ELEC-E8406 Electricity Distribution and Markets, Exercise 04 Reliability

1. Examine the following distribution network.

   a) Which customers experience an interruption and for how long when a fault occurs at point A? At point B? At point C?

   b) What is the total interruption cost caused by a single fault at point C if the CIC values for all customers are €1 / kW / fault and €10 / kWh, the manual switching time is 1h, the remote switching time is 0.15 h, the substation circuit breaker operating time is insignificant, the repair time is 10 h and the maximum demand (on which the CIC values are based) at each secondary substation is 1 MW?

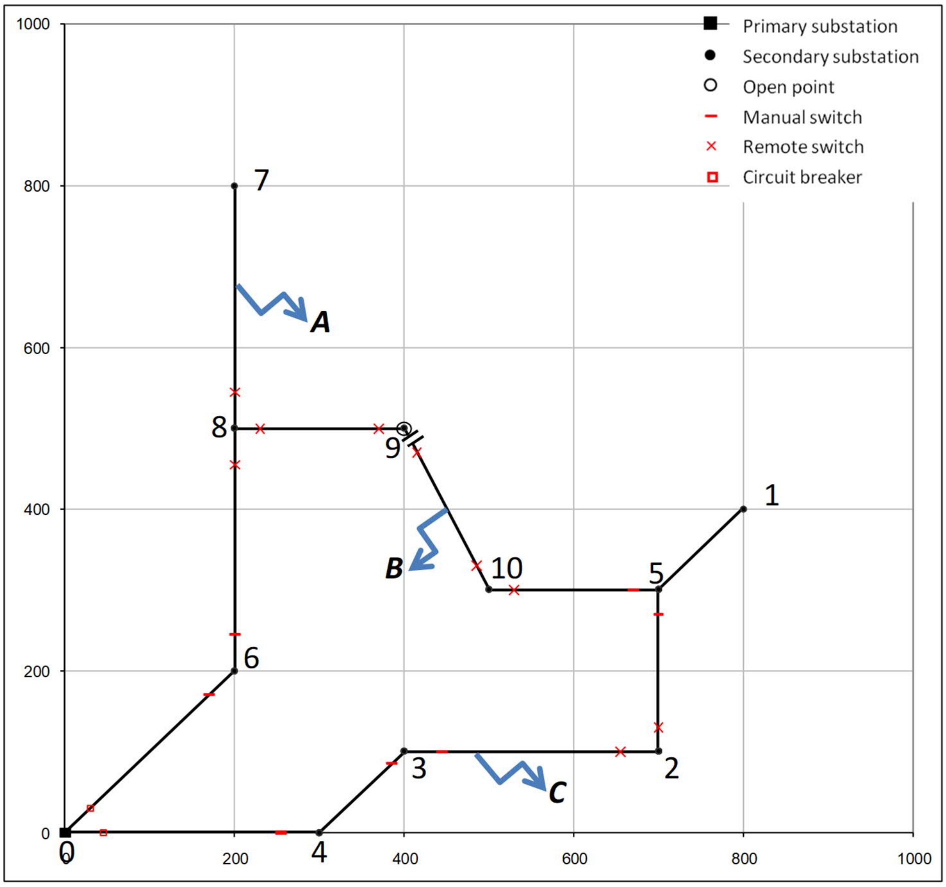
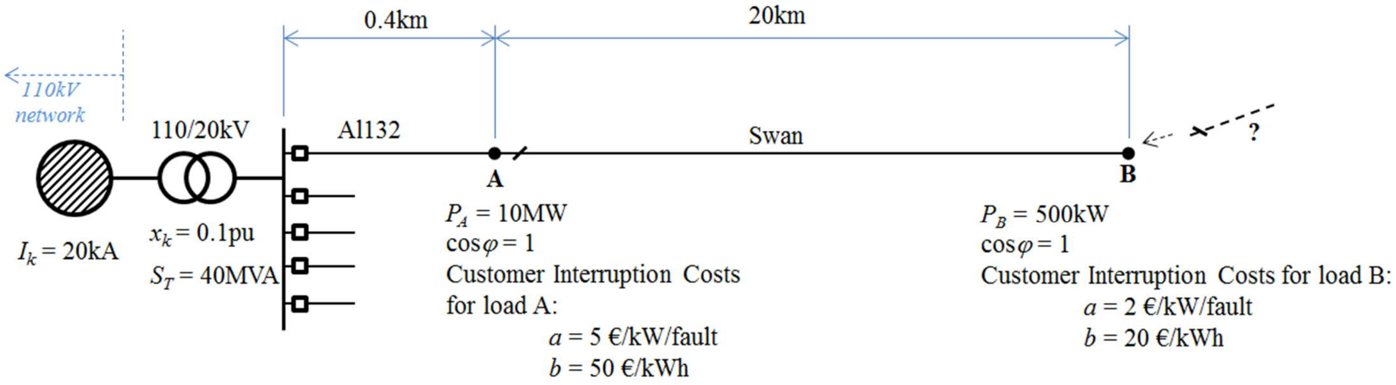


