Voltage Drop and Branching Circuit Design Calculations

Week 5-6-7

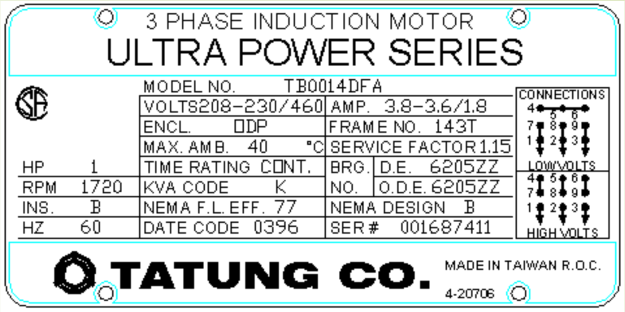
Voltage considerations

Nominal Voltage

- The nominal voltage is the voltage **by which the system** is designated for example 230/400V, 400/690V, 120/208V etc.

Rated Voltage

- This is the nameplate voltage and it is the voltage at which the **equipment** is designed to operate for optimal performance.



Rated values for 3ph IM

Voltage considerations

Service voltage

- The service voltage is the voltage at the point where the electrical of the supplier and the user are interconnected. **This is normally at the meter**. Maintaining an acceptable voltage at the service entrance is the utility's responsibility.

Utilization voltage

- This is the voltage at the line terminals of utilization equipment. It is less than the service voltage by the amount of voltage drop in the facility from the service point to the utilization point. This voltage is the facility's responsibility. Equipment manufacturers should design equipment which operates satisfactorily within the specified limits. These limits allow for some voltage drop within a facility, so service voltage requirements are tighter than utilization requirements.

IEC and ANSI Standards

European Union

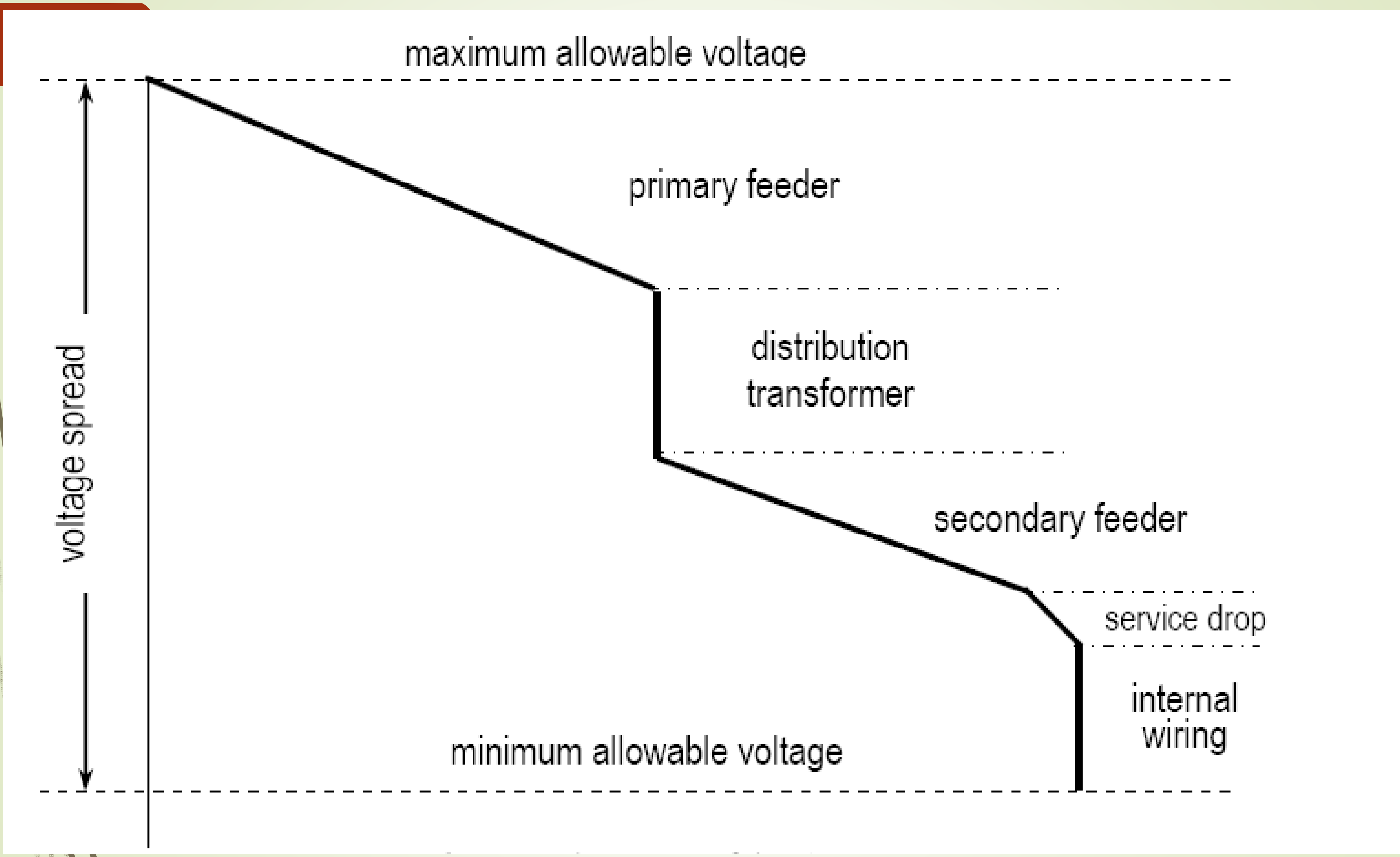
- The voltage tolerance permitted depends on the prevailing standard in use. Today there are, the European IEC60034-1 and IEC60038 and the American ANSI C84.1.
- In the European Union the nominal voltages are now 230/400V with a tolerance range of ±10% for equipment in general and of ±5% for rotating electrical equipments. The ±10% limits set the voltage at 253/440V maximum and 207/360V minimum. The ± 5% limits set the voltages at 242/420V maximum and 218/380V minimum.

