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Performance Analysis of Overhead Transmission Line Design

Aye Aye Maw
Department of Electrical Power Engineering
Technological University (Mawlamyine)
Mawlamyine, Myanmar

Abstract: An overhead transmission line may be used to transmit or distribute electric power. The purpose of this paper is to transmit optimum power at a given power factor, over a given distance and voltage regulation. The design and analyze of a three phase , 50Hz, 160km long overhead line supplies 150MW at 230kV,0.9 power factor lagging are presented. In the mechanical design includes types of tower, span, ground clearance, tension and sag for different spans with poles at equal height. And also electrical design consists of choice of conductor, percentage voltage regulation and efficiency of transmission line. The system performance can be developed by correcting the power factor shunt capacitor bank.
Keywords: transmission line, mechanical design, electrical design, voltage regulation, transmission efficiency, capacitor bank

1. INTRODUCTION

The purpose of a transmission network is to transfer electric energy from generating unit to various locations to the distribution system which ultimate supplied the load.. Conductor, insulator and support are the main parts of transmission system. Resistance, inductance and capacitance are constants for electrical design of the transmission line.

There are two types of transmission line which are AC transmission line and DC transmission line. The transmission voltages levels are 66kV, 132kV, 230kV and 500kV. The suitable method is to employ three phase three wire AC system for transmission systems.

Power factor correction (PFC) is a technique of counteracting the undesirable effects of electric loads that create a power factor that is less than one. Power factor correction may be applied either by an electrical power transmission utility to improve the stability and efficiency of the transmission. Therefore, shunt capacitors are widely used in power factor correction applications.

2. PERFORMANCE OF POWER TRANSMISSION LINE

The fundamental purpose of the electric utility transmission system is to transmit power from generating units to the distribution system that ultimately supplies the loads. This objective is served by transmission lines that connect the generators into the transmission network, interconnect various areas of the transmission network, interconnect one electric utility with another, or deliver the electrical power from various areas within the transmission network to the distribution substations. Transmission system design is the selection of the necessary lines and equipment which will deliver the required power and quality of service for the lowest overall average cost over the service life. The system must also be capable of expansion with minimum changes to existing facilities.

2.1Classification of Overhead Line

A transmission line has three contents R, L, C distributed uniformly along the whole length of the line. The resistance and inductance form the series impedance. The capacitance existing between the conductors for a single phase line or from a conductor to neutral for a three phase line forms a shunt path throughout the length of the line. Therefore, capacitance effects introduce complications in transmission line calculations. Depending upon the manner in which capacitance is taken into account; the overhead transmission lines are classified as:

(i)Short Transmission Line
(ii)Medium Transmission Line
(iii)Long Transmission Line

2.1.1Short Transmission Line

When the length of an overhead transmission line length is less than 30 miles, or the line voltage is not over < 33 kV, it is usually considered as a short transmission line. Due to smaller length and lower voltage, the shunt capacitance and conductance effects are small and hence can be neglected. Therefore, while studying the performance of a short transmission line, only inductance and resistance of the line are taken to account.

2.1.2Medium Transmission Line

When the length of an overhead transmission line is about 30-80 miles and the line voltage is moderately high (>33 kV and 66 kV), it is considered as a medium transmission line. Due to sufficient length and voltage of the line, the capacitance effects are taken into account. For purpose of calculation, the distributed capacitance of line is divided and lumped in the form of the condensers shunted across the line at one or more points.

2.1.3Long Transmission Line

When the length of an overhead transmission line is more than 80 miles and line voltage is very high (>66 kV), it is considered as a long transmission line. For the treatment of such a line, a line constants are considered uniformly distributed over the whole length of the line.

3. MECHANICAL DESIGN OF TRANSMISSION LINE

The successful operation of an overhead line depends to a great extend upon the mechanical design of the line. While constructing an overhead line, it should be ensured that mechanical strength of the line is such so as to provide against the most probable weather conditions.