Fig. 1 20 kV network, 1 primary substation (node 0) and 10 secondary substations

2. A rural line connected to an industrial feeder



	Cross-section (mm²)	**Resistance (Ω/km)**	**Reactance (Ω/km)**	**Max load current (A)**
Al132	54	0.219	0.348	495
Swan	25	1.358	0.416	155

Average fault rate for both line sections: 7 faults / 100km
Average repair time: 3 hours

The load growth is 3 %/year, the interest rate is 5 %/year and the review period is 20 years. The manual switches at A and on the proposed backup connection take 30 minutes to operate. It is assumed that faults only occur one at a time (not simultaneously).

Should a backup connection be provided to point B in Fig.1 if the connection including a manual switch costs 25 000 euros?

If you had 3500 € left in your budget, sufficient for another manual load breaking switch, where would you install it?

What else might you suggest?

What other benefit might the backup connection give (e.g., if it is connected to another primary substation)

What was overlooked (due to insufficient data) in this exercise?

This formula converts load related annual costs to present day value of life costs (for a lifetime of t years):

$\kappa = \gamma \dfrac{\gamma^t - 1}{\gamma - 1}$ where, for load related annual costs: $\gamma = \dfrac{(1 + r/100)}{(1 + p/100)}$,

r is load growth (%/year) and p is interest rate (%/year)

Answers

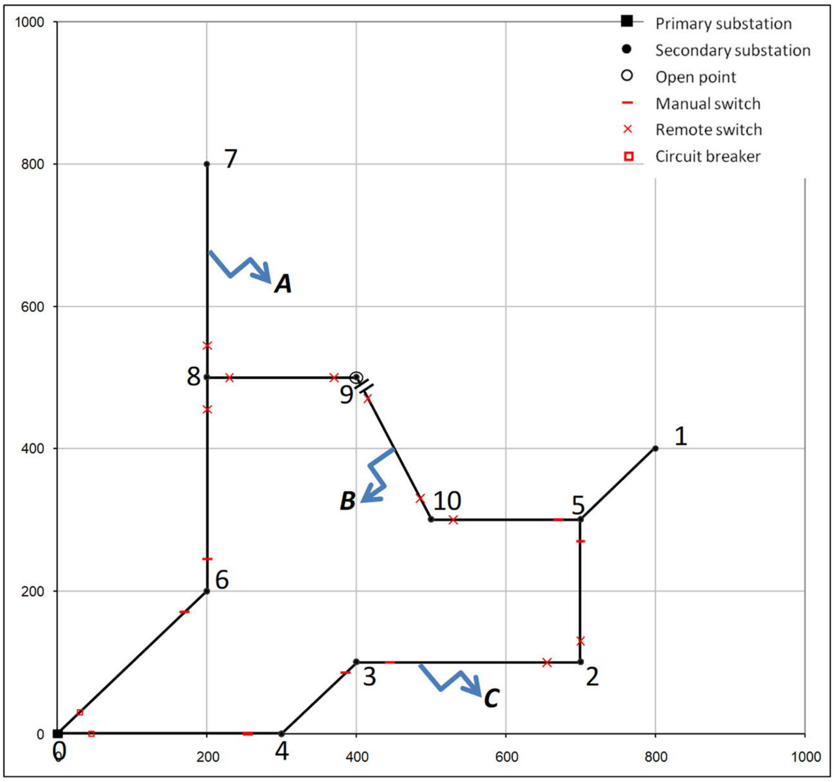
1. Examine the following distribution network.

   c) Which customers experience an interruption (due to a circuit-breaker opening) and for how long (repair + switching time, switching time, where switching may be remote or manual) when a fault occurs at point A? At point B? At point C?

Fault at A:	Fault at B:	Fault at C:
Interruption: customers 6, 8, 7, 9	Interruption: 4, 3, 2, 5, 1, 10	Interruption: 4, 3, 2, 5, 1, 10
Manual switch time: ---	Manual switch time: ---	Manual switch time: 4, 3
Remote switch time: 6, 8, 9	Remote switch time: 4, 3, 2, 5, 1, 10	Remote switch time: 2, 5, 1, 10
Repair (plus switch time): 7	Repair: ---	Repair: ---

   d) What is the total interruption cost caused by a single fault at point C if the CIC values for all customers are €1 / kW / fault and €10 / kWh, the manual switching time is 1h, the remote switching time is 0.15 h, the substation circuit breaker operating time is insignificant, the repair time is 10 h and the maximum demand (on which the CIC values are based) at each secondary substation is 1 MW?

   e)