IEC and ANSI Standards

United states

- In the United States the standard established two ranges for voltage variations designated as Range A and Range B. Basically Range A utilization voltage range is ±5% of nominal and Range B has the asymmetric range +6% to −12% of nominal. Utilization equipment is to be designed to give fully satisfactory operation throughout range A limits for utilization voltages. Range B allows for voltages above and below Range A limits.
- According to the standard when voltages are outside range A but inside range B, **they shall be limited in duration, extent and frequency, and corrective measures should be taken within a reasonable time to restore the service voltage to range A limits**.

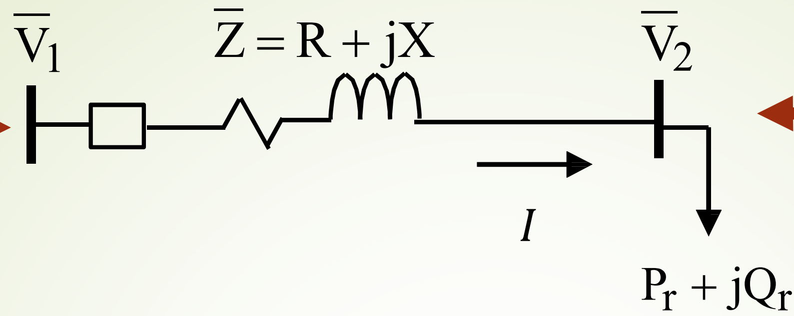
Voltage profile diagram



Why do we need voltage drop calculations?

- 1% voltage drop can lead to reduction in tungsten lamp illumination by 3%
- Some home appliances which are operated by motors can be affected by reduction in voltage (P=VI cos (pi))
- Reduction in voltage level will be accompanied by a rise in current level in circuit
- Since this voltage drop is within the 10% decrease, current will normally increase within the same limits without any tripping of the circuit breaker. On the long run, equipment will suffer from 10% current increase that could lead to equipment failure due to gradual temperature rise.

Voltage drop calculations in single phase circuit:



Voltage at the sending end

Voltage at the receiving end

$$\Delta V = V_1 - V_2 = 2\sum IR$$

$$R = \frac{\rho l}{A} = \frac{l}{\gamma A}$$

$$\Delta V = V_1 - V_2 = \frac{2}{\gamma A}\sum IL = \frac{2}{V_r \gamma A}\sum PL$$

For each conductor, we call it "go and return"

$$\%\Delta V = \frac{2\times 100}{V_r^2 \gamma A}\sum PL$$

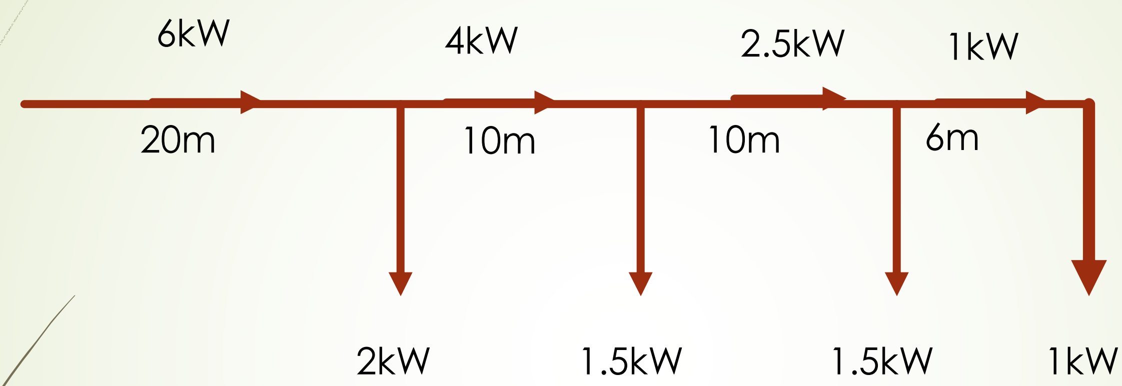
If you have more than one tap point in the same line i.e more points between V1 and V2, multiply each load by the distance

TIBTECH	Electrical conductivity (10.E6 Siemens/m)	Electrical resistivity (10.E-8 Ohm.m)
copper	58,5	1,7
Aluminium	36,9	2,7

Some of these values are smaller as they depend on the purity of copper so its subject to manufacturer data

Short circuit Current calculation: حساب تيار قصر الدارة

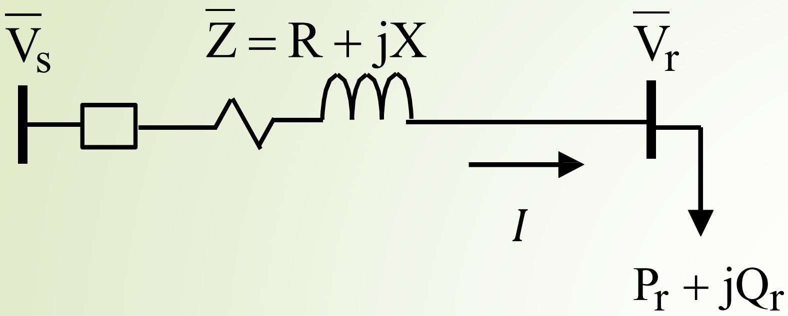
Assume rated voltage is 220V, single phase, resistive load, copper cables are used whose cross section area is 6 mm2. Calculate voltage drop

