Advances in UHV Transmission and Distribution
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Lecture – 19
Introduction to Towers and importance of foundations

Good morning. We have discussed about the insulators for the ultra high voltage transmission, subsequent to that we have also discussed about various types of conductors which are used for the transmission; particularly at EHV and UHV levels which are of important the next of the next topic for discussion is the important and most important component being the towers the transmission.

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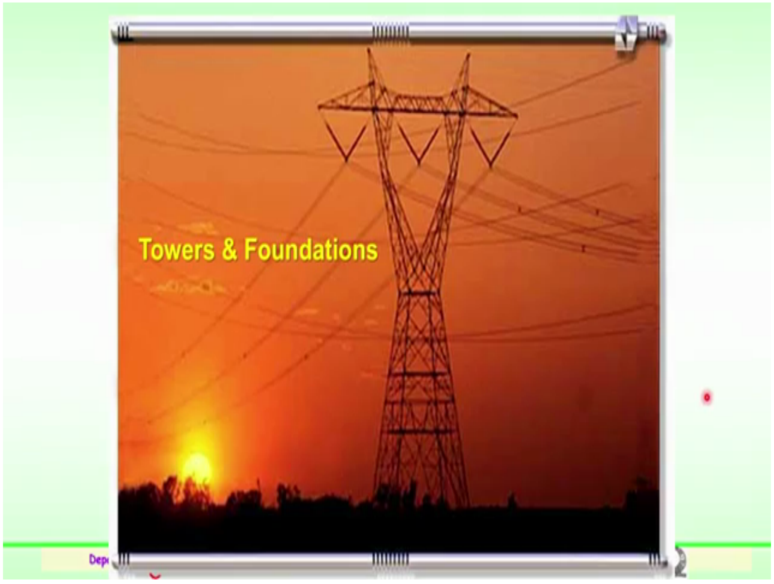

And further we will be looking in to the foundation aspects of the tower to a brief (Refer Time: 00:51) very briefly about various foundations which are being used for the tower depending upon the area or depending upon the configuration of the tower how the foundations have to be carried out.

So, towers are very important for the mechanical strength they have to carry a various insulator configurations the insulator load the conductor load the accessories connected with insulator and the conductors the ground wire or earth wire then it is own weight of the steel structure. So, the tower plays a very important role in the high voltage transmission systems. So, the towers and foundations are very important.

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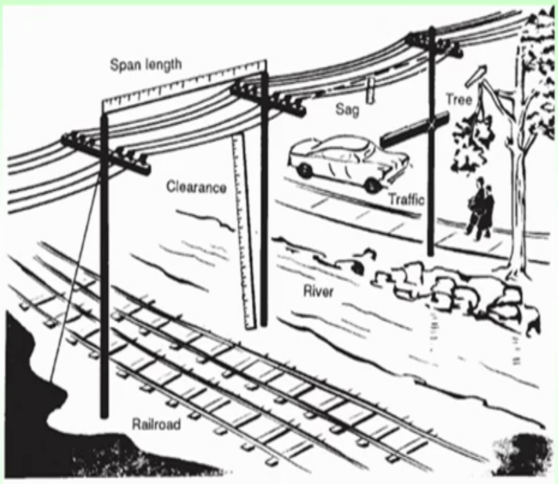

Obstacles to be overcome in designing and constructing an overhead distribution system.

This figure shows the clearances to be adopted in case for the distribution system and also the span is a very important taking into the concentration of the sag the vegetation and various obstacles which could overcome hard to be considered for the proper design and the construction of the overhead transmission or a distribution lines.

So, as per the international and the national standard a various specifications are laid to see that in case of the rail transport or the river or the normal traffic what are the minimum clearances to be maintained apart from the electrical clearances for the tower the span length and the tower height is the very critical while estimating the tower for a particular voltage level. So, this shows the span length span length is from tower to tower distance is known as the span length the minimum clearances from the ground to the conductor is a ground clearance or the clearances which is termed in the electrical aspect.

So, these clearances apart from the electrical clearances a minimum clearances in case of the transportation or the river crossing or the vegetation have to be adhered as per the norms and specification prescribed by the international electricity rules or Indian electricity rules before the towers are being constructed at the different locations.

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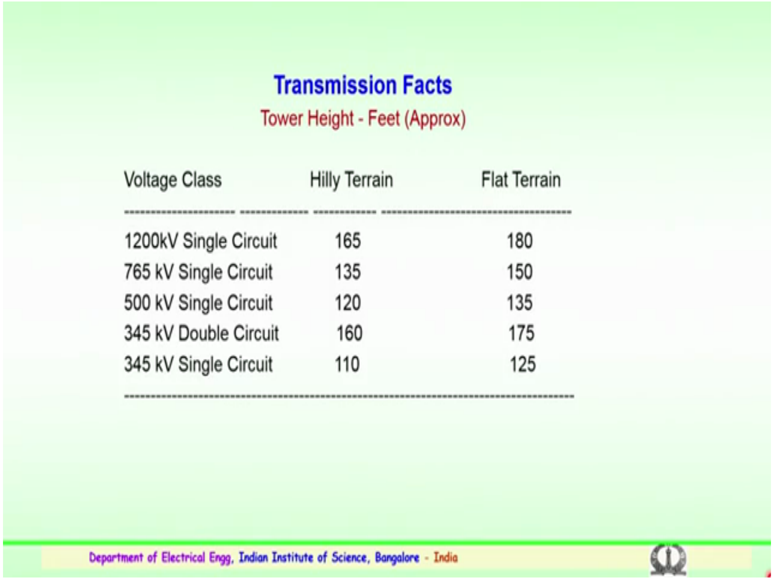
Transmission Facts

