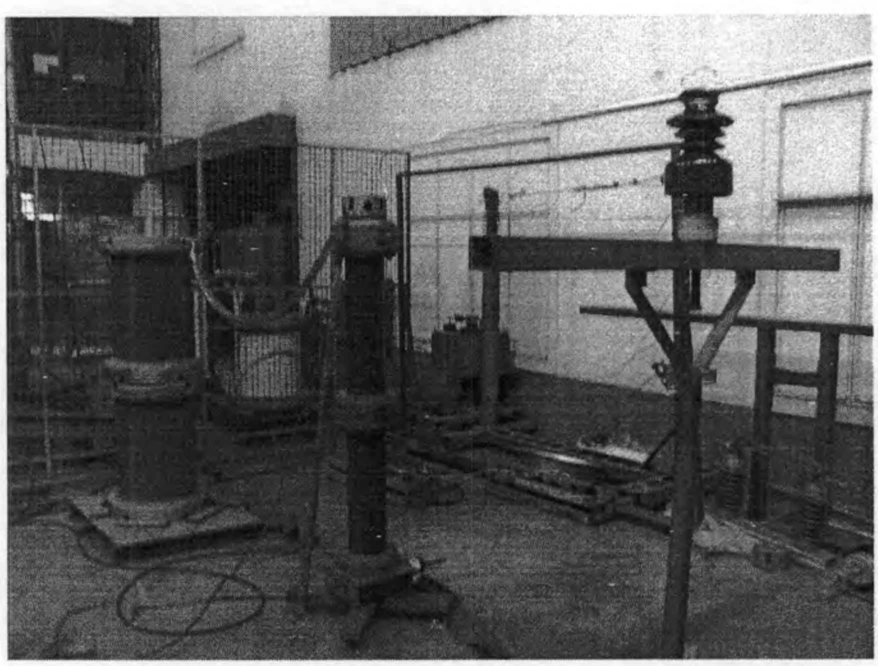


Figure 3.6 AC voltage arrangements in HV Laboratory

3.2.2 Test procedure

When using power frequency, the initial applied voltage is quickly increased to approximately 75% of the expected average flashover voltage value. The continue rate of the voltage increase shall be such that the time to flashover will be not less than 5 seconds nor more than 30 seconds after 75% of the flashover value is reached.

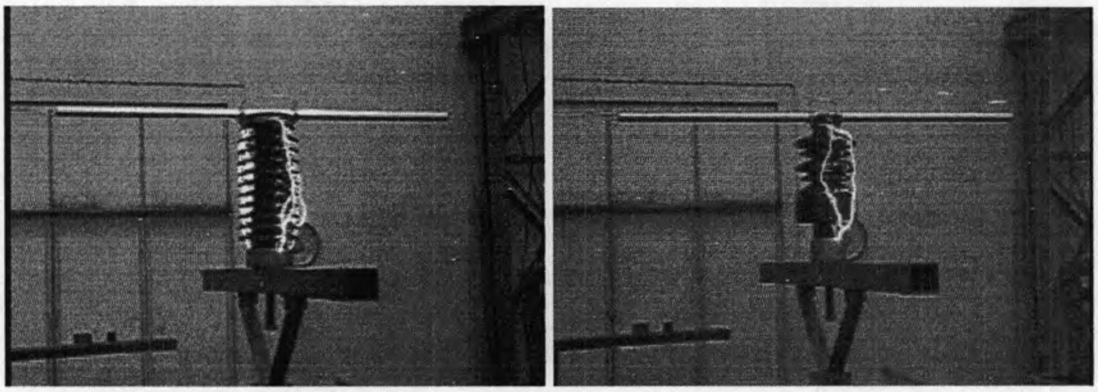
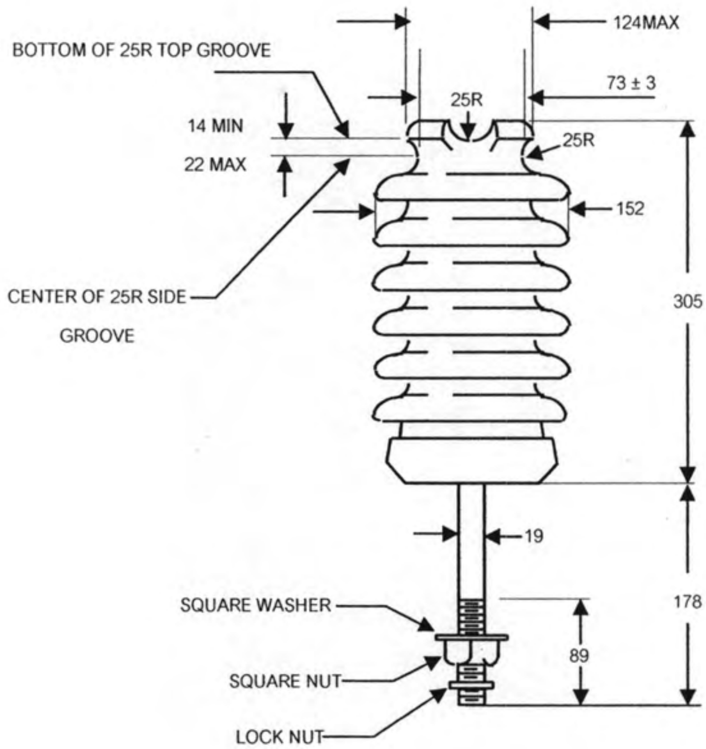


