ED&M Calculation Exercise Session 1: Power Flow (more correctly, summation!)

Q1. Figure 1 shows a section of MV (20 kV) demand-dominated distribution network. Which conductor size is needed to cope with the worst contingency (a fault in the line sections (0-1 and 0-13) closest to the primary substation)? The cables are buried in trefoil with screens bonded at both ends.

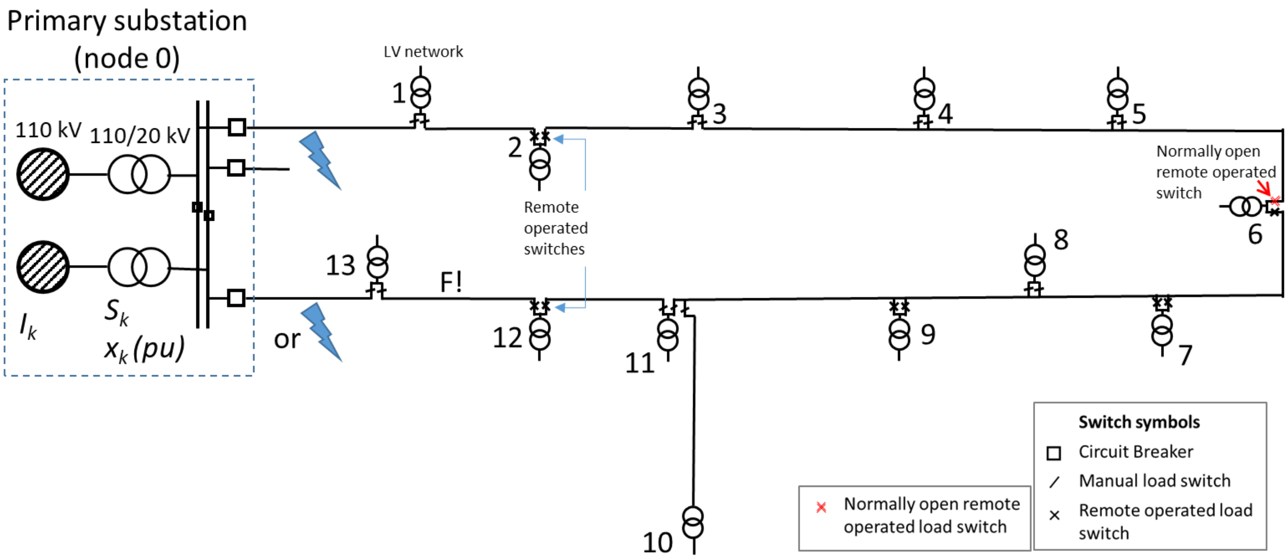
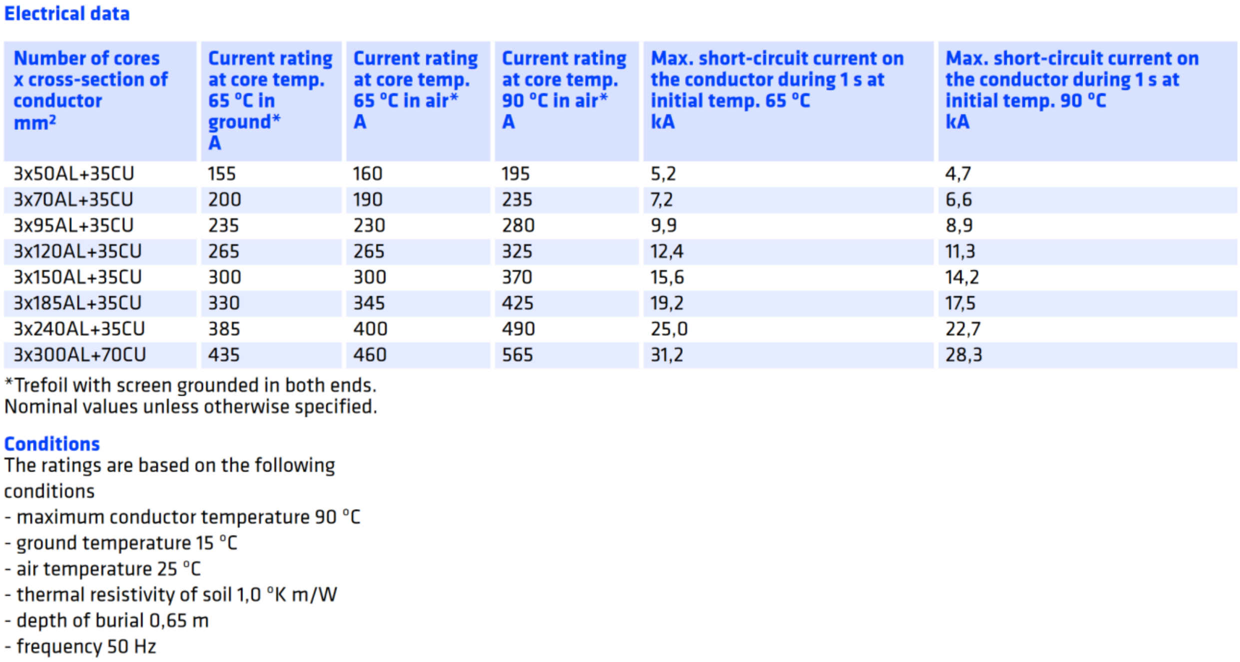