Tower Height - Feet (Approx)

Voltage Class	Hilly Terrain	Flat Terrain
1200kV Single Circuit	165	180
765 kV Single Circuit	135	150
500 kV Single Circuit	120	135
345 kV Double Circuit	160	175
345 kV Single Circuit	110	125

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So, some transmission facts this gives the idea of the total height of the tower brief information for a 400-500 and 765 1200 kV towers, you can just see for the various voltage class say for 345 or 400 kilo volts single circuit if it is a double circuit or in case of a 500 kV single circuit or 765 and 800 kV single circuit and 1200 kV single circuit.

Two options are given here one is for the hilly terrain where the land is not planar and the terrain is of uneven in nature in such cases and for a flat terrain. So, what are the clearances minimum ground clearances to be adopted say for 400 kV or 345 kV single or single circuit the height is 125 feet; 125 is a approximately 40 meters from the ground level has to be maintained in case of a flat terrain where as for a hilly terrain it is 110 feet. So, 110 feet is approximately 32 or 33 meters from the ground level. Similarly if it is a double circuit the clearance is 175 feet and 160 in case of the hilly terrain and for a 500 kV single circuit lines it is 135 in case of flat and 120 feet that is around 40 meters from the ground in case of a 500 kV.

So, verse subsequently for higher the voltage is ultrahigh voltage ranges you can see for 765 or 800 kV single circuit towers the minimum height required in case of a hilly terrain is 135 feet approximately 40 meters from the ground level and if it is a flat, it is slightly higher it is 150 feet. So, around 50 meters from the ground level. So, similarly for 1200 kV single circuit the clearances required in case of hilly terrain is 165 feet and in case of a flat terrain it is 160-180 feet.

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Reference heights

Item	Description	Reference height (feet)
1.0	Track rails	22.0
2.0	Roads, streets, alleys, etc	14.0
3.0	Residential driveways	14.0
4.0	Other lands traversed by vehicles	14.0
5.0	Spaces and ways--pedestrians only	8.0/10.0
6.0	Water areas--no sail boating	12.5
7.0	Water areas—sail boating	
	Less than 20 acres	16.0
	20 to 200 acres	30.0
	200 to 2000 acres	30.0
	Over 2000 acres	36.0
8.0	Areas posted for rigging or launching sailboats	See item 7.0

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So, what are the minimum clearances as mentioned in the previous slide example what are the minimum clearances to be left to be considered apart from the electrical clearances in case of the railway traction or railway zone where the transmission or a distribution conductors are passing near the railway junctions or railway tracks the minimum clearances to be added for the passenger the trains or in case if it is a river or in case of a normal traffic or because of vegetation the following clearances have to be maintained. So, this gives the reference height particularly in feet to be considered for the distribution lines in addition to the electrical clearances.

So, in case if the rail tracks you have to have a 20 2 feet minimum consideration for the area then in case of normal road or the streets fourteen feet then residential driveways it may be a vehicle or traffic movement a fourteen feet is to be considered similarly if it is only pedestrian 8 to 10 feet is normally considered apart from the electrical clearances. So, the places where the water bodies are available and the distribution lines pass on this water bodies in such cases depending upon the activity like the steam boat or the boating activity the clearances have to be maintained anywhere between 12.5 feet minimum.

So, again the activity in agricultural areas if the activity is around a 20 acres of land then the clearances have to be around 16 feet if it is more than a 20 acres the clearances adopted is 30 to 36 feet. So, these are all the reference details height details given as per the international or the national standards which are to be adhered during the distribution tower construction. So, that necessary clearance has to be maintained where the electrical accidents do not occur.