Figure 3.7 Flashover voltage on insulator surface

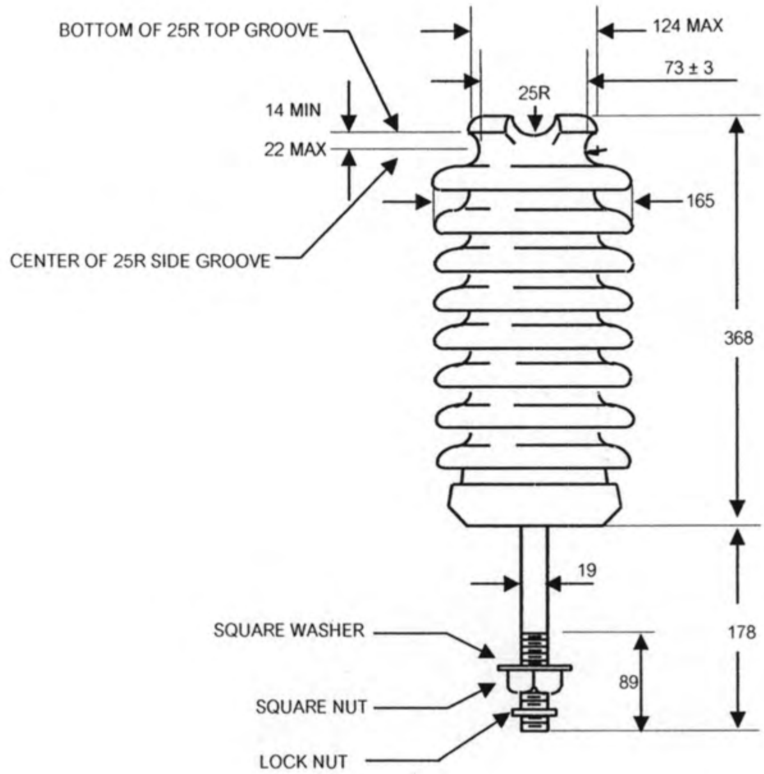
3.3 Test Objects

In order to study the flashover voltage of pin-post and line-post insulators under atmospheric condition in Thailand, three classes of insulator were used, namely: 57-2, 57-3, 57-4 for line-post insulators and 56/57-2, 56/57-3, 56/57-4 for pin-post insulators. Dimension of all insulators are shown in figure 3.8 – 3.13.



