Power Distribution Systems

Lecture 7

Power Loss

&

Determining Size of Conductor

Introduction

In power systems, the technical losses are due to energy dissipated in the conductors, equipment used for transmission line, transformer, subtransmission line and distribution line and magnetic losses in transformers. The major amount of losses is in primary and secondary distribution lines.

Determining the size of conductor is one of the things to do for designing distribution systems. While the voltage drop is the main criterion to determine appropriate size of conductors, power loss is particularly used to determine economical size of conductor.

Percent Power (or Copper) Loss

The power (or conductor) loss of a circuit can be expressed as

$$P_{\mathrm{LS}} = I^2R = I^2rd$$

where

R: conductor distance resistance, Ω

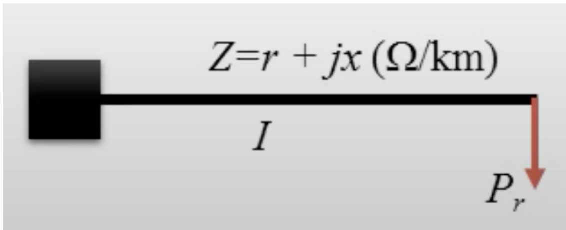
r : conductor linear resistance, Ω/km

d : distance on the feeder, km

The power loss can also be expressed as

$$\% I^2R = \frac{P_{\mathrm{LS}}}{P_r} \times 100$$

$$= \frac{I^2R}{P_r} \times 100$$

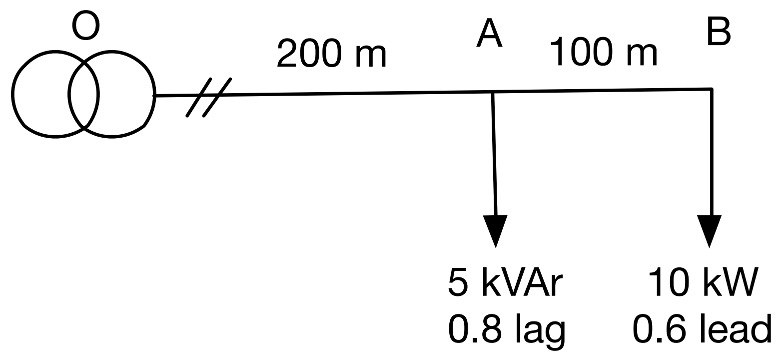


P_r : power delivered by the circuit, kW

Example 7.1

In the following single phase distribution feeder, conductor linear resistance and reactance are r=0.4 Ω/km-phase and x=0.3 Ω/km-phase, respectively. Calculate

a) the power loss for section OA, AB and OB
b) the percent power loss for section OA, AB and OB



Determining Size of Conductor

In order do determine the size of conductor in power distributions systems, the following considerations should be taken into account;

- Current carrying capacity of conductor
- Voltage drop
- Short circuit current
- Power loss (for economical sizing)

Conductor should carry the nominal load current. And for the nominal current the voltage drop through line should be within the allowed limits. For this aim, the tables provided by the manufacturers are used.

Conductors should withstand the short currents for specified time. We will not see this criterion in this lesson.

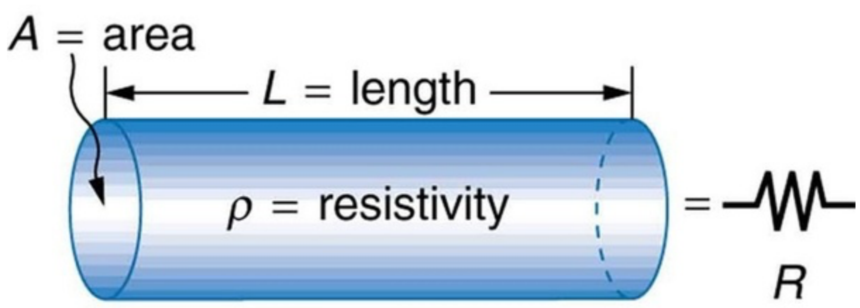
Power loss should also be considered to determine the conductor size for economical operation.