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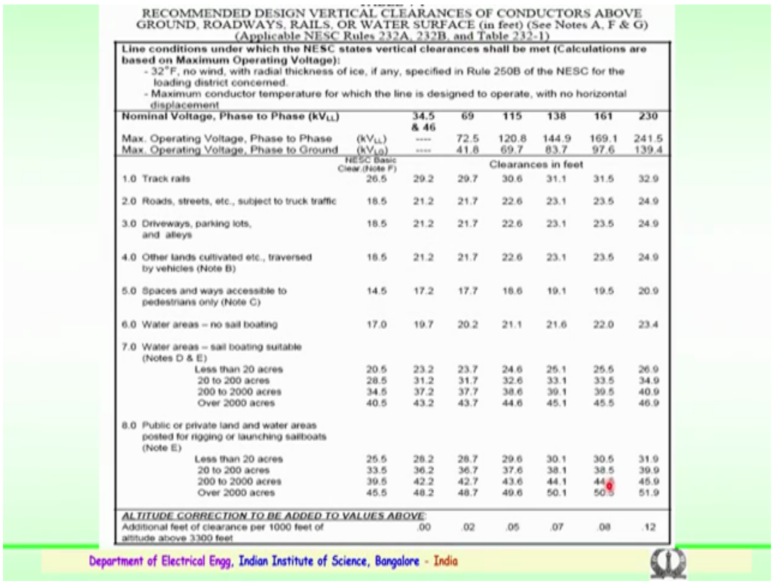
RECOMMENDED DESIGN VERTICAL CLEARANCES OF CONDUCTORS ABOVE GROUND, ROADWAYS, RAILS, OR WATER SURFACE (in feet) (See Notes A, F & G)
(Applicable NESC Rules 232A, 232B, and Table 232-1)

Line conditions under which the NESC states vertical clearances shall be met (Calculations are based on Maximum Operating Voltage):
- 32°F, no wind, with radial thickness of ice, if any, specified in Rule 250B of the NESC for the loading district concerned.
- Maximum conductor temperature for which the line is designed to operate, with no horizontal displacement

Nominal Voltage, Phase to Phase (kV_{LL})		**34.5 & 46**	**69**	**115**	**138**	**161**	**230**
Max. Operating Voltage, Phase to Phase	(kV_{LL})	----	72.5	120.8	144.9	169.1	241.5
Max. Operating Voltage, Phase to Ground	(kV_{LG})	----	41.8	69.7	83.7	97.6	139.4
	NESC Basic Clear.(Note F)	Clearances in feet					
1.0 Track rails	26.5	29.2	29.7	30.6	31.1	31.5	32.9
2.0 Roads, streets, etc., subject to truck traffic	18.5	21.2	21.7	22.6	23.1	23.5	24.9
3.0 Driveways, parking lots, and alleys	18.5	21.2	21.7	22.6	23.1	23.5	24.9
4.0 Other lands cultivated etc., traversed by vehicles (Note B)	18.5	21.2	21.7	22.6	23.1	23.5	24.9
5.0 Spaces and ways accessible to pedestrians only (Note C)	14.5	17.2	17.7	18.6	19.1	19.5	20.9
6.0 Water areas – no sail boating	17.0	19.7	20.2	21.1	21.6	22.0	23.4
7.0 Water areas – sail boating suitable (Notes D & E)							
Less than 20 acres	20.5	23.2	23.7	24.6	25.1	25.5	26.9
20 to 200 acres	28.5	31.2	31.7	32.6	33.1	33.5	34.9
200 to 2000 acres	34.5	37.2	37.7	38.6	39.1	39.5	40.9
Over 2000 acres	40.5	43.2	43.7	44.6	45.1	45.5	46.9
8.0 Public or private land and water areas posted for rigging or launching sailboats (Note E)							
Less than 20 acres	25.5	28.2	28.7	29.6	30.1	30.5	31.9
20 to 200 acres	33.5	36.2	36.7	37.6	38.1	38.5	39.9
200 to 2000 acres	39.5	42.2	42.7	43.6	44.1	44.5	45.9
Over 2000 acres	45.5	48.2	48.7	49.6	50.1	50.5	51.9
ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE:							
Additional feet of clearance per 1000 feet of altitude above 3300 feet		.00	.02	.05	.07	.08	.12

So, these are the some recommended vertical distances or a clearances of the conductors which are above the ground a road ways railways or water surface places where these have to be adhered. So, in such cases the international rules very clearly specify the for various voltage levels the clearances have to be adopted in case of railway tracks roads or driveways a parking lots or the agriculture activity where the land is being cultivated or the spaces for the pedestrians and water bodies and also the public or private land where the activity like the sail boats or so on are being employed.

So, these vertical clearances are given depending upon the voltage level up to 46 kilo volts these are the clearances for the 66 kV systems these are the minimum clearances which have to be maintained apart from the electrical clearances to be added to these number; so for 232 kV 160 and 230 and so on. The clearances are clearly specified where the national electrical code or the Indian electricity rules where ever the towers are being erected either distribution or the transmission this clearances have to be added for the a proper clearances and no accidents could occur in case if the rules are adhere to.