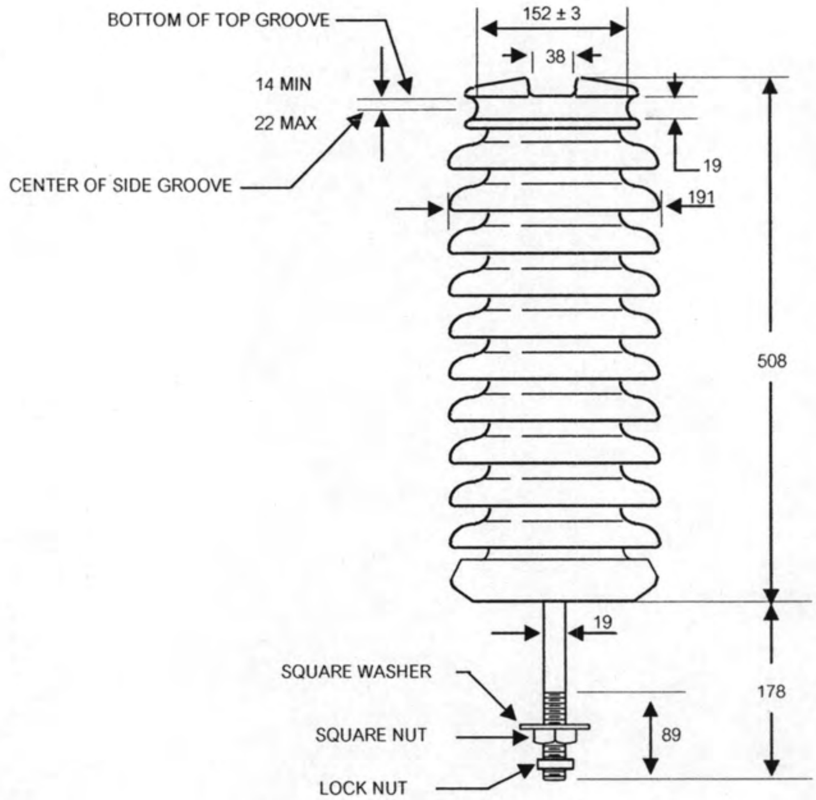
Dimensions	Rating
Leakage distance, mm	559
Dry-arcing distance, mm	241
Mechanical Values	
Cantilever strength, kN	12.5
Cantilever proof load, kN	5
Electrical Values	
Low frequency dry flashover, kV	110
Low frequency wet flashover, kV	85
Critical impulse flashover, positive, kV	180
Critical impulse flashover, negative, kV	205
Radio Interference Voltage Data	
Low frequency test voltage, rms to ground kV	22
Maximum RIV at 1000 kHz, microvolt	100

Figure 3.8 Line-post insulator Class 57-2



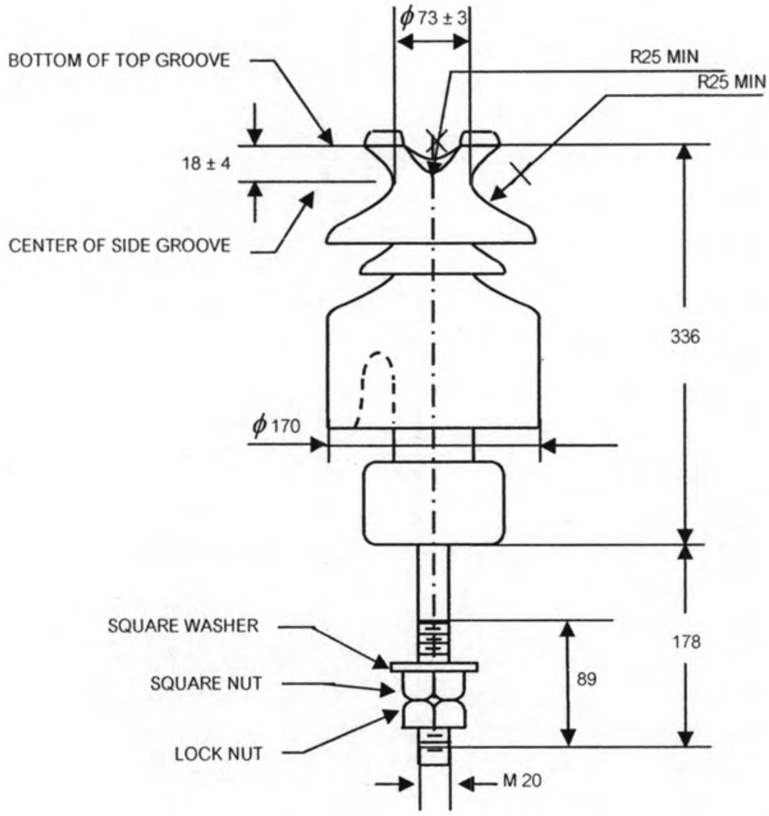
Dimensions	Rating
Leakage distance, mm	737
Dry-arcing distance, mm	311
Mechanical Values	
Cantilever strength, kN	12.5
Cantilever proof load, kN	5
Electrical Values	
Low frequency dry flashover, kV	125
Low frequency wet flashover, kV	100
Critical impulse flashover, positive, kV	210
Critical impulse flashover, negative, kV	260
Radio Interference Voltage Data	
Low frequency test voltage, rms to ground kV	30
Maximum RIV at 1000 kHz, microvolt	200

