ELEC-E8406 2023 Electricity Distribution Network Planning Assignment: Due on March 20, midnight (or before!)

(Worth 0-50% of your final grade, whatever helps you the most, to be done in groups of 3 to 6)

A (Working-) Life Skill – Multiculturalism and Celebrating Differences

First, a few comments on a working life skill that has been integrated into this course. You are the victims of a group-forming algorithm that I use to create diverse groups, in terms of country of origin, academic discipline, gender and personality. In 'my' opinion (a subjective and partial view), country of origin, skin colour and religion are more superficial 'initial distinctions' than personality, but personality is very difficult to assess in a quick questionnaire – e.g., when I fill in a personality profile test, am I responding as I actually am, or as I would like to appear to the world? Have you noticed this?

What am I, actually? One view: an incredibly complex transient interweaving of evolving genetic proclivities interacting (epigenetically and memetically?) with multitude streams of conditioning. If we probe deeply what culture or rather culturing is, things like skin colour and even some crude personality stamping seem highly inadequate and limiting, and the crude attempts to classify human beings in these terms should be treated with some humour! One delightful recent finding is that the first "Englishmen" were dark-skinned [1]! It should also be stated clearly that there is nothing superior (or inferior) about a particular gender, skin colour, odour, ethnicity, country of origin, academic discipline, proclivity or personality type. Some of these are just symbols used for convenience in communication and social grouping, and others were appropriate instruments for survival in the savannah and jungle, but need not be overly identified with. For example, I do not have to cling to being a male to be a male – I just happen to be male – a rather unfashionable slightly off-white heterosexual male! Another observation from this life is that humans seem to be the most aggressively defensive about the things that have the least inherent reality (it is hardly necessary to defend the self-evident, and perhaps the 'self' itself is the biggest fiction of all [2]?)... Another observation is that how we are is largely accidental ("I" did not choose my parents, the environment I was born into, the genetic material I inherited, etc., etc…). This is not an excuse for fatalism. It just means that while we strive to do our best, act with integrity, clarity and compassion, we realise with gratitude that being able to do our 'best' is due to good luck in terms of conditioning (both environmental and genetic). We are all better off if we work to remove the institutional and cultural barriers that shackle both us, and the large swathe of humanity who are not so 'lucky', but equally worthy. I hope such a sentiment unites humanity, regardless of whether we lean left or right in our politics!

In the last few years, international students have been a bit thinner on the ground, but we have an increasing number of females in this field of study, which is long overdue! If some males contend engineering is in some sense "male", that is because males have made it so. It is to be hoped that a more heterogeneous grouping of human animals will increase the field's empathy, and help integrate the 'externalities' to end the days of exploitation and resource depletion that have accompanied the technological wealth accumulation for the minority.

What we have is a mixture of groups, ranging from 3 to 6 members, all of which are to some degree heterogeneous. Each of the 7.8 billion human life expressions on this planet are unique but, once again, this is not stuff to cling to. If it is, it is, and 'your' uniqueness is as incredible as 'mine'...

In your group work, then, try to celebrate the differences (which may occur even in the apparently homogeneous groups). Perhaps the biggest challenge in this course is dealing with the curly-haired disordered Kiwi, John, who tries to balance teaching, research, supervision, music, meditation, and friends and family in a rather too busy life! Realise that each of our views of the world or any particular part of it are filtered and bound to be distorted (unconscious bias [3]). Meeting people and situations where our views are challenged is of incredible benefit.

So, if you encounter disagreements, cross-cultural misunderstanding, or any stress-causing factor at all, that is part of the learning process! Take a few breaths, let go into the physical feeling of stress (or joy!), it is just what is arising, neither 'me' nor 'mine'... Speak to John if things become dysfunctional in your group! Let him know if things are going fine! Is Covid still a thing? The geopolitical strife on earth, our only home, is very evident. How do we still allow this?

Take it easy on yourselves. Close the laptop (and the mobile phone!) sometimes. Take a brief walk or do some stretches! Breathe!

Let this 2+7 week period of group work be an opportunity to reflect on interpersonal dynamics, as you collectively work towards the common goal of a good set of distribution network plans, and debate about the essay topic to craft a content and thought-rich essay! Let us hold our views lightly and be aware of our own highly conditioned nature, even whilst working, interacting and living passionately, and do not be afraid to challenge John's (slightly left-leaning) opinions!