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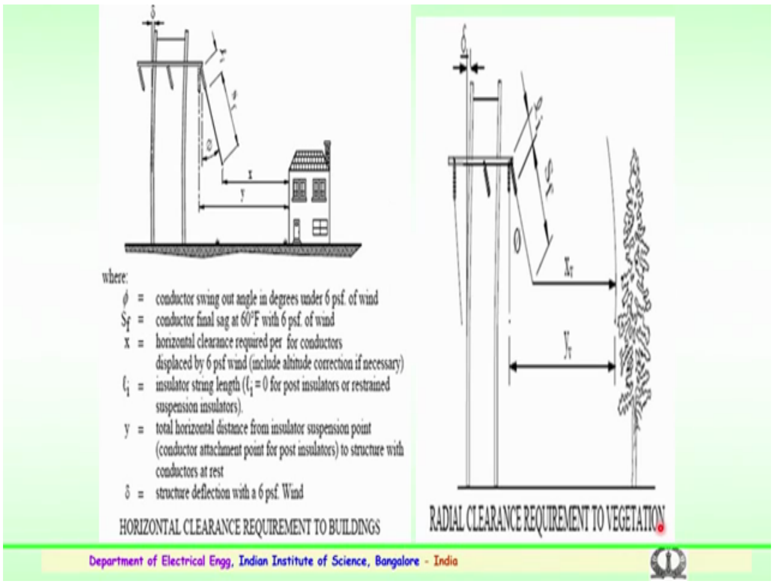

So, how are the horizontal clearances in case of a domestic buildings very important aspect, but how it is to be added in case there is a building; consider a building. So, how closed could the distribution tower or a transmission tower could be there near the domestic construction or if the already the domestic towers or the distribution towers or the high voltage towers are existing. So, how far should the house being constructed. So, this gives an idea this is again as per the international or Indian rules where the minimum clearances have to be maintained you can very clearly see these are the distribution tower this shows the insulator string there will be a swing during the wind or during the vibrations or activity of heavy winds.

So, this angle of the swing is known as the phi. So, this phi the movement of the horizontal insulator that is our suspension insulator to a tilt angle phi the distance is here. So, this distance minimum should be clearance is x. So, x is the minimum horizontal clearance required per for any conductors which are displaced by 6 pound per square feet is the wind. So, the wind blows the minimum clearances have to be maintained is x x corresponds to 6 pounds per square feet it just include altitude corrections in some cases similarly y y is the actual distance of the insulator string to the constructed a house or the residential apartment where this shows the horizontal or a total horizontal distance from the insulator that is a suspension insulator to the structure.

So, this is very important the swing angle has to be considered for a particular area again the phi is being the conductor swing angle in degrees under 6 pound were square feet of the wind S f, S f is this distance which is the conductor final sag at 60 degrees with the same wind pressure and x is horizontal and l I; l I is this distance is the insulator string length l I is 0 for post insulator because if we use a single rod insulator this could be considered as a 0 or restrained some for equivalent to suspension insulators. So, y y is the horizontal you can see this y; y is the total horizontal distance from the insulator suspension point.

Then delta is the small shift here you can see the delta s small shift in the structure deflection this happens because of the heavy winds or because of the movement of the conductors and the insulator string. So, a deviation in the structure could take place by a small angle delta. So, the delta is a structure deflection angle with reference to 6 pound per square feet wind. So, these are the minimum horizontal clearances requirement to be made for buildings or the apartments which are constructed near by the distribution or the transmission towers. So, these distances are clearly given in the international and the Indian electricity rules.

So, the activity should not be the distances should not be reduced for a particular voltage level. So, similarly in case of vegetation or a forest area where the distribution or the transmission lines are passing a similar clearances have to be maintained and this shows how the radial clearances required for the vegetation again a similar total horizontal distance have to be maintained in case of swing what is a minimum horizontal clearances required for the conductors which are displaced at that particular wind speed. So, a similar arrangement for the vegetation also exists along with the small angle delta tilt angle or a shift angle of the entire structure deviation which happens because of the wind flow.

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So, this have to be considered for the proper functioning of the transmission system the clearances have to be maintained. So, we have discussed this aspects must several of the countries including our country, we see several transmission and distribution lines are crossing the domestic and the commercial buildings. So, here care has to be taken not only by the utilities the public at large have to see and follow the rules which are laid by the electricity authorities and the distribution companies where a minimum clearances or the right of way which we term it we will be discussing about that aspect.

So, the right of way is the minimum clearances from the mid portion of the tower to the either side have to be maintained and this right of way is very clearly specified for a various voltage levels to be added else there could be a electrical accidents because of the conductors coming in contact with our residential buildings or the apartments. So, strictly the utility is public have to be adhered to the rules of the minimum clearances has stipulated by the Indian electricity authorities, Indian utilities or the distribution companies who are supplying the electrical power.

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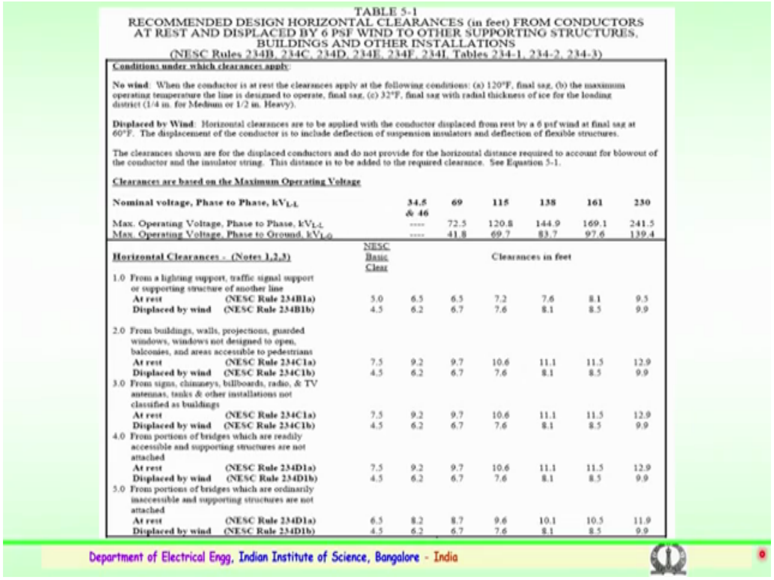