Figure 3.9 Line-post insulator Class 57-3



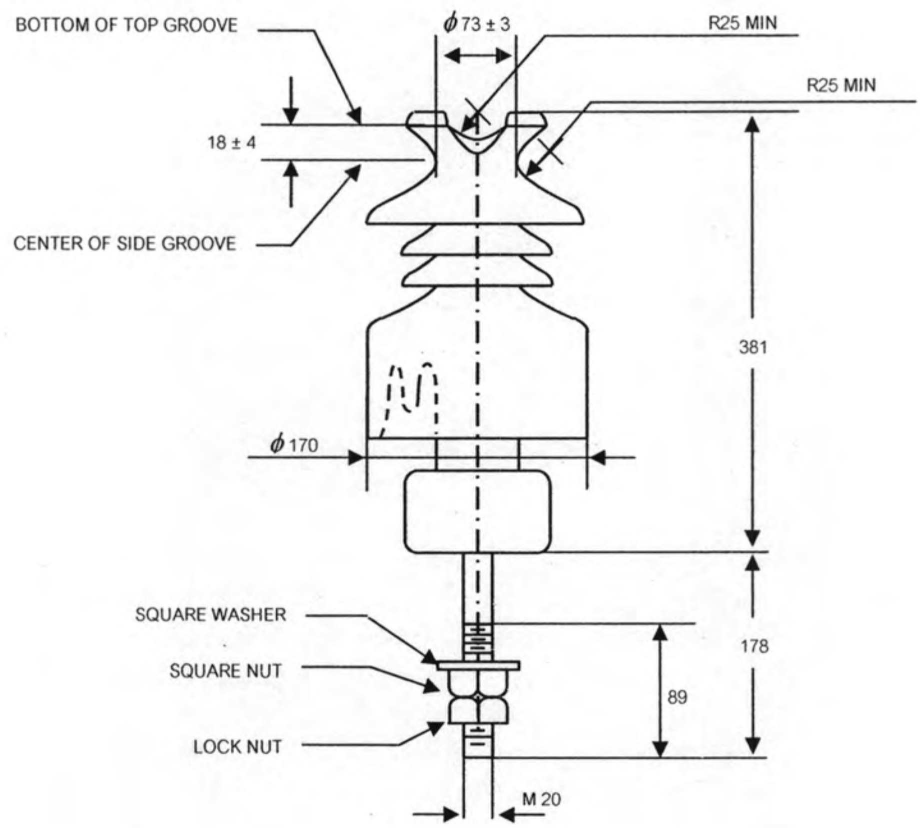
Dimensions	Rating
Leakage distance, mm	1015
Dry-arcing distance, mm	368
Mechanical Values	
Cantilever strength, kN	12.5
Cantilever proof load, kN	5
Electrical Values	
Low frequency dry flashover, kV	150
Low frequency wet flashover, kV	125
Critical impulse flashover, positive, kV	255
Critical impulse flashover, negative, kV	340
Radio Interference Voltage Data	
Low frequency test voltage, rms to ground kV	44
Maximum RIV at 1000 kHz, microvolt	200

Figure 3.10 Line-post insulator Class 57-4



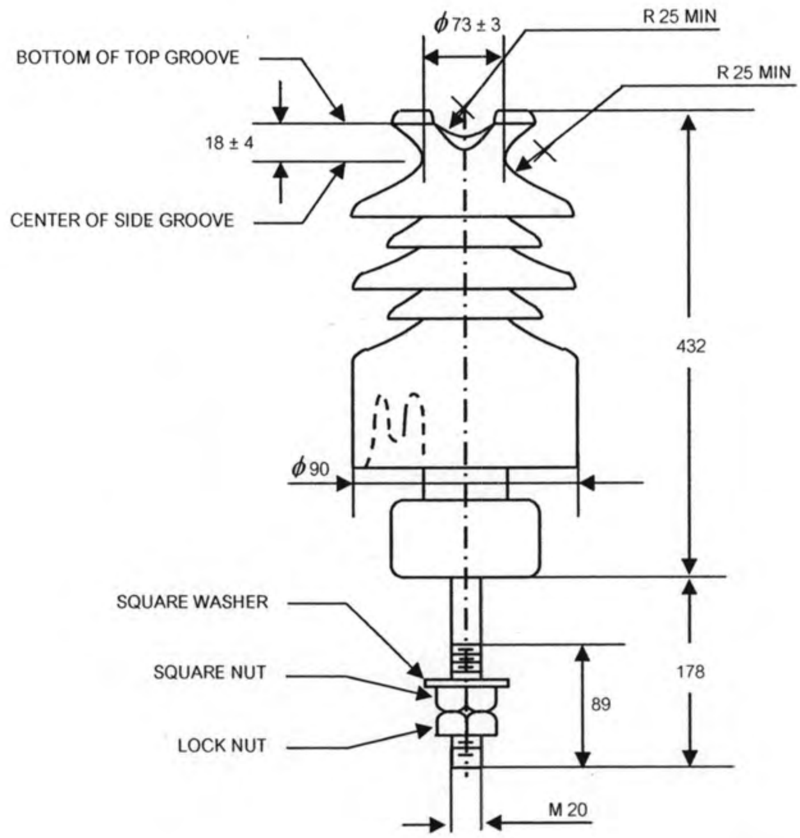
Dimensions	Rating
Leakage distance, mm	1015
Dry-arcing distance, mm	368
Mechanical Values	
Cantilever strength, kN	12.5
Cantilever proof load, kN	5
Electrical Values	
Low frequency dry flashover, kV	150
Low frequency wet flashover, kV	125
Critical impulse flashover, positive, kV	255
Critical impulse flashover, negative, kV	340
Radio Interference Voltage Data	
Low frequency test voltage, rms to ground kV	44
Maximum RIV at 1000 kHz, microvolt	200