3.1 Supports of Transmission Line

The different types of structure (poles or towers) used for supporting the overhead transmission lines or wires, such types are called line supports. The line support plays a major role in power transmission. It kept the proper spacing between the conductors and maintained the conductor at the distance from its ground parts. It also maintained the specified ground clearance. Requirement of the line supports is low cost, low maintenance and long life. The line supports are made of wood,

concrete, steel or aluminum. It is mainly classified into two types;
(i) Electrical Pole
(ii) Electrical Tower

3.2 Overhead Insulators

The overhead line conductors should be supported on the poles or towers in such a way that currents from conductors do not flow to earth through supports i.e. line conductors must be properly insulated from supports. This is achieved by securing line conductors to supports with the help of insulators. The insulators provide necessary insulation between line conductors and supports and thus prevent any leakage current from conductors to earth. The insulators are made of porcelain, glass and polymer. There are mainly types of insulator used as overhead insulator likewise;

(i) Pin Insulators
(ii) Shackle Insulators
(iii) Strain Insulators
(iv) Egg/Stay Insulators
(v) Suspension Disc Insulators

3.3 Sag in Overhead Line

The difference in level between points of supports and the lowest point on the conductor is called sag. There are two different levels.

3.3.1. Supports are at equal levels

Consider a conductor between two equal level supports A and B with O as the lowest point as shown in Figure (1). It can be proved that lowest point will be at the mid-span.

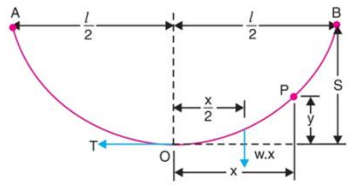

Figure1. Sag at Normal Ground Level two supports

$$\text{Sag (S)} = \frac{Wl^2}{8T} \quad (1)$$

where, W = unit weight of conductor (kg/m)
l = span (m)
T = horizontal tension of conductor (kg)

3.3.2. Supports are at unequal levels

In hilly areas, we generally come across conductors suspended between supports at unequal levels. In Figure (2), shows a conductor suspended between two supports A and B which are at different level. The lowest point on the conductor is O.

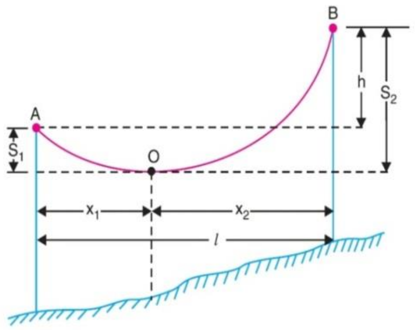

Figure2. Sag at Unbalance Ground Level two supports

If W is the weight per unit length of the conductor, then,

$$\text{Sag,} \quad S_1 = \frac{Wx_1^2}{2T} \quad (2)$$

$$\text{Sag,} \quad S_2 = \frac{Wx_2^2}{2T} \quad (3)$$

Where, l = Span length
h = Difference in levels between two supports
x_1 = Distance of support at lower level A from O
x_2 = Distance of support at higher level B from O

3.4. Effect of Wind Loading

The worst weather conditions expected which will be the case occurred wind pressure, temperature, conductor tension expected when the weather is fine. Cable operation (Stringing work) must be calculated in advance what to do. In the severe weather condition,

Let Temperature $= t_1$
Conductor tension $= T_1$
Actual length of conductor = L

$$L_1 = l + \frac{W_1^2 l^3}{24T_1^2} \quad (4)$$

In the good weather condition,
At starting stringing progress, the temperature and tension will change.

Temperature $= t_2$
Conductor tension $= T_2$
Actual length of conductor = L
And also changing the load on conductor W_2,

$$L_2 = l + \frac{W_2^2 l^3}{24T_2^2} \quad (5)$$

Different between two weather conditions, the length of conductor are Changing.
Solve equation (1) and (2),

$$\Delta L = \frac{W_2^2 l^3}{24T_2^2} - \frac{W_1^2 l^3}{24T_1^2} \quad (6)$$

T_1=max: working Tension
= 3500 kg (35% of UTS = 10000 kg)
W_1=weight of conductor at bad weather
W_2=conductor weight only

Other way, calculating the of changing of conductor length

$$\Delta L_1 = \frac{(T_2 - T_1)l}{EA} \quad (7)$$

Where, E = Young's Modulus of elasticity
A = Sectional area of conductor

And also changing of conductor by $t_1$and t_2, form of temperature coefficient

$$\Delta L_2 = \alpha l\,(t_2 - t_1) \quad (8)$$

Temperature coefficient (coefficient of linear expansion) = α
Equation (7) + (8),

$$\Delta L = \frac{(T_2 - T_1)l}{EA} + \alpha\, l\,(t_2 - t_1) \quad (9)$$

Simplify equation (6) and (9),

$$\frac{W_2^2 l^3}{24T_2^2} - \frac{W_1^2 l^3}{24T_1^2} = \frac{(T_2 - T_1)l}{EA} + \alpha\, l(t_2 - t_1)$$