Determining Size of Conductor

The resistance of conductor can be expressed as

$$R = \rho \frac{L}{A} = \frac{L}{\sigma A}$$

ρ : resistivity of conductor [Ω-mm²/m]
σ: conductivity of conductor [m/ Ω-mm²]
L: length of conductor [m]
A: cross-sectional area of conductor [mm²]

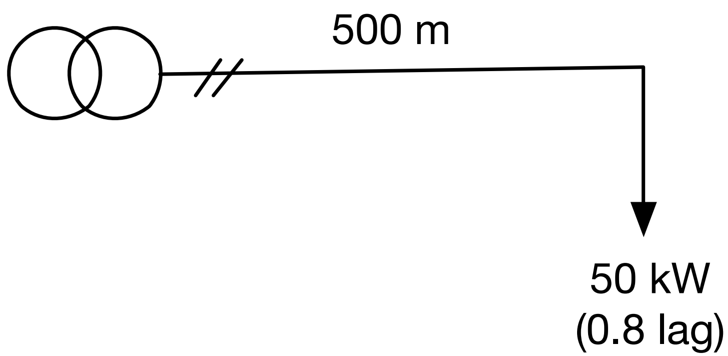


Example 7.2

In the following single phase distribution feeder, the nominal voltage is 600 V. If the conductor conductivity and reactance are r σ =56 m/Ω-mm^2 and x=0.185 Ω/km-phase, respectively., calculate

a) cross-sectional area of conductor for $\Delta u\% \leq 5$

b) the sending end voltage (assume the receiving end voltage as reference)

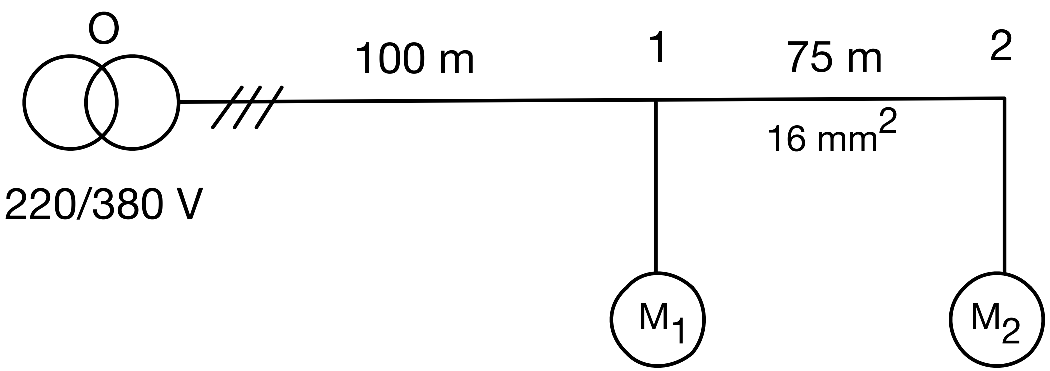


Example 7.3

Two asynchronous motors with same power are supplied from transformer as shown in the following figure. When the motors are run with full load, the voltages at terminals 1 and 2 are 373.2 V and 369.2 V, respectively. If the size of cable installed between terminal 1 and 2 is 16 mm², calculate

a) rated power of motors

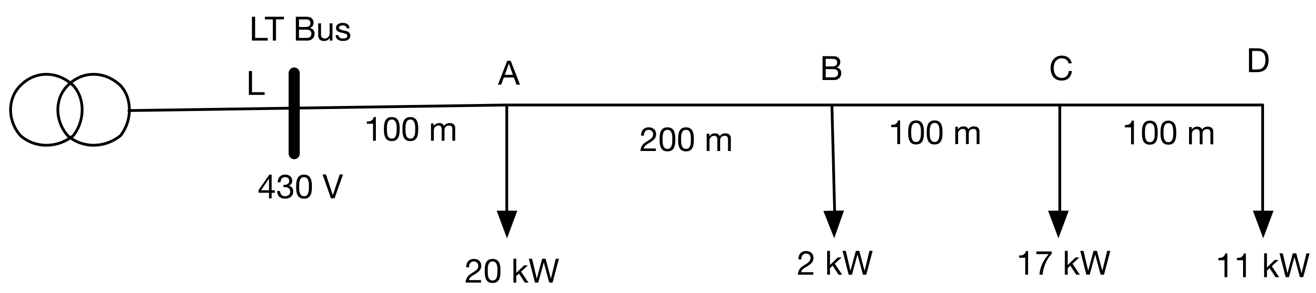
b) cross-sectional area of conductor from transformer to terminal 1



p.s. Assume that currents drawn from motors are the same

Example 7.4

A LT 3-phase 4-wire overhead distribution system is to be designed for giving electric supply to various industrial consumers as shown in figure below. Determine the size of conductors appropriate for distribution feeder line. The sending end voltage ate consumer’s apparatus should not fall below 415 V. All apparatus are three-phase power with power factor 0.8. Use the table given in next slide for standard conductor size.