TABLE 5-1
RECOMMENDED DESIGN HORIZONTAL CLEARANCES (in feet) FROM CONDUCTORS AT REST AND DISPLACED BY 6 PSF WIND TO OTHER SUPPORTING STRUCTURES, BUILDINGS AND OTHER INSTALLATIONS
(NESC Rules 234B, 234C, 234D, 234E, 234F, 234I, Tables 234-1, 234-2, 234-3)

Conditions under which clearances apply:

No wind: When the conductor is at rest the clearances apply at the following conditions: (a) 120°F, final sag, (b) the maximum operating temperature the line is designed to operate, final sag, (c) 32°F, final sag with radial thickness of ice for the loading district (1/4 in. for Medium or 1/2 in. Heavy).

Displaced by Wind: Horizontal clearances are to be applied with the conductor displaced from rest by a 6 psf wind at final sag at 60°F. The displacement of the conductor is to include deflection of suspension insulators and deflection of flexible structures.

The clearances shown are for the displaced conductors and do not provide for the horizontal distance required to account for blowout of the conductor and the insulator string. This distance is to be added to the required clearance. See Equation 5-1.

Clearances are based on the Maximum Operating Voltage

		NESC Basic Clear						
Nominal voltage, Phase to Phase, kV_{L-L}			**34.5 & 46**	**69**	**115**	**138**	**161**	**230**
Max. Operating Voltage, Phase to Phase, kV_{L-L}			----	72.5	120.8	144.9	169.1	241.5
Max. Operating Voltage, Phase to Ground, kV_{L-G}			----	41.8	69.7	83.7	97.6	139.4
Horizontal Clearances - (Notes 1,2,3)			Clearances in feet					
1.0 From a lighting support, traffic signal support or supporting structure of another line								
At rest	**(NESC Rule 234B1a)**	5.0	6.5	6.5	7.2	7.6	8.1	9.5
Displaced by wind	**(NESC Rule 234B1b)**	4.5	6.2	6.7	7.6	8.1	8.5	9.9
2.0 From buildings, walls, projections, guarded windows, windows not designed to open, balconies, and areas accessible to pedestrians								
At rest	**(NESC Rule 234C1a)**	7.5	9.2	9.7	10.6	11.1	11.5	12.9
Displaced by wind	**(NESC Rule 234C1b)**	4.5	6.2	6.7	7.6	8.1	8.5	9.9
3.0 From signs, chimneys, billboards, radio, & TV antennas, tanks & other installations not classified as buildings								
At rest	**(NESC Rule 234C1a)**	7.5	9.2	9.7	10.6	11.1	11.5	12.9
Displaced by wind	**(NESC Rule 234C1b)**	4.5	6.2	6.7	7.6	8.1	8.5	9.9
4.0 From portions of bridges which are readily accessible and supporting structures are not attached								
At rest	**(NESC Rule 234D1a)**	7.5	9.2	9.7	10.6	11.1	11.5	12.9
Displaced by wind	**(NESC Rule 234D1b)**	4.5	6.2	6.7	7.6	8.1	8.5	9.9
5.0 From portions of bridges which are ordinarily inaccessible and supporting structures are not attached								
At rest	**(NESC Rule 234D1a)**	6.5	8.2	8.7	9.6	10.1	10.5	11.9
Displaced by wind	**(NESC Rule 234D1b)**	4.5	6.2	6.7	7.6	8.1	8.5	9.9

So, what are the minimum clearances this again gives the entire data for the various voltage levels recommended design horizontal clearances from the conductors. So, the minimum clearances from the conductors at rest and displaced by with reference to 6 pound for the square feet wind pressure to other supporting structure buildings other than insulations. So, these are again as per national electrical standards and code which are adhere to be followed. So, this data is been given for various voltage levels starting from 33 kV to 220 and further higher the voltages.

So, this data is available in the electricity authority websites and also the central electricity authority of the government of India website where you have to adhere at the minimum clearances is necessitated and has been maintained by the government or by the electrical authority or utilities of that respective area.