Figure 3.11 Pin-post insulator class 56/57-2



Dimensions		Rating
Leakage distance, mm	1015	
Dry-arcing distance, mm	368	
Mechanical Values		
Cantilever strength, kN	12.5	
Cantilever proof load, kN	5	
Electrical Values		
Low frequency dry flashover, kV		150
Low frequency wet flashover, kV		125
Critical impulse flashover, positive, kV	255	
Critical impulse flashover, negative, kV	340	
Radio Interference Voltage Data		
Low frequency test voltage, rms to ground kV	44	
Maximum RIV at 1000 kHz, microvolt	200	

Figure 3.12 Pin-post insulator class 56/57-3



Dimensions	Rating
Leakage distance, mm	1015
Dry-arcing distance, mm	368
Mechanical Values	
Cantilever strength, kN	12.5
Cantilever proof load, kN	5
Electrical Values	
Low frequency dry flashover, kV	150
Low frequency wet flashover, kV	125
Critical impulse flashover, positive, kV	255
Critical impulse flashover, negative, kV	340
Radio Interference Voltage Data	
Low frequency test voltage, rms to ground kV	44
Maximum RIV at 1000 kHz, microvolt	200

Figure 3.13 Pin-post insulator class 56/57-4

3.4 Standard mounting arrangement of post insulator[15]

The post insulator shall be mounted vertically upright on a horizontal earthed metal support consisting of U-channel section with the flange pointing downward. This metal support shall have a width about equal to the diameter of the mounting surface of the post insulator under test and a length at least equal to twice the high of the post insulator, and shall be placed at least 1m above ground for post insulators not higher than 1.8m. For higher post insulators, distance above ground shall be a least 2.50m.
A cylindrical conductor, maintained in the horizontal plane, and perpendicular to the earthed support, shall be attached to the top of the post insulator. The length of the conductor shall be at least equal to 1.5 times the height of the post insulator and it shall extend at least 1m on each side of the post insulator axis. The diameter of the conductor shall be approximately 1.5% of the height of the post insulator, with a minimum of 25mm.
The test voltage shall be applied between the conductor and the earthed support, the high voltage connection being made at one end of the conductor.
During the test, no object other than those described in this clause shall be nearer to the top of the post insulator than 1m or 1.5 times the height of the post insulator, whichever is the greater.

3.5 Least squares line regression

The purpose of least squares linear regression is to present the relationship between one or more independent variable $x_1, x_2, ...$ and a variable y that is depend upon them in the following form:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \varepsilon \tag{3.2}$$

Where

x_j the jth independent variable

y the dependent variable

ε the error term or residual

β_j the regression slope for the variable x_j and β_0 the y - axis intercept

Sample least square linear regression assumes that there is only one independent variable x and equation (3.2) reduces to:

$$y = mx + c + \varepsilon \tag{3.3}$$

Where m is the slope of the line and c is the y-axis intercept. Simple least square linear regression makes four important assumptions.

1. Individual y values are independent.
2. For each value of x, x_i, there are an infinite number of possible values of y, which are normally distributed.
3. The distribution of y given a value of x has equal standard deviation for all x-values and is centered about the least square regression line.
4. The mean distribution of y at each x-value can be connected by a straight line $y = mx + c$.

