Rajdhani DATE / / 1

Design of EHV-AC lines

Introduction :

Two important governing factors stressed for design of EHV-AC lines are,

i) steady state operating limits
ii) Insulation design based upon transient overvoltages.

Other problems usually associated with transmission lines are,

(a) transient and dynamic stability
(b) Short-circuit currents and voltages.

These depend on the characteristics of the connected generating stations & system inter-connection. High voltage insulation problems can be generalized in sequential steps when the system transient studies are conducted & the air gap insulation characteristics are understood to offer a proper level of safe operation which is determined on a probability basis of allowing a certain level of line outages. But the steady state compensation requirements depend upon the power transmitted & line length.

Design factors under steady state :

All designs can be considered as synthesis of analytical procedures that are available and an enumeration of the limits & constraints under which line designs have to be carried out. The steady-state considerations are the following:

i) Maximum allowable bus voltages for a given voltage level:

The limits for max. operating voltages are as follows :

Nominal system (KV)	220	345	400	500	750
Max. voltage (KV)	245	362	420	525	765

ii) Current density in conductors which determine the cross-sectional area, resulting temp. rise etc.

Current density normally encountered lies between $0.75\ A/mm^2$ to $1\ A/mm^2$.

iii) Bundling of conductors :

Bundling, corona inception gradient & energy for these factors are important for fixing the conductor diameter & no. of conductors in the bundle. Charge of conductors (bundled) governs the electrostatic field in line vicinity, the surface voltage gradient on conductors & the resulting radio interference, audible noise & corona loss.

iv) Electrostatic field under the line at 50Hz.

v) Corona loss

Annual average corona loss amounts only to 10% of I^2R loss, on the assumption of continuous full load carried. With load factors of 60 to 70%, the corona loss will be a slightly higher percentage. During rainy months, the generating station has to supply the heavy corona loss & in some cases it has been the experience that generating stations have been unable to supply full rated load to the transmission line. Thus corona loss is a very serious aspect to be considered in line design.

vi) Audible noise :

When corona is present on the conductors, EHV lines generate audible noise which is especially high during foul weather. Design of line dimensions at EHV levels is now governed more by the need to limit audible noise levels to the following values:

No complaints : less than 52·5 dB
Few complaints : 52·5 dB to 59 dB
Many complaints : Greater than 59 dB

vii) Radio interference : (RI)

Corona on conductors also causes interference to carrier communication & signalling in the frequency range 30 KHz to 500 KHz. It is the responsibility of a designer to keep noise level of RI level from a line below a limiting value at the edge of the right-of-way (R-O-W) of the line corridor.

viii) Compensation requirements for voltage control :

This must be designed to hold the bus voltage within limits given by standard specification.

— Line insulation design based upon transient over-voltages :—

Here we will discuss the important topic of selection of long air gap clearances required between

(a) Conductor to ground &
(b) Conductor to conductor to withstand
i) Switching surges

ii) Power frequency voltage
iii) lightning

The magnitudes of overvoltages & the probability of their occurrence is an individual characteristic of a system so that no fixed designs can be given in this discussion, but only the guiding principles can be illustrated through examples.

The principles upon which insulation levels are selected on,

1) A knowledge of all relevant properties of overvoltages which a system might experience; and

2) A knowledge of insulation characteristics for all types of voltages to which it will be subjected.

I) Discussion of Rod-Plane gap design :

The basis for selection of air gap clearance between any given type of electrode geometry can best be understood by relating it or comparing it with the design of a rod-plane gap, which shows the lowest flashover & withstand voltage of any type of electrode geometry.

We illustrate the procedure by,

(a) Selecting a range of positive switching surge magnitudes from 1.8 p.u. to 3 p.u. on a 400 kV & a 750 kV system;

(b) then using two representative formulae to calculate the required rod-plane gap length d

i) Leroy & Gallet formula

$$d = \frac{8}{\left(\frac{3400}{V_{50}} - 1\right)}$$

where, d = rod-plane gap length in m.
V_{50} = Critical flashover voltage = 50% flashover vtg. in kV, crest.

ii) Paris's formula:

$$d = \left(\frac{V_{50}}{500}\right)^{1.667}$$

2) Conductor – tower, Conductor – ground, and conductor – conductor clearances:

Paris's formula for these cases are used which are as follows:

$$d = \left(\frac{V_{50}}{500}\right)^{1.667}$$

$$\therefore V_{50} = 500 \cdot d^{0.6} \quad \text{--- (1)}$$

Conductor – tower:

$$V_{50} = 1.3 \times V_{50} \text{ for rod-plane}$$
$$= 1.3 \times 500 \times d^{0.6}$$
$$= 650\, d^{0.6} \quad \text{--- (2)}$$

$$\therefore d = \left(\frac{V_{50}}{650}\right)^{1.667} \text{ meters} \quad \text{--- (3)}$$

~~Conductor – ground:~~

for this case, the gap factor is 1.3

Conductor – ground:

Having calculated the required conductor – tower clearance 'd' for the anticipated switching-surge magnitudes, the minimum clearance from conductor to ground will be,

$$H = 4.3 + 1.4\, d \text{ --- meters.} \quad \text{--- (4)}$$

Conductor - conductor or phase-to-phase clearance:

This also described by a 'gap-factor' whose value is 1.8. Thus

$$V_{50} = 900\, d^{0.6} \quad \text{--- (5)}$$

However, in this case, the switching surge is between phases which is not equal to $\sqrt{3}$ x phase to ground magnitude of switching surge. These must be determined by experiments carried out on models ~~on~~ or digital computer calculations.

3) Air-gap clearance for power frequency & lightning:

The equations for the strength of a long rod-plane air gap for power frequency & lightning are as follows:

Power frequency : $V_{50} = 652 \times d^{0.576}$, kV crest — (6)

Lightning : $V_{50} = 500d$, kV, crest. — (7)

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