Determining Size of Conductor

Example 7.4

Current Rating, Resistance and Impedance of ACSR Conductor (assuming average ambient temperature of 30ÉC)

Trade Name	*Number of strands and diameter of each strand in mm*	*Number of strands and diameter of each strand in inches*	*Area in sq.mm*	*Current carrying capacity (Amps) for a conductor for temperature of*		*Resistance per km in ohms*	*Inductance per km in ohms*	*Impedance per km in ohms*
				30°C	*50°C*			
Squirrel	6/1/2.11	6/1/.083	20.71	70	97	1.366	0.320	1.400
Weasel	6/1/2.59	6/1/.102	31.21	100	123	0.9047	0.308	0.955
Ferret	6/1/3.00	6/1/.118	41.87	125	155	0.6760	0.298	0.738
Rabbit	6/1/3.33	6/1/.132	52.21	148	183	0.5404	0.291	0.614
Mink	6/1/3.66	6/1/.144	62.32	167	208	0.4540	0.285	0.536
Beaver	6/1.4.22	6/1/.166	82.85	207	252	0.3418	0.2725	0.437
Otter	6/1/4.22	6/1/.166	82.85	207	252	0.3418	0.2725	0.437
Cat	6/1/4.50	6/1/.177	94.21	299	285	0.3005	0.2725	0.406
Hare	6/1/4.72	6/1/.185	103.6	254	311	0.2722	0.2695	0.383
Leopared	6/1/5.28	6/1/.208	129.7	286	367	0.2177	0.2625	0.340

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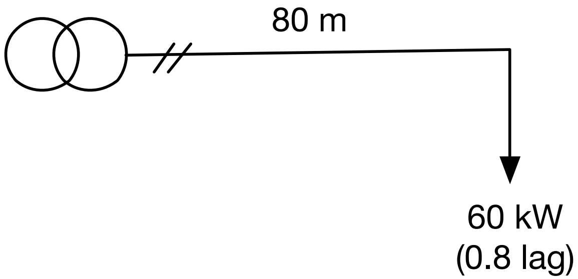
Example 7.5

In the following three-phase distribution feeder, the nominal phase voltage is 380 V. If the voltage drop allowed is $\Delta u\% \leq 5$, determine the cable size by using voltage drop factor table.



Voltage drop factors for 0,6/1 kV cables YVV(NYY) U=380 V

Conductor c.s.a. [mm²]	Resistance R' [Ω/km]	Reactance X' [Ω/km]	Voltage drop factor ΔU [V/kWkm] PF 1	0,95	0,90	0,80	0,70	0,60	Percent voltage drop factor ΔU% [%/kWkm] PF 1	0,95	0,90	0,80	0,70	0,60
4x1,5	14,5	0,115	38,16	38,26	38,30	38,38	38,47	38,56	10,04	10,07	10,08	10,10	10,12	10,15
4x2,5	8,87	0,107	23,34	23,43	23,48	23,55	23,63	23,72	6,143	6,167	6,179	6,198	6,218	6,241
4x4	5,52	0,106	14,53	14,62	14,66	14,74	14,81	14,90	3,823	3,847	3,858	3,878	3,898	3,921
4x6	3,69	0,101	9,711	9,798	9,839	9,910	9,982	10,06	2,555	2,578	2,589	2,608	2,627	2,649
4x10	2,19	0,095	5,763	5,845	5,884	5,951	6,018	6,096	1,517	1,538	1,548	1,566	1,584	1,604
4x16ç	1,38	0,090	3,632	3,709	3,746	3,809	3,873	3,947	0,956	0,976	0,986	1,002	1,019	1,039
4x25ç	0,870	0,088	2,289	2,366	2,402	2,463	2,526	2,598	0,602	0,623	0,632	0,648	0,665	0,684
4x35ş	0,627	0,085	1,650	1,724	1,758	1,818	1,878	1,948	0,434	0,454	0,463	0,478	0,494	0,513
4x50ş	0,463	0,085	1,218	1,292	1,327	1,386	1,447	1,517	0,321	0,340	0,349	0,365	0,381	0,399
4x70ş	0,321	0,082	0,845	0,916	0,949	1,007	1,065	1,132	0,222	0,241	0,250	0,265	0,280	0,298
4x95ş	0,232	0,082	0,611	0,681	0,715	0,772	0,831	0,898	0,161	0,179	0,188	0,203	0,219	0,236
4x120ş	0,184	0,080	0,484	0,553	0,586	0,642	0,699	0,765	0,127	0,146	0,154	0,169	0,184	0,201
4x150ş	0,150	0,080	0,395	0,464	0,497	0,553	0,610	0,675	0,104	0,122	0,131	0,145	0,160	0,178
4x185ş	0,120	0,080	0,316	0,385	0,418	0,474	0,531	0,596	0,0831	0,101	0,110	0,125	0,140	0,157
4x240ş	0,0925	0,080	0,243	0,313	0,345	0,401	0,458	0,524	0,0641	0,0823	0,0909	0,106	0,121	0,138
4x300ş	0,0747	0,080	0,197	0,266	0,299	0,354	0,411	0,477	0,0517	0,0699	0,0786	0,0933	0,108	0,126
4x400ş	0,0597	0,079	0,157	0,225	0,258	0,313	0,369	0,434	0,0413	0,0593	0,0678	0,0824	0,0972	0,114
4x500ş														