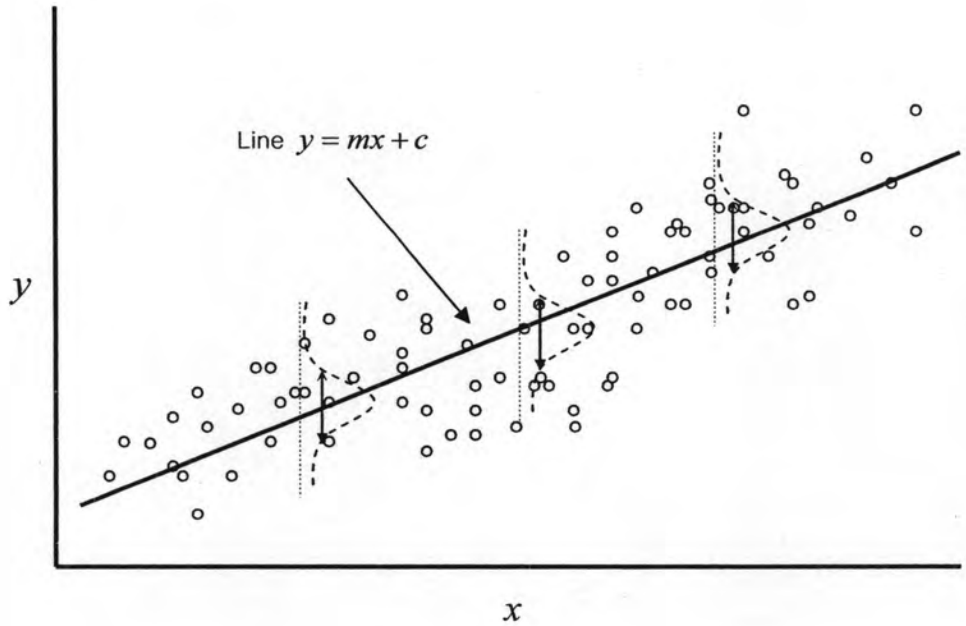


Figure 3.14 An illustration of the concepts of least squares regression

These concept are shown in figure 3.14 there is an infinite number of straight line that could be drawn through any set of data points. The simple least squares regression model determines the straight line that minimizes the sum of the square of the ε_i error for a set of observation $\{x_i, y_i\}$. It can be shown that this occurs when

$$m = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sum_{i=1}^{n}(x_i - \overline{x})^2} \tag{3.4}$$

$$c = \overline{y} - m\overline{x} \tag{3.5}$$

Where $\overline{x}, \overline{y}$ are the mean of the observed x and y data and n is the number of data pairs (x_i, y_i).

For least square regression, the fraction of the total variation in the dependent variable that is explained by the independent variable is known as the coefficient of determination R^2, which is calculated as

$$R^2 = 1 - \frac{SSE}{TSS} \tag{3.6}$$

Where SSE, the sum of square errors, is given by

$$SSE = \sum_{i=1}^{n}(y_i - \hat{y}_i)^2 \tag{3.7}$$

and TSS, the total sum squares, is given by

$$TSS = \sum_{i=1}^{n}(y_i - \hat{y}_i)^2 \tag{3.8}$$

and where $\hat{y}_i$ are the predicted y-values at each x_i:

$$\hat{y}_i = mx_i + c \tag{3.9}$$

For simple least squares regression (i.e. only one independent variable), R^2 is equivalent to the simple correlation coefficient r^2

$$R^2 = r^2 \tag{3.10}$$

r may alternatively be calculated as

$$r = \frac{\left(\sum_{i=1}^{n}(x_i - \bar{x})\right)\left(\sum_{i=1}^{n}(y_i - \bar{y})\right)}{\sqrt{\left(\sum_{i=1}^{n}(x_i - \bar{x})^2\right)\left(\sum_{i=1}^{n}(y_i - \bar{y})^2\right)}} \tag{3.11}$$

r provide a quantitative measure of the linear relationship between x and y. It ranges from -1 to $+1$: a value of $r = -1$ indicates a perfect linear fit, and $r = 0$ indicates no linear relationship exists at all. As $\sum_{i=1}^{n}(y_i - \hat{y})^2$, the sum of square errors between the observed and predicted $y-$values, tend to zero, so r^2 tends to 1 and therefore r tends to -1 or $+1$, its sign depending on whether m is negative or positive respectively.