$$\frac{W_2^2 l^2 E}{24T_2^2} - \frac{W_1^2 l^2 E}{24T_1^2} = \frac{T_2}{A} - \frac{T_1}{A} + \alpha tE$$

$$\frac{W_2^2 l^2 E}{24T_2^2} = \frac{T_2}{A} - \frac{T_1}{A} + \frac{W_1^2 l^2 E}{24T_1^2} + \alpha tE$$

$$\frac{W_2^2 l^2 E}{24} = T_2^2\left[\frac{T_2}{A} - \left(\frac{T_1}{A} - \frac{W_1^2 l^2 E}{24T_1^2} - \alpha tE\right)\right]$$

$$M = \frac{W_2^2 l^2 E}{24} \quad (10)$$

$$K = \frac{T_1}{A} - \frac{W_1^2 l^2 E}{24T_1^2} \quad (11)$$

$$M = T_2^2\left[\frac{T_2}{A} - (K - \alpha tE)\right] \quad (12)$$

$$S = \frac{W_2 l^2}{8T_2} \quad (13)$$

Ground clearance = Tower height – Sag (14)

4. ELECTRICAL DESIGN OF TRANSMISSION LINE

Transmission of electric power is done by 3-phase, 3-wire overhead lines. An a.c. transmission line has resistance, inductance and capacitance uniformly distributed along its length. These are known as constants or parameters of the line. The performance of a transmission line depends to a considerable extent upon these constants. For instance, these constants determine whether the efficiency and voltage regulation of the line will be good or poor.

4.1. Conductors

Transmission line conductors are normally made from aluminum with certain reinforcements. Copper is not usually at high voltage because of its costs even though it has a very low resistance. The conductors are made of aluminum strands which are reinforced by another material. The reinforcement, by steel for instance, provides a ratio of high strength to weight.Aluminum conductors are classified as follows:

AAC = All Aluminium Conductor

ACSR = Aluminium Conductor Steel Reinforcement

AAAC = All Aluminium Alloy Conductor

4.2. Reactance of Transmission Line

Inductance and capacitance of transmission lines is calculated per phase. Inductance consists of self inductance of the phase conductor and mutual inductance between the conductors. Capacitance is considered the actual outside radius of the conductor.

4.2.1 Inductance of Symmetrical Three-Phase Line

In symmetrical three-phase line, all the conductors are placed at the corners of the equilateral triangle. Such an arrangement of conductors is also referred to as equilateral spacing. It is shown in the diagram below.

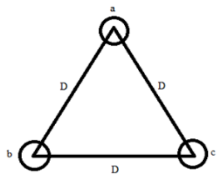

Figure 3. Symmetrical Three-Phase Line

D is the geometric mean of the three spacing of the three phase line and the radius of each conductor, r.

GMD, $D_m = \sqrt[3]{D_{ab}D_{ac}D_{bc}}$

GMR, $D_s = 0.7788r$

$$L = 2\times10^{-7}\ln\frac{GMD}{GMR} \quad [H/m]$$

$$L = 2\times10^{-7}\ln\frac{D_m}{D_s} \quad [H/m] \qquad (15)$$

$$X_L = 2\pi fL \ \Omega/\text{phase} \qquad (16)$$

where, GMR is the geometric mean radius and GMD is the geometric mean distance.

4.2.2. Capacitance of Symmetrical Three-Phase Line

The three conductors a, b and c of the 3-phase overhead transmission line having charges Qa, Qband Qcper metre length respectively. Let the conductors be equidistant (D metres) from each other. The capacitance from line conductor to neutral in this symmetrically spaced line is calculated per phase.

$$C_N = \frac{1}{8\times10^9 \,\text{Ln}\,(\frac{D_m}{r})} \quad F/m \qquad (17)$$

$$X_C = \frac{1}{2\pi f C_N} \quad \Omega/\text{phase} \qquad (18)$$

4.3. General Formula for Long Transmission Line

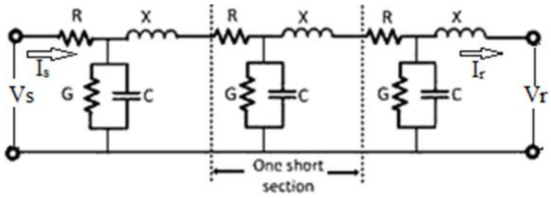

Figure 5. Circuit Diagram of Long line

$$V_s = AV_r + BI_r \qquad (19)$$

$$I_s = CV_r + DI_r \qquad (20)$$

Where, V_s= Sending end voltage per phase

I_s = Sending end current

V_r = Receiving end voltage per phase

I_r = Receiving end current

A, B, C and D are constants and generally complex number.