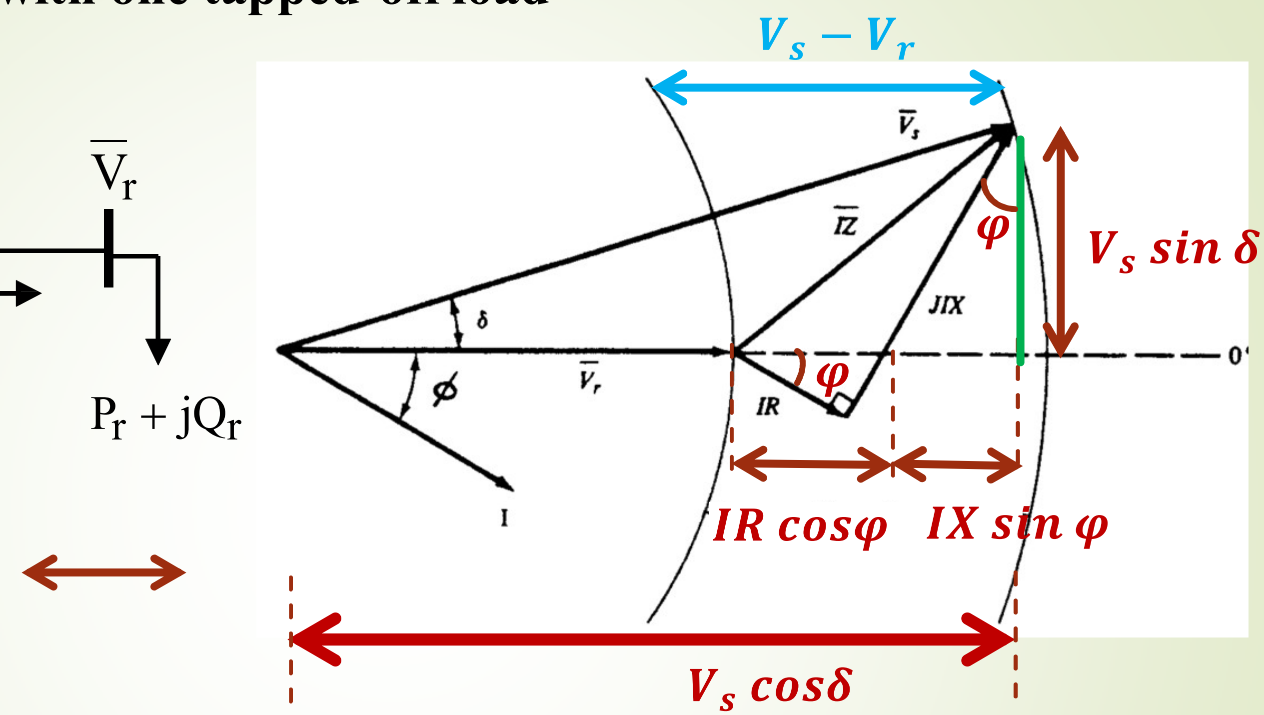


$$\%\Delta V = \frac{2\times100}{V_r^2\gamma A}\sum PL = \frac{2\times100}{220^2 \times6\times56}\sum(6\times20+4\times10+2.5\times10+1\times6) = 2.35\%$$

Voltage Drop Calculations

1. Radial -type feeder with one tapped-off load





$V_s = V_r + \mathrm{IZ}$

$V_s\ cos\delta = V_r + \mathrm{I.R.(cos\ \varphi) + I.x.(sin\ \varphi)}$

$\therefore VD \approx V_s - V_r \approx \mathrm{I.R.cos\varphi + I.x.sin\ \varphi}$

$$VD_{pu} = \frac{IR\cos\varphi + IX\sin\varphi}{V_B}$$

R & X= ohms
r & x= ohm/ unit length

$$VD_{pu} = \frac{3V_r IR\cos\varphi + 3V_r IX\sin\varphi}{3V_r V_B} \approx \frac{S_{3\varphi} \times l_{eff} \times (r\,cos\varphi + x\,sin\varphi) \times \left(\frac{1}{3} \times 1000\right)}{V_B^2}$$

$S_{3\varphi}$

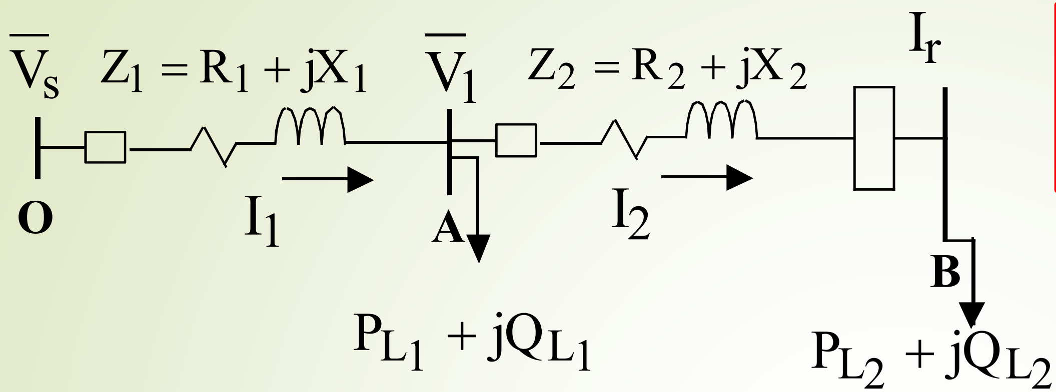
= ثابت
k

$$\approx K \times S_{3\varphi} \times l_{eff}$$
$$\approx K \times \textbf{Load Moment}\ (in\ kVA - km)$$

l_{eff}:	The effective length of the feeder main (in km)
$S_{3\varphi}$:	The three-phase **kVA-Loading**
r & x :	The **resistance** and **inductive** reactance parameters of the feeder main in **Ohm/km**.
K :	The **K-parameter** in pu voltage drop per kVA- km