Figure 1 Topology of MV network section

Table 1 Maximum demands in year 1, but load growth *r* = 2%/annum for 20 years

Node	0	1	2	3	4	5	6	7	8	9	10	11	12	13
P_{max} **(kW)**	0	650	700	750	300	450	600	250	800	625	400	900	800	850
Q_{max} **(kvar)**	0	214	230	247	99	148	197	82	263	205	131	296	263	279

Table 2 Line data (*Source:* http://media.drakakeila.ee/2015/05/AHXAMK-W-24kV.pdf)



Electrical data

Number of cores x cross-section of conductor mm²	**Current rating at core temp. 65 °C in ground* A**	**Current rating at core temp. 65 °C in air* A**	**Current rating at core temp. 90 °C in air* A**	**Max. short-circuit current on the conductor during 1 s at initial temp. 65 °C kA**	**Max. short-circuit current on the conductor during 1 s at initial temp. 90 °C kA**
3x50AL+35CU	155	160	195	5,2	4,7
3x70AL+35CU	200	190	235	7,2	6,6
3x95AL+35CU	235	230	280	9,9	8,9
3x120AL+35CU	265	265	325	12,4	11,3
3x150AL+35CU	300	300	370	15,6	14,2
3x185AL+35CU	330	345	425	19,2	17,5
3x240AL+35CU	385	400	490	25,0	22,7
3x300AL+70CU	435	460	565	31,2	28,3

*Trefoil with screen grounded in both ends.
Nominal values unless otherwise specified.

Conditions

The ratings are based on the following conditions

- maximum conductor temperature 90 °C
- ground temperature 15 °C
- air temperature 25 °C
- thermal resistivity of soil 1,0 °K m/W
- depth of burial 0,65 m
- frequency 50 Hz

Q1 Answer.

This is quite simple! Since we have not learned a ‘proper’ power flow in this course, but it has been suggested that a quick back-of-the-envelope method is to sum the active and reactive power components separately and then calculate the apparent power and current in the component of interest. In this case, we want to make sure we have a cable size that can cope with the worst fault, a cable failure in line section 0-1 or 0-13. A single cable connection would have to cope with the entire load, so we can transfer Table 1 to Excel and sum all the P_{max} values and Q_{max} values, and calculate the apparent power. The other thing to remember to consider is load growth. 2 %/annum equates to $(1+2/100)^{20}$. In a mathematical form:

$$S_{line,1} \approx \left(1 + {}^{r}/_{100}\right)^{t_{growth}} \sqrt{\left(\sum_{n=1}^{13} P_{max,n}\right)^2 + \left(\sum_{n=1}^{13} Q_{max,n}\right)^2}$$

$$= \left(1 + {}^{2}/_{100}\right)^{20} \sqrt{(8075)^2 + (2654)^2}$$

$$= 12631 \text{ kVA}$$

$$I_{max,1} \approx \frac{S_{line,1}}{\sqrt{3}\, U_{lower_{bound}}}$$

$$= \frac{12631 \cdot 10^3}{\sqrt{3}\, 19.5 \cdot 10^3} = 374 \text{ A}$$

Which implies that the 3x240AL cable (240 mm^2 Aluminium conductor) should be adequate as far as thermal limits are concerned. Although we are quite close to the limit (385 A), we are assuming a coincidence factor of 1 for the demand, i.e., that the peak annual loads of each secondary substation will occur at the same time, and we are using a steady-state limit, but loads, even during contingencies, are very rarely static (the output of a nuclear power plant is probably one of the few significant players in the power system that can be considered constant…).

Q2. The question is whether to provide an MV (20 kV) connection to a proposed wind farm or to extend a radial 110 kV feeder and provide a new primary substation at the wind park.

a) What is the approximate peak rating of the wind park available with two MV feeders, each the largest conductor size from Table 2?

Each MV cable system has a steady-state rating of 435 A, so the total apparent power rating of the MV connection would be approximately

$$S_{max,MV} = \text{number\_of\_cable\_systems} \cdot \sqrt{3} \cdot U \cdot I = 2 \cdot \sqrt{3} \cdot 20 \cdot 10^3 \cdot 435 = 30 \text{ MVA}$$

b) What is the approximate peak rating of a single (3-phase) 110 kV overhead line (bare conductor), the AAC 132 rated at 495 A

$$S_{max,HV} = \sqrt{3} \cdot 110 \cdot 10^3 \cdot 495 = 94 \text{ MVA}$$

(Source:
https://fi.prysmiangroup.com/sites/default/files/business_markets/markets/downloads/datasheets/AAC.pdf

Do you have any comments about the relative merits of underground cables vs overhead lines feeding wind farms?

You might be able to get more out of the overhead 110 kV line as when the wind turbines are producing peak power, it is windy, so that may cool the overhead lines – this is not the case with underground cables.

The installed CAPEX of the 110 kV overhead lines might be cheaper than the 20 kV underground cables, but the cost of a new primary substation may be the deal breaker. Of course, other technical parameters, such as voltage rise, need to be checked as well. There have been incidents of poor cable installations to wind parks, meaning they don’t always reach the catalogue ratings…