For constant A, $A = 1 + \frac{ZY}{2}$ (21)

For constant B, $B = Z\,[1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \ldots]$ (22)

For constant C, $C = Y\,[1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \ldots]$ (23)

For constant D, $D = 1 + \frac{ZY}{2}$ (24)

Where, Y = Shunt admittance of the line

Z =Series impedance ofthe line

For series impedance Z,

$$Z = R + jX_L \ \Omega/\text{phase} \qquad (25)$$

For shunt admittance Y,

$$Y = j2\pi fC_N \ \mho/\text{phase} \qquad (26)$$

4.4. Effect of Load Power Factor on Voltage Regulation and Efficiency

The regulation and efficiency of a transmission line depend to a considerable extent upon the power factor of the load.

4.4.1. Effect on regulation

The performance of a transmission line is desirable to determine its voltage regulation he difference in voltage at the receiving end of a transmission line between conditions of no load and full load is called voltage regulation and is expressed as a percentage of the receiving end voltage. When a transmission line is carrying current, there is a voltage drop in the line due to resistance and inductance of the line. The result is that receiving end voltage (V_r) of the line is generally less than the sending end voltage (V_S). This voltage drop (V_S–V_r) in the line is expressed as a percentage of receiving end voltage VR and is called voltage regulation. Mathematically,

$$\%\ \text{Voltage Regulation,VR} = \frac{V_s - V_r}{V_r} \times 100\ \% \qquad (27)$$

4.4.2. Effect on transmission efficiency

The power obtained at receiving end of a transmission line is generally less than the sending end power due to losses in the line resistance. The power delivered to the load depends upon the power factor.

$P = 3V_r I \cos\phi$ (For 3-phase line)

∴

$$I = \frac{P}{3V_r \cos\phi_r}$$

(28)

Power losses, $P_L = 3I^2R$

% Transmission Efficiency, $\eta = \frac{\text{Receiving end power}}{\text{Sending end power}} \times 100$ (29)

$$= \frac{V_r I_r \cos\phi_r}{V_S I_S \cos\phi_S} \times 100$$

$$= \frac{3V_r I_r \cos\phi_r}{3V_r I_r \cos\phi_r + \text{Losses}} \times 100$$

Where V_r, I_r and $\cos\phi_r$ are receiving end voltage, current and power factor while V_S, I_S and $\cos\phi_S$ are sending end voltage, current and power factor.

5. POWER FACTOR IMPROVEMENT

The system performance can be improved by correcting the power factor. The system power factor is given by:

Power Factor = kW/kVA (30)

Where kW and kVA are the real and apparent power, respectively. The power factor of any operating system can be lagging or leading. The direction of active and reactive power can be used to determine the nature of the power factor. If both the real and reactive power flow are in the same direction, then the power factor is lagging. If the reactive power flows in the direction opposite to that of the real power, then the power factor is leading.

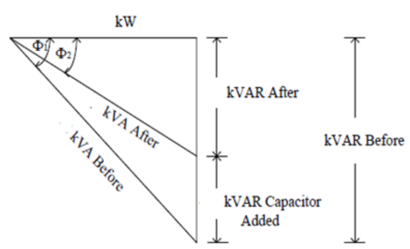

Figure 4. Power Factor Correction Triangle

If power factor is raised to $\cos\phi_2$,

Desired kVA Demand, kVA_2 = Present load/ Desired power factor

Desired kVA Demand , $kVA_2 = kW/\cos\phi_2$

$kVAR_2$ at power factor $\cos\phi_2 = kVA_2 \times \sin\phi_2$ or

$= \sqrt{(kVA_2^2 - kW^2)}$

Capacitor rating = $kVAR_1$(Uncorrected) $-$ $kVAR_2$(Corrected)

6.CALCULATION OF POWER TRANSMISSION LINE

The high voltage overhead transmission line has a various span between level supports. In the central regions of Myanmar, the most powerful air pressure is $66 kg/m^2$ and in that time the temperature is 28° C.

The following data are obtained from Thaton-Mawlamyine power transmission line to design shunt capacitor bank for power factor correction. In this design calculation, suitable size of shunt capacitor bank is installed.