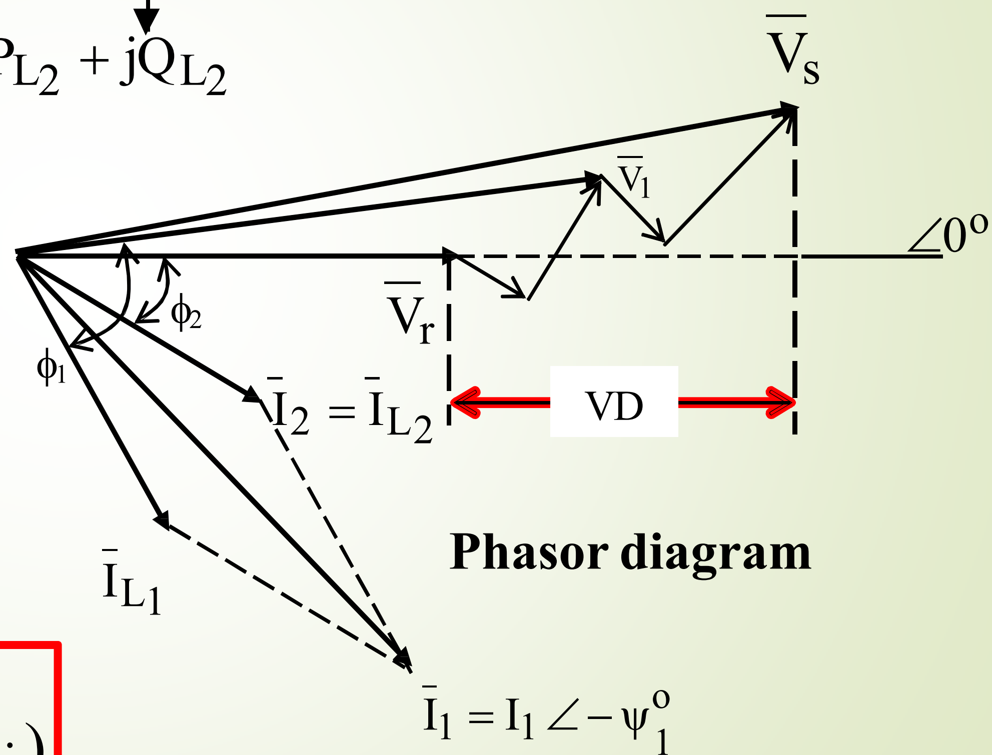
cosφ is considered 0.9 as it is regulated and depends on the loads. **Residential are usually higher than 0.9**

2. Radial -type feeder with multi tapped-off loads



Single line diagram

$$VD \approx I_1 \left(R_1 \cos\psi_1 + X_1 \sin\psi_1\right) + I_{L_2}\left(R_2 \cos\varphi_2 + X_2 \sin\varphi_2\right)$$



Phasor diagram

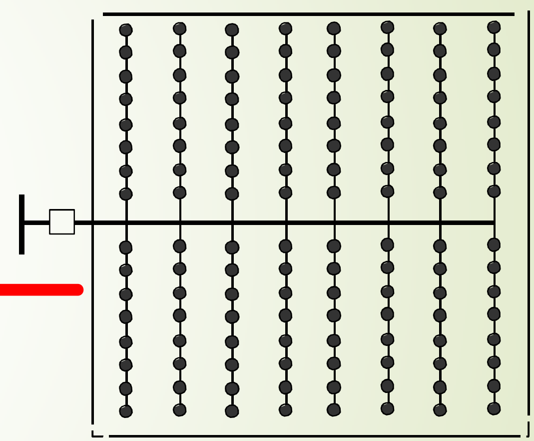
r + j**x** is the impedance per unit length of the feeder main

$$VD = \sum_{i=1}^{n} I_{L_i}\ l_i\ (r \cos\varphi_i + x \sin\varphi_i)$$

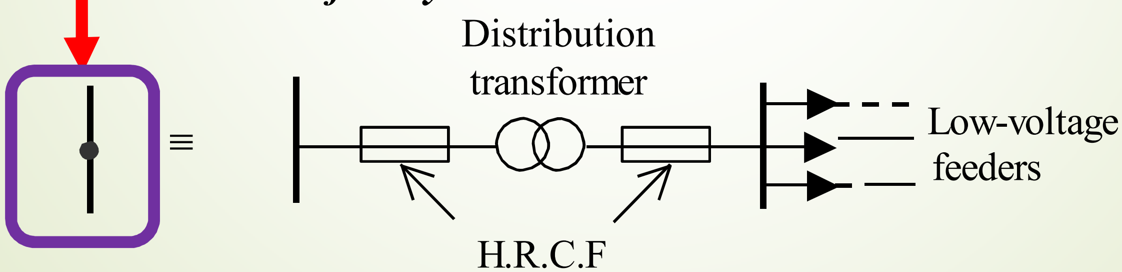
3. Radial -type feeder with uniformly distributed load

Many times it can be assumed that loads are uniformly distributed along a line where the line can be a three-phase, or a single-phase feeder or lateral. This is certainly the case on single phase laterals where the same rating transformers are spaced uniformly over the length of the lateral. When load is uniformly distributed, its not necessary to model each load in order to determine the voltage drop from source end to the last load.