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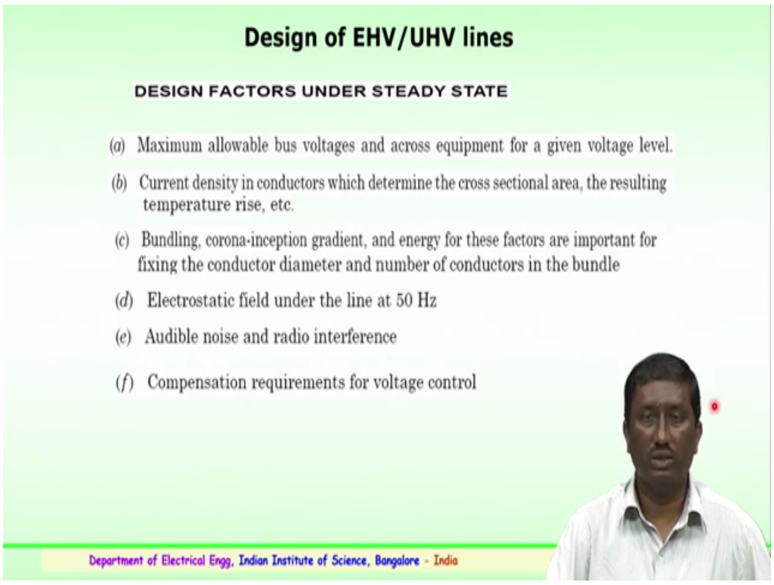

So, we from the distribution we will move to the extra high voltage or ultra high voltage transmission towers how to consider the design factors particularly under a steady state.

So, what are the parameters to be looked in to? So, the maximum allowable that is the bus voltage bus voltage could be any voltage of transmission could be 220, 400, 765 or 800 kilo volts. So, the minimum maximum allowable bus voltage is a important factor to be considered here and across the equipment for a given a voltage level. So, any specified voltage level for the equipment which is being used at that level has to be considered the second point is the current density in the conductors. So, what is the current carrying capability the dimension of the conductor the diameter of the conductor and what is the conductor which how much is a current density in that which determine the cross sectional area.

So, this again depends on the resulting temperature rise or etcetera. So, this is very important further bundling what type of a bundling has been done is a twin or quadruple or hexagonal or octagonal a type of bundling and particularly per phase have to be considered then corona inception gradient again this depends on the size of the conductor the surface conditions of the conductor and the energy for these factors are important for fixing the conductor diameter and the number of conductors to be put in the bundle. So, all these are very important; what is the voltage level and how many bundling have to be carried down what is the corona inception and gradient. So, this helps in fixing the current conductor diameters and number of conductors whether to go in for twin bundle going for a quadruple bundle or going for a hexagonal or octagonal depending upon the voltage level to be transmitted.

Next will be the electrostatic field under the line at the power frequency operating conditions. So, the minimum clearances or the minimum electrostatic field which is specified has to be considered for the design aspects then further audible noise and the radio interferences these add audible noise and the radio interferences are again crossed, because of the hardware the corona or radio interferences are normally crossed by the hardware the conductors the insulator the hardware corona control rings.

So, many of this metal parts in case if they are of not in a smooth condition could create a noise and this noise further travels in the conductors and will be a disturbance to the radio circuits. So, that is the reason where the minimum noise generated by the samples have to be mandatory as per the 400 or 765 kV levels and typically a 55 or 56 decibel noise is the allow for the transmission system for radio interference of 400 kilo volts and above thousand micro volts or a 56 d b is the tolerable limits and it should not increase more than sixty d b that is thousand micro volts is very very important.

So, these conditions have to be considered for the design the conductors or the hardware which are being used for the towers. So finally, the compensation requirement for the voltage control is again a factor under steady state which is to be considered for design of the extra high voltage or the ultra high voltage transmission lines for the tower configurations.

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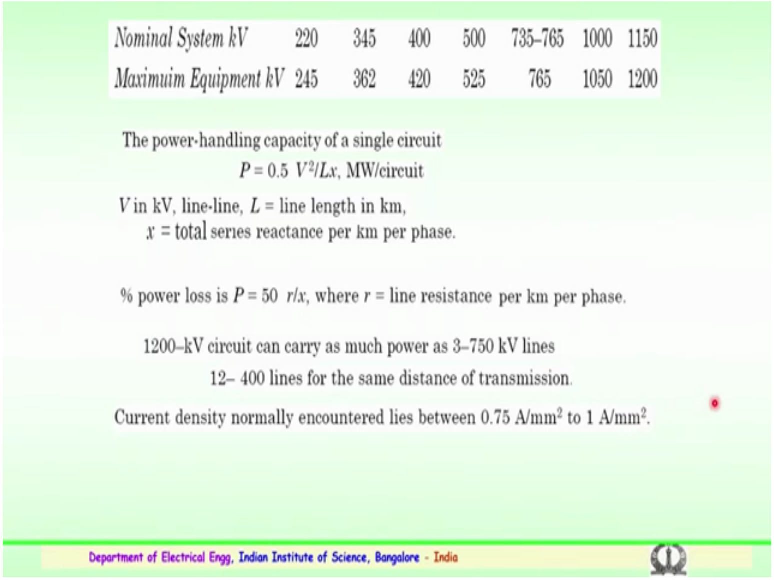

So, this again I repeat the table which is shown which gives a important information about the nominal system voltages and the maximum system voltages where the equipment is designed the insulation aspect is considered and design. So, for 220 kV typically 245 is the maximum operating voltage of that equipment or the insulating system similarly for 345 it is 360 and 400 it is 420. So, in India we followed 220 and 400 kV transmission then further 765 and 1200 is in experimental stage.