Present load, kW = 150MW

Present kVA_1 = 166.67MVA

Present $kVAR_1$= 72.649MVAR

Present Power Factor = 0.9

Desired Power Factor = 0.95

Voltage = 230kV

If power factor is raised to 95%,

Desired kVA Demand,

kVA_2 = Present load/ Desired power factor

= 150/0.95 = 157.895MVA

The size of the capacitor required to accomplish this is determined from the KVAR at the two values of power factor as follows:

$kVAR = \sqrt{(kVA^2 - kW^2)}$

At 90% power factor,

$kVAR_1 = \sqrt{(kVA_1^2 - kW^2)} = \sqrt{(166.67^2 - 150^2)}$

= 72.649MVAR

At 95% power factor,

$kVAR_2 = \sqrt{(kVA_2^2 - kW^2)}$

$= \sqrt{(157.895^2 - 150^2)}$ = 49.303MVAR

Capacitor rating = $kVAR_1$(Uncorrected) $-$ $kVAR_2$(Corrected)

= 72.649MVAR $-$ 49.303MVAR

= 23.346MVAR

Table 1. Results of Sag, Tension and Ground Clearance (GC) for Transmission Line

Types of Conductor (ACSR)	Tower Height (m)	Span (m)	Tension (kg)	Sag (m)	GC (m)
$346.4 mm^2$ (DUCK)	20	344	2209	7.8	9.75
	58	678.35	2104	31.71	23.84
	58	643	2109	28.43	27.12
$374.7 mm^2$ (GROSBE AK)	20	344	2237	8.6	8.95
	58	678.35	2186	34.18	21.37
	58	643	2188	30.68	24.87

Table 2. Results of Voltage Regulation and Transmission Line Efficiency for 0.9 Power Factor

Type of Conductor (ACSR)	Current (A)	V drop (kV)	Diameter (mm)	V.R (%)	Line η (%)
$346.4 mm^2$	418.37	18.366	24.21	13.8	95.18
$374.7 mm^2$	418.37	17.927	25.15	13.45	95.44

Table 3. Result of Transmission Line Performance for After Power Factor Correction

Types of conductor (ACSR)	power factor					
	0.9 (Lagging)			0.95 (Lagging)		
	V drop (kV)	V.R (%)	Line η (%)	V drop (kV)	V.R (%)	Line η (%)
$346.4 mm^2$	18.37	13.8	95.18	14.36	10.8	95.57
$374.7 mm^2$	17.93	13.5	95.44	13.96	10.5	95.81

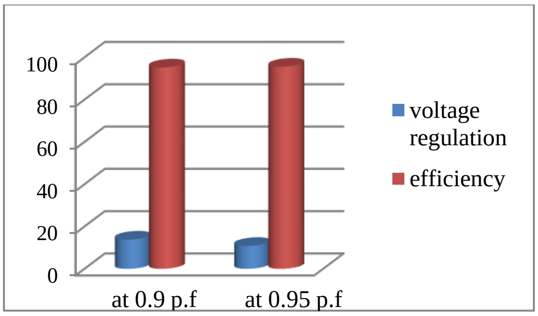

Figure 6.Results from 346.4mm^{2}ACSR(DUCK) Conductor

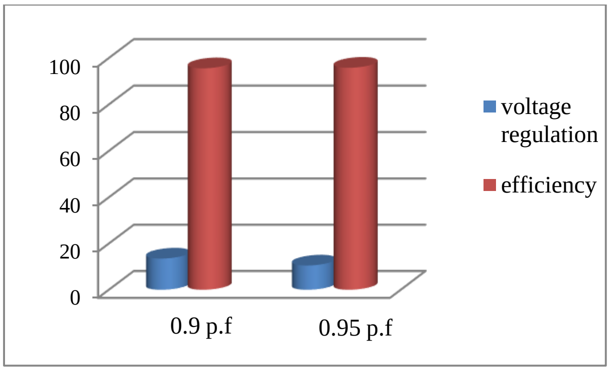

Figure 7. Results from 374.7mm^{2}ACSR(GROSBEAK) Conductor

7. CONCLUSIONS

In this paper, the line conductor and tower are determined and calculated voltage regulation and transmission efficiency to design the transmission line. Overhead transmission lines depend on area of installation, the design of these lines requires maximum clearances to be observed to maintain safety. Sag and tension for different span at equal height are calculated with two types of conductor size and temperature. Shunt capacitors are widely used in power factor correction applications. This paper illustrated the basis issues related to power factor improvement by using shunt capacitor banks for transmission system.The performance of results are presented by the table.

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