In the case of a uniformly distributed load, load density is given in (kVA/km2) as well as the total area which the load is occupying



MV radial-type primary feeder with uniformly distributed load

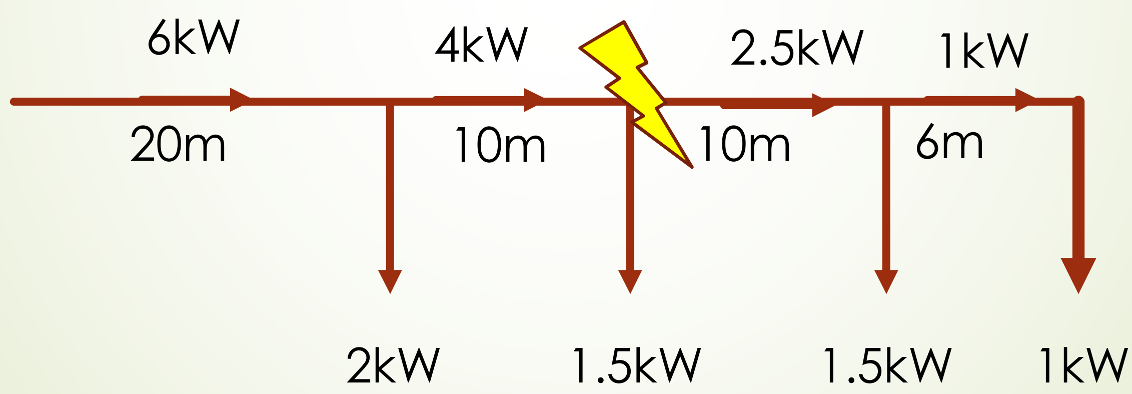


Tapped-off distribution transformer load

In this case, the total load is represented by a single load at the mid distance

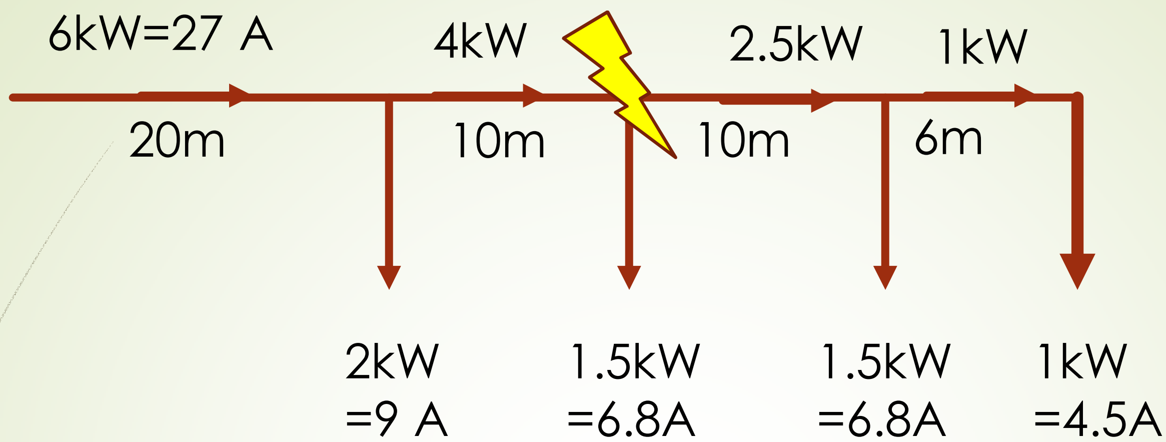
Short Circuit Current Calculation: حساب تيار قصر الدارة

- Short circuit current is the current flowing in an electrical circuit due to fault occurrence which is different than the normal current (could reach 10 times more than normal current)
- Short circuit could be :
  - Symmetric (3phase),
  - unsymmetrical (two phase, two phase to earth, single phase to earth)
  - Most occurred one is single phase to earth and symmetric 3 phase fault.



Calculate short circuit current if a single phase short circuit occurred between phase a and ground, occurring at entrance of load 2

Short circuit Current calculation: حساب تيار قصر الدارة



Assume rated voltage is 220V, single phase, resistive load, copper cables are used whose cross section area is 6 mm2

$$R = \frac{\rho L}{A} = \frac{1.78 \times 10^{-8} \times 30}{6 \times 10^{-6}} = 0.089\Omega$$