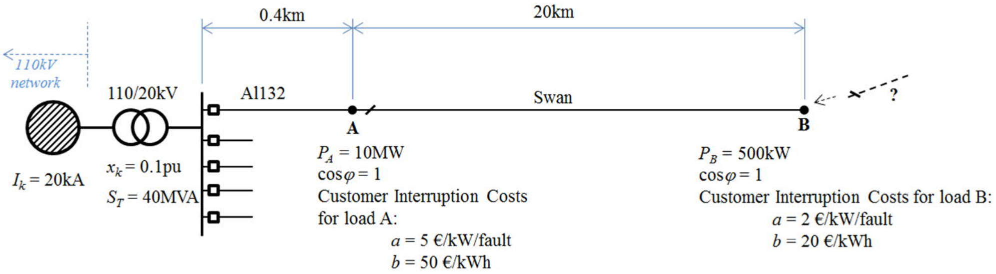


The cost of a single fault at C would be:

$$c_{\mathrm{int}} = A\sum_{i=1}^{I} P_i + B\left(\sum_{j=1}^{J} P_j T_{remote\_sw} + \sum_{k=1}^{K} P_k T_{manual\_sw} + \sum_{l=1}^{L} P_l T_{repair}\right)$$

$$= 1 \cdot 6 \cdot 1000 + 10\left(4 \cdot 1000 \cdot 0.15 + 2 \cdot 1000 \cdot 1 + 0\right) = 32000\ € \,/\, \text{fault at C}$$

2. A rural line connected to an industrial feeder



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Should a backup connection be provided to point B in Fig.1 if the connection including a manual switch costs 25 000 euros?

The load growth is 3 %/year, the interest rate is 5 %/year and the review period is 20 years. The manual switches at A and on the proposed backup connection take 30 minutes to operate. It is assumed that faults only occur one at a time (not simultaneously).

This formula may be of use: $\kappa = \gamma \dfrac{\gamma^t - 1}{\gamma - 1}$ where, for load related annual costs: $\gamma = \dfrac{(1 + r/100)}{(1 + p/100)}$

Answer: First, $\kappa = 16.44\ \text{(years?)}$, which converts load-related annual costs to the net present value of lifetime costs

Now, think about it! What benefit will the proposed backup connection offer?

Faults on Al132: will not benefit node A, but will benefit node B, which will only suffer an interruption lasting the switch time rather than repair plus switching, i.e. the repair component of the interruption cost is removed...

Faults on Swan section: will not benefit node A or B, unless a switch is also installed on the upstream side of node B, but that is not indicated in this question. So, we only have to calculate the benefit to node B when faults occur on Al132.

Please note that whatever we do in turns of switch placement and reserve connections has no effect on short interruptions (the ‘a’ KAH (CIC) €/kW/fault component), hence the 0s in the following equations.

$$C_{benefit} = 16.44(\text{years}) \cdot \frac{7(\text{faults})}{100(\text{km})} \cdot 0.4(\text{km}) \cdot \left(0 + 20\left(\frac{€}{\text{kWh}}\right) \cdot 3(\text{h})\right) \cdot 500(\text{kW}) = 13810\ €$$

This is less than the cost of the new connection (25 000 €), so it is not viable.

But, if for another 3500 € we could place another disconnector on the upstream side of node A, we would have additional benefit, in that a fault in line section A would only affect node A for the switch time rather than the repair plus switch time (this is a further benefit).

$$C_{further\_benefit} = 16.44\ \frac{7}{100} 0.4\big(0 + 50\ (3)\big)\ 10000 = 690480\ \ €$$

$$\begin{aligned} C_{total\_benefit} &= C_{benefit} + C_{further\_benefit} - C_{backup} - C_{switch} \\ &= 13810 + 690480 - 25000 - 3500 \\ &= 675790 \end{aligned}$$

This makes the backup connection with an additional small investment in a load breaking switch worthwhile from a reliability perspective, but what haven’t we checked?

Is it technically feasible? Can such a high load (10MW) be fed by a 20km length of Swan overhead line?

$I_{\max} = \frac{10 \cdot 10^6}{\sqrt{3} \cdot 20 \cdot 10^3} = 288$ A, which is way over the steady-state limit for this line.

If the line were replaced with Al132 conductors, would that be OK for voltage drop?

From ED&M03: $U_d = \sqrt{3}(IR\cos\varphi + IX\sin\varphi)$

$U_d \approx \sqrt{3} \cdot 288 \cdot (20 \cdot 0.219 \cdot 1 + 20 \cdot 0.348 \cdot 0) = 2185$, which is 11% - still a problem, given that the back-up connection itself will add to the voltage drop. The backup option is not really sensible then!

For the student to consider:

What about forgetting about the dubious backup connection with its ampacity and voltage problems, and replacing the manual switch on the downstream side of A with a remote switch or a circuit breaker...?