So, this gives the idea what is a normal operating or a nominal operating system voltage and the maximum voltage where the equipment has to be designed for that voltage level. So, how the power handling capability with the reference to a single circuit; an example is considered here so, the power handling capability of a single circuit; that is one tower consisting of 3 conductors r y be phase in a single tower the power handling capability is given by the in empirical formula which is given here p is equal to 0.5 V square by l x this is in terms of a megawatt per circuit when if it is a single circuit it will be megawatt per circuit where V is in kilo volts l is the line length in kilometers and x being the total series reactance per kilometer per phase.

So, very important this is the simplest formula where you can estimate the power handling capability either for a single or a double or again there is a changes in case if it is a double circuit this formula is for a single circuit power handling capability. So, here the percentage power loss the total percentage of power loss p is defined as 50 r by x. So, where r is a line resistance per kilometer per phase, if you consider 1200 kV circuit can carry as much as power usually for a 765 line. So, going in for the higher the transmission voltage earlier also we have got discussed how much beneficial is going in for 765 to 1200.

So, you can see the transmission could be improved 3 times using a 1200 kV of the 765 kV lines and it will be 12 times of the 400 lines of the same distance of transmission. So, that is the advantage of going in for the higher the voltage the power transmitted will be very very high. So, the current density normally encountered lies between anywhere between 0.75 amperes per millimeter square to 1 ampere per millimeter square these are some of the information to be known as for the power handling and the power loss component of the transmission system.

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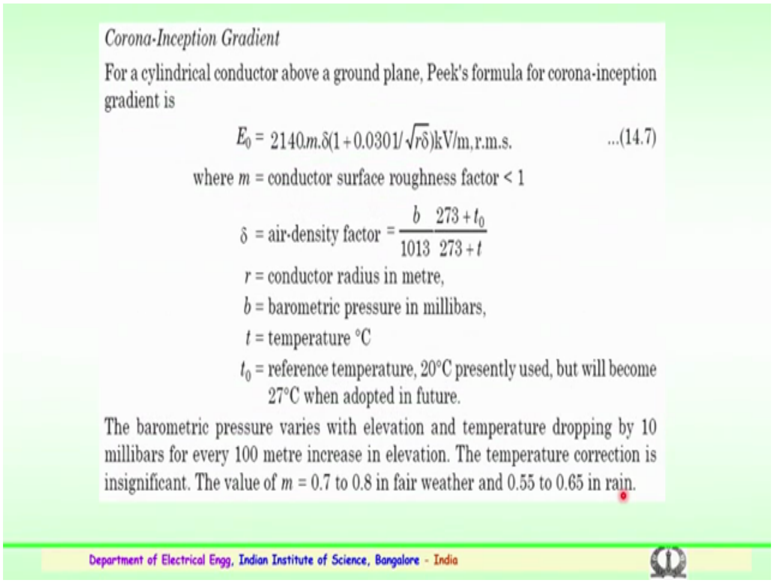

So, how the corona inception gradient that is a corona inception or there are 2 factors here corona inception from the conductors which could be depending upon the diameter of the conductor. So, here there is a standard peeks formula well known formula for the calculation of the estimation of the corona inception gradient which is given as 2140 into m into delta the whole into 1 plus 0.031 divided by square root of r into delta which is in kV per meter the value will be in r m s it is not peek it is in r m s. So, here it is a very clear, very simple formula which gives where m factor is the conductor surface roughness. So, the conductor surface roughness identifies whether the conductor is damaged the conductor has projections or the conductor smooth. So, the surface roughness factor should be less than 1.

So, usually 0.9 or the 0.6 is considered for the normal case 0.9 for wet conditions or the surface rain conditions roughness is considered delta is the air density factor again air density factor is given by b multiplied by 273 plus t 0 divided by 1013; 273 plus t where very clearly it is defined r being the conductor radius in meters b is the pressure in millibars t being the temperature and degree centigrade and t naught being the reference temperature. So, usually standard the temperature as per the standard temperature and pressure conditions 20 degrees is being used as a reference at temperature this is again plan to be considered in the revised standards a 27 may be in future in case of this value is adopted the reference temperature could be 27 presently as per the standards it is 20 degree centigrade which is taken as a reference temperature.

So, the barometric pressure varies again with elevation and the temperature drops by 10 millibars for every 100 meters this is approximately increase in the elevation. So, the temperature correction is insignificant it depending upon the area to the value of m whatever the conductor surface roughness which I was mentioning here should be less than one is generally chosen the value of m is chosen to be 0.7 to 0.8 in case of thin weather condition that is a fair weather what we call normal condition no rain no fog dry conditions and it is assumed to be 0.55 to 0.65 in case of fog rain or in the foul weather conditions. So, these are the calculations how to be used or the formulae which is used for the calculations of corona inception for the conductors which are being used for the other transmission lines.