References

[1] https://www.theguardian.com/science/2018/feb/07/first-modern-britons-dark-black-skin-cheddar-man-dna-analysis-reveals

[2] Jay L. Garfield, "Losing Ourselves: Learning to Live without a Self", Princetown University Press, Jul 19, 2022, ISBN: 9780691220284

[3] https://www.unconsciousbiasproject.org/resources/explain-unconscious-bias (accessed Dec. 30, 2022)

The Contemplation Exercise and Essay

i. **Get in touch with** your group members and decide whether you want to do the contemplation exercise (Exercise ii) as a group or individually, and begin discussions about which existential questions(s) (part iii) you will explore.

ii. A secular **contemplation exercise**: Audio recording of these instructions will be available soon.

- Sit with back upright but relaxed
- Start with the eyes relaxed and half-closed
- Let the eyes stay half-closed, or open, or close…
- Allow a few deeper breaths, but don't strain
- Let the breathing do its own thing, and be with the breathing
- Try and find the 'who' that is breathing, the seat of your attention, the 'you' in all this
- Smile with the paradox! (An eye or an "I" cannot see itself, fingertips cannot feel themselves!)
- Let go of any trying
- Just be with, and be OK with, whatever is arising (thoughts, emotions, sounds, images, whatever...)

iii. (**The essay**): What are the major existential crises (plural) your group identifies in our only home, planet earth? Choose one (or more) of these crises, not necessarily the most related to this course, that you would like to investigate in terms of root causes (including inappropriate human attitudes and behaviour). Suggest possible ways for humanity to negotiate its way through the crisis you have identified (including promoting appropriate human attitudes and behaviour). Provide an essay with 1 page per student member (so 5 pages for a group with 5 members). The essay can be passionate and express 'angst', it is not a language test, but some well-referenced fact-based material should also be included! You may use AI but please think critically and list all references (including Chat GTP, Grammarly, etc.). Any large chunks of text taken from any source should be put in quotation marks with a citation, e.g.,

"To be or not to be", Shakespeare, William. Hamlet. Edited by G. R. Hibbard, Oxford UP, 2008.

If you have time and are willing, repeat Exercise ii as a group after collectively creating the essay! Feel free to comment on this exercise in your essays and/or the "Learning Together" forum in MyCourses and/or in private discussion with John.

Suggested due date for essay: ***Midnight, February 14***

The Planning Task

The planning task gives you the opportunity to plan a realistic section of distribution network using futuristic load and DG data, and note, the *future* is approaching faster than expected! Each group is assigned a pair of fictitious primary substations, and a set of about 16 secondary substations, which should be sensibly placed in the region between (or close to) the two primary substations. Each substation has a given mix of consumption and generation that is based loosely on measured data from renewable DG-rich Germany and some demand increase to account for domestic electric vehicle charging and general electrification. The given load growth is chosen to nearly double the demand and distributed generation over the next 20 years. Your task is to plan and cost an MV (20 kV) network, including appropriate switching, backup, line type and conductor sizing. You will need the parameters given in the Appendices (A to E) to perform the distribution network planning task. You will complete the planning task **by verifying at least one aspect of your plan with a software tool**, such as Matlab Simscape® or a GIS/power flow tool developed by an AEE project group and former student of this course, Joona Kukkonen.

This document should contain sufficient help, data and information to perform the tasks. Organising the tasks evenly among group members will be logistically challenging, but that is part of the exercise. <u>You should schedule at least two 20 minute meetings (per group) with John</u>. In addition, he will be available in the lecture halls during the lecture periods when there are no lectures - it is advised that you use these 'free-from-lecture' sessions for working on the assignment. Zoom meetings are also an option if it is challenging for members of your group to come to campus. It is expected that you will need 30-40 hours per person, so get started and good luck!

John Millar, January 29, 2024.

Introduction

Figure 1 presents the assignment planning area and primary substation positions, taken from a beautiful region somewhere in the far north of this extraordinary planet that we are lucky to find ourselves on. The coordinates and information given in the Appendix will show you how to accurately locate the primary substations for your particular group's planning task on a map background to help you sensibly locate the secondary substations, plan the lines to suitably connect the substations, and measure their distances.