$$I_{sc} = \frac{V}{R} = \frac{220}{0.089} = 2471.94\ A$$

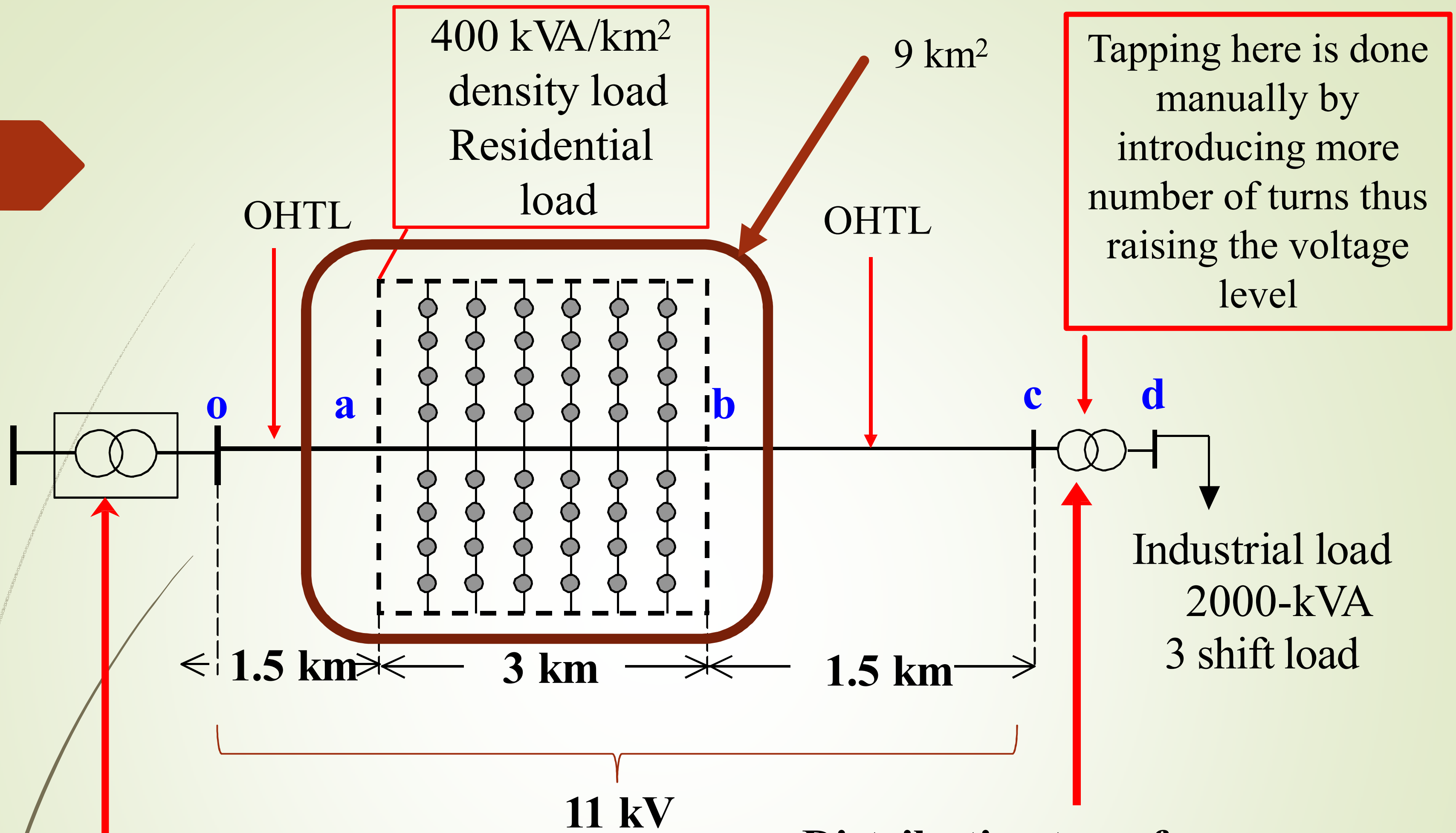
Application Examples:

A squared-shaped service area ($A=9\ km^2$) with a uniformly distributed load density of 400 kVA/ km^2 at peak loading and 125 kVA/ km^2 at off-peak loading. The lumped load of industrial plant working three shifts a day at constant loading of 2000 kVA. Primary feeders use over-head four-wire grounded bare copper conductors with manufacturer data as given in Table 1.

Determine for **both peak and off-peak loadings**:

i) The percentage voltage drop from sub-station to taping-off point a, from taping a to b, from taping b to c, and from taping c to d on the main primary feeder.

ii) The line-to-ground voltages at the tapings a, b, c, and d.



Substation :

- Nominal voltage ratio 66/11-kV
- V_{ss} (at peak loading) = 1.025 p.u of 66 kV
- V_{ss} (at off-peak loading) = 1.0 p.u of 66 kV

Distribution transformer :

- Ratings: 2000 kVA & 11 kV / 380 V
- Low-voltage tapings at operation = +5%
- Transformer impedance, ZT =0.0+ j0.05 pu

Manufacturer data for hard-drawn copper type conductors				
OHTL section	Conductor Size (mm^2)	Outside diam (mm)	GMR/R ratio	Resistance at 50 Hz & 50°C (Ω/km)
bc	25	6.606	0.7265	1.212
oa	120	14.57	0.7581	0.16

To calculate the TL inductance parameters for OHTL, we apply the following:

$$L = 2 \times 10^{-7} \ln \frac{GMD}{GMR} \frac{H}{km},$$

- GMR= 0.7788 times the actual radius(r) of conductor
- GMD = $\sqrt[3]{(D1D2D3)}$

For a GMD of 1.0 m, then:

$$L = 2 \times 10^{-7} \ln \frac{GMD}{GMR} \quad H/km$$

- 1.026×10^{-3} $(for\ 25\ mm^2)$
- 1.04×10^{-3} $(for\ 120\ mm^2)$

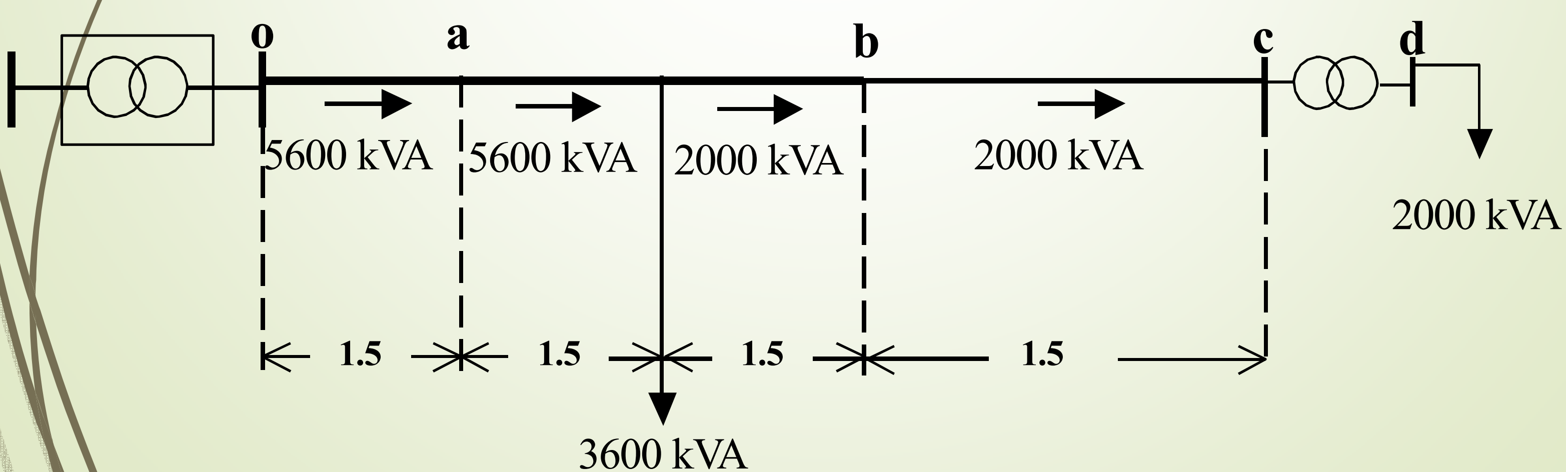
Inductive reactance is obtained by: $X_L = 2\,\pi\, f\, L$

Conductor Size (mm^2)	Parameters in Ω/km		K-factor %VD per kVA.km
	r	x_L	
25	1.212	0.379	0.00104
120	0.16	0.3267	0.00024

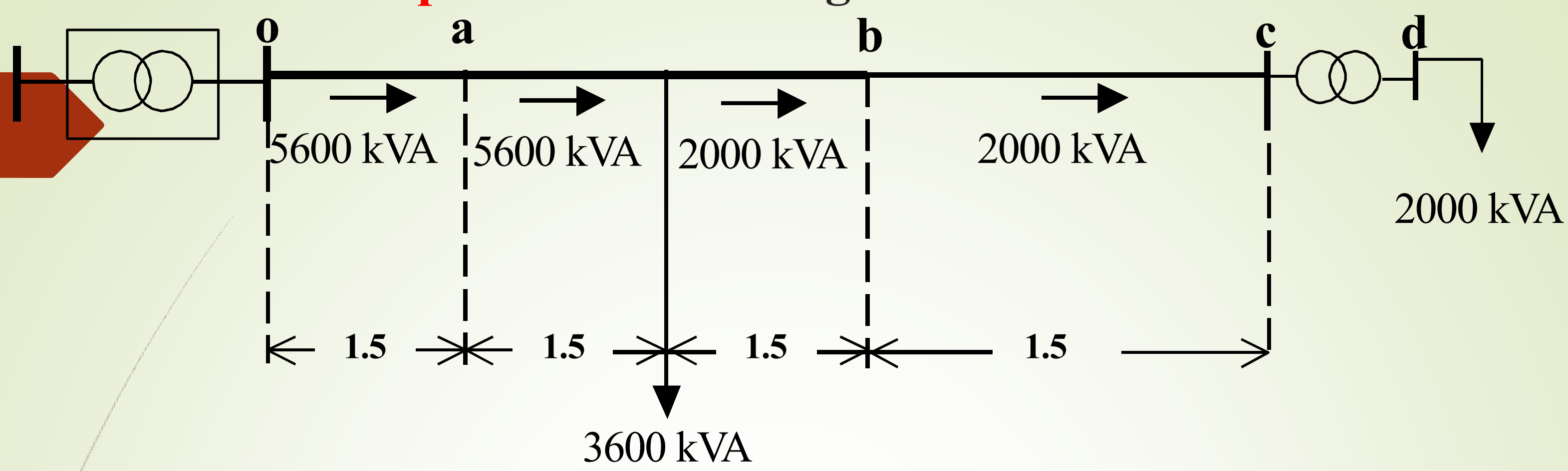
K factor calculations based on 0.9 pf:

$$K\big|_{at\,0.9P.F} = \frac{(r \times 0.9 + x_L \times 0.4358) \times \left(\frac{1}{3} \times 1000\right)}{\left(11000/\sqrt{3}\right)^2} \times 100$$

%VD-calculations at peak hours loadings:



%VD-calculations at peak hours loadings:



$$\%VD_{SS\rightarrow a} = 0.00024\times(5600\times1.5) = 2.016\%$$

$$\%VD_{a\rightarrow b} = 0.00024\times(5600\times1.5+2000\times1.5) = 2.736\%$$

$$\%VD_{b\rightarrow c} = 0.00104\times(2000\times1.5) = 3.12\%$$

$$\%V_{drop} = (102.5-2.016-2.736-3.12) = 94.628\%$$

To determine the %VD in sections c-d, transformer load current need to be determined:

$$I_{Load} = \frac{2000-kVA}{\sqrt{3}\times(0.94628\times11-kV)} = 110.93A \qquad A = \frac{110.93}{2000/\sqrt{3}\times11} = 1.056 \quad pu$$

pu current

The percentage of voltage reaching to the transformer after the voltage drop on the way

$$\text{pu} \quad Z_T = 0.0 + j0.05$$

Transformer impedance is usually given in pu values

$$\text{pu } VD_{cd} = \frac{I_{Load}|_{pu} \times (R_T \cos\phi + X_T \sin\phi)}{V_{base}|_{pu}} - 0.05$$