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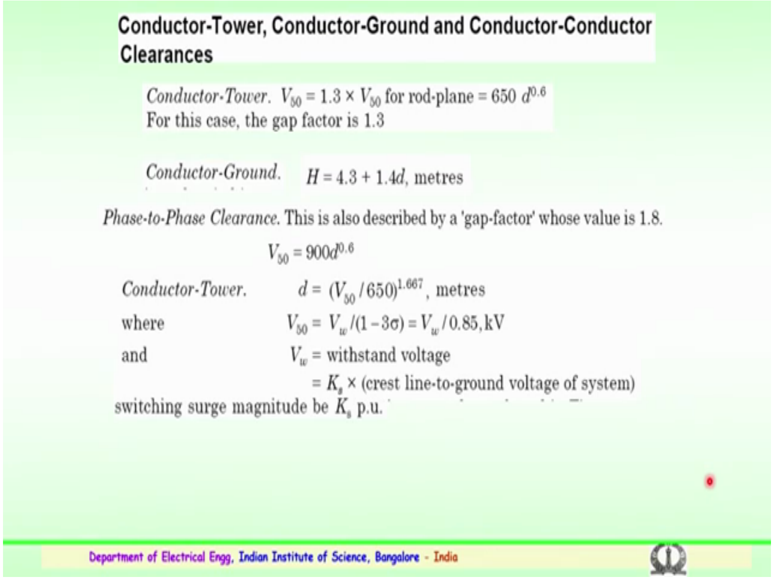

So, how the clearances are important now the conductor to tower a conductor to ground then conductor to conductor clearances are very important in the tower any tower configuration. So, these play a role for a various aspects and these clearances have to be considered not only for the electrical clearances apart from electrical clearances we have to look into the surges which earlier discussed like the lightning surges or the switching surges and the power frequency over voltage and the environmental conditions. So, the clearances are very important. So, while estimating the clearances for the conductor from the insulator string it is a conductors to the tower clearances conductor to ground and conductor to conductor are very very important and at most consideration have to be done on proper calculations have to be carried out.

So, conductor to tower how it is done it is its given by simple formula where V 50 is equal to 1.3 in to V 50 for rod plane type of arrangement which is equivalent to 650 where d to the power of 0.6 for this case the gap factor is now generally assumed to be 1.3 and for conductor to conductor h is equivalent to 4.3 plus 1.4 d being in a distance in meters.

For phase to phase clearances this is also described by a gap factor phase to phase what you call one conductor to the other conductor phase conductors 3 conductors in a single circuit or 6 conductors in a double circuit so on.

So, the conductor to conductor or the phase to phase clearances is also sometimes described as a gap factor whose value is 1.8. So, V 50 is 900 d to the power of 0.6. So, conductor to tower what is the clearances this is given d is equal to V 50 by 650 to the power of 1.6767 meters where V 50 is equal to V w by 1 minus 3 sigma which is equal to V w by 0.85 kV and V w is equal to withstand voltage. So, withstand voltage of that gap or clearance is V w which is further equal to V w is equal to k s into crest is peak line to ground voltage of the system.

So finally, the switching surge magnitude be whatever the factors k s per unit. So, this has to be clearly understood for the clearances well while estimating for various voltage levels and various tower configurations.

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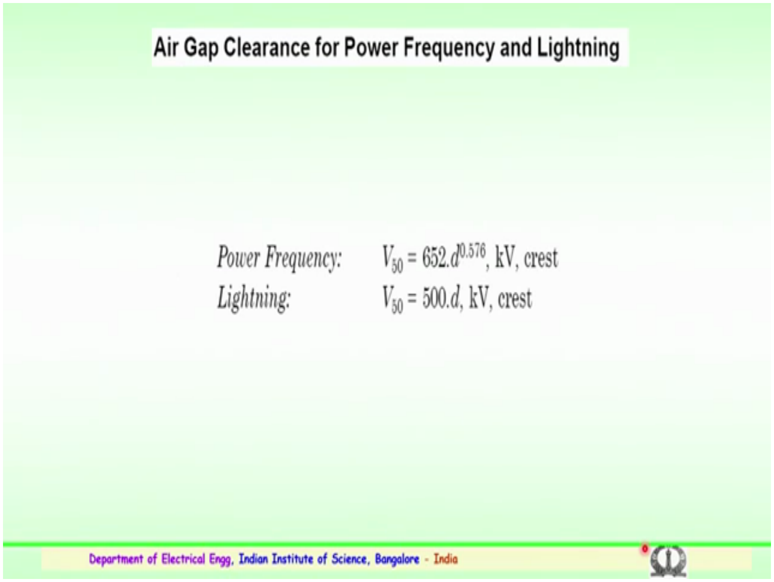

So, what is the air gap which is required to be maintained that was for the switching surges which we looked here this formulae or for the switching surges for case of power frequency and lightning aspects. So, the minimum clearances have to be adhered is for the power frequency V 50 652; 0.652 into d to the power of 0.576 kV crest, crest is the peak and for lightning it is V 50 is equal to 500 d kilo volts peek.

So, these are the important prescribed formula while estimating the air gap clearances for the power frequency a lighting or the switching related surges for various tower configurations.