$$VD_{pu} \approx KS_{3\phi}\, l_{\text{eff}}$$

$$VD_{pu} \approx K'P_{3\phi}\, l_{\text{eff}}$$

K' is the parameter in pu voltage drop per kW-km

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Economic Choice of Conductor

The most economical area of conductor is that for which the total annual cost of distribution line is minimum. This is known as *Kelvin's Law.* The total annual cost of distribution line can be divided broadly into two parts *viz.*,

- annual charge on capital outlay
- annual cost of energy wasted in the conductor

(i) Annual charge on capital outlay

This is on account of interest and depreciation on the capital cost of complete installation of distribution line. The conductor cost is proportional to the area of X-section and the cost of installation is constant. Therefore, annual charge can be expressed as:

$$\text{Annual charge} = P_1+P_2.a$$

where P_1 and P_2 are constants and a is the area of X-section of the conductor.

Determining Size of Conductor

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(*ii*) *Annual cost of energy wasted*

This is on account of energy lost mainly‡ in the conductor due to *I2R* losses. Assuming a constant current in the conductor throughout the year, the energy lost in the conductor is proportional to resistance. As resistance is inversely proportional to the area of X-section of the conductor, therefore, the energy lost in the conductor is inversely proportional to area of X-section. Thus, the annual cost of energy wasted in an overhead transmission line can be expresses as:

$$\text{Annual cost of energy wasted} = P_3/a$$

where P_3 is a constant.

Total annual cost,

$$\begin{aligned} C &= \text{exp. } (i) + \text{exp. } (ii) \\ &= (P_1 + P_2\, a) + P_3/a \\ C &= P_1 + P_2\, a + P_3/a \end{aligned}$$

Determining Size of Conductor

The total annual cost of transmission line will be minimum if differentiation of *C w.r.t. a is zero*

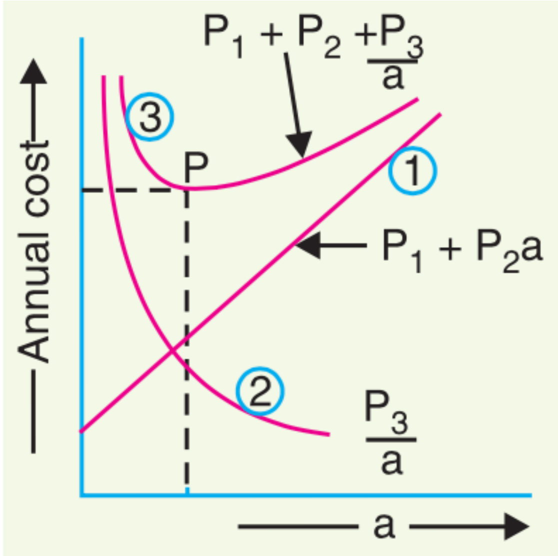
$$\frac{d}{da}(C) = 0$$

$$\text{or} \quad \frac{d}{da}(P_1 + P_2\, a + P_3 / a) = 0$$

$$\text{or} \quad P_2 - \frac{P_3}{a^2} = 0$$

$$\text{or} \quad P_2 = P_3 / a^2$$

$$\text{or} \quad P_2\, a = \frac{P_3}{a}$$



i.e. Variable part of annual charge=Annual cost of energy wasted

Example 7.6

A 2-conductor cable 1 km long is required to supply a constant current of 200 A throughout the year. The cost of cable including installation is \$ (20 a + 20) per meter where 'a' is the area of X-section of the conductor in cm . The cost of energy is ¢5 per kWh and interest and depreciation charges amount to 10%. Calculate the most economical conductor size. Assume resistivity of conductor material to be 1.73 µ Ω-cm.