Due to tapping, which is raised by 5% so the effect is such to make an opposite effect to voltage drop

$$= \frac{1.056 \times (0.0 \times 0.9 + 0.05 \times 0.4358)}{1.0} - 0.05 = -0.027$$

$\% VD_{cd} = -2.7$ (i.e. voltage rise)

To compensate for the drop that will occur in the industrial load

$$\% VD|_{SS \to a} = 0.00024 \times (5600 \times 1.5) = 2.016\%$$

$$\% VD|_{a \to b} = 0.00024 \times (5600 \times 1.5 + 2000 \times 1.5) = 2.736\%$$

$$\% VD|_{b \to c} = 0.00104 \times (2000 \times 1.5) = 3.12\%$$

$$\% VD|_{c \to d} = -2.7\%$$

%VD-calculations at off-peak hours loadings:

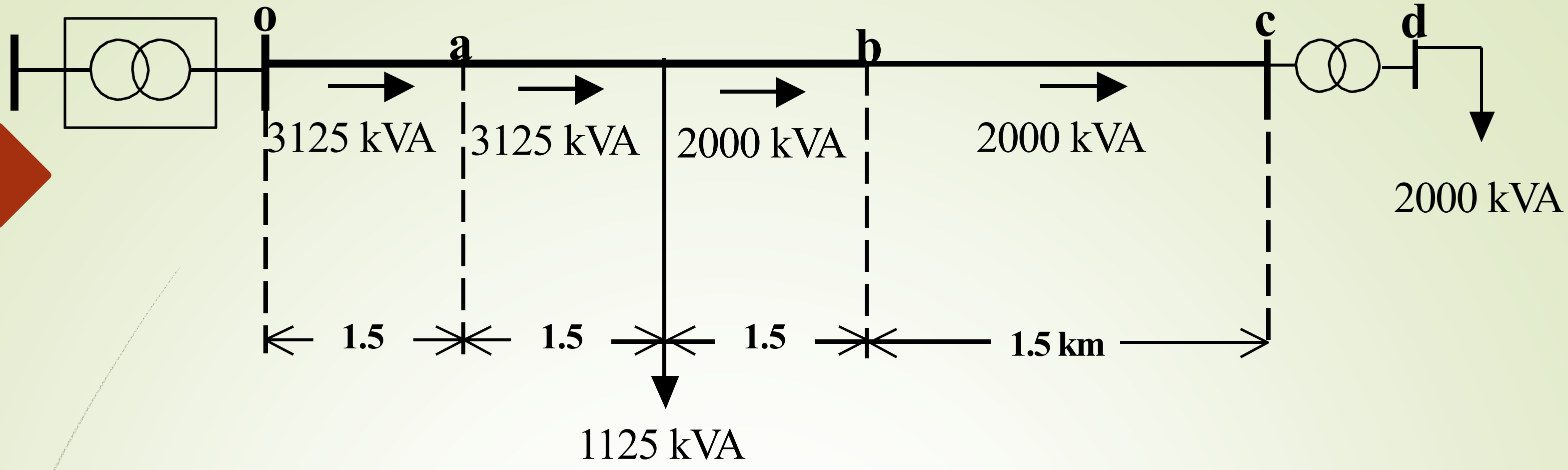
Line-to-neutral bus voltages calculations at peak hours loadings

$$V_a = pu\,V_a \times V_{base} = pu(V_o - VD_{oa}) \times V_{base}$$
$$= (1.025 - 0.02016) \times \frac{11}{\sqrt{3}} = 1.00484 \times \frac{11}{\sqrt{3}} = 6.3816\ kV$$

$$V_b = pu\,V_b \times V_{base} = pu(V_a - VD_{ab}) \times V_{base}$$
$$= (1.0048 - 0.02736) \times \frac{11}{\sqrt{3}} = 0.97748 \times \frac{11}{\sqrt{3}} = 6.20783\ kV$$

$$V_c = pu\,V_c \times V_{base} = pu(V_b - VD_{bc}) \times V_{base}$$
$$= (0.97748 - 0.0312) \times \frac{11}{\sqrt{3}} = 0.94628 \times \frac{11}{\sqrt{3}} = 6.00968\ kV$$

$$V_d = pu\,V_d \times V_{base} = pu(V_c - VD_{cd}) \times V_{base}$$
$$= (0.94628 + 0.027) \times 220 = 0.9733 \times 220 = 214.12 \quad V$$



%VD-calculations at off-peak hours loadings:

$$V_a = pu\,V_a \times V_{base} = pu(V_o - VD_{oa}) \times V_{base}$$

$$= (1.0 - .01125) \times \frac{11}{\sqrt{3}} = 0.98875 \times \frac{11}{\sqrt{3}} = 6.2974 \text{ kV}$$

$$V_b = pu\,V_b \times V_{base} = pu(V_a - VD_{ab}) \times V_{base}$$

$$= (0.98875 - 0.01845) \times \frac{11}{\sqrt{3}} = 0.9703 \times \frac{11}{\sqrt{3}} = 6.1622 \text{ kV}$$

$$V_c = pu\,V_c \times V_{base} = pu(V_b - VD_{bc}) \times V_{base}$$

$$= (0.9703 - 0.0312) \times \frac{11}{\sqrt{3}} = 0.9391 \times \frac{11}{\sqrt{3}} = 5.9641 \text{ kV}$$

$$V_d = pu\,V_d \times V_{base} = pu(V_c - VD_{cd}) \times V_{base}$$

$$= (0.9391 + 0.027) \times 220 = 0.9661 \times 220 = 212.54 \quad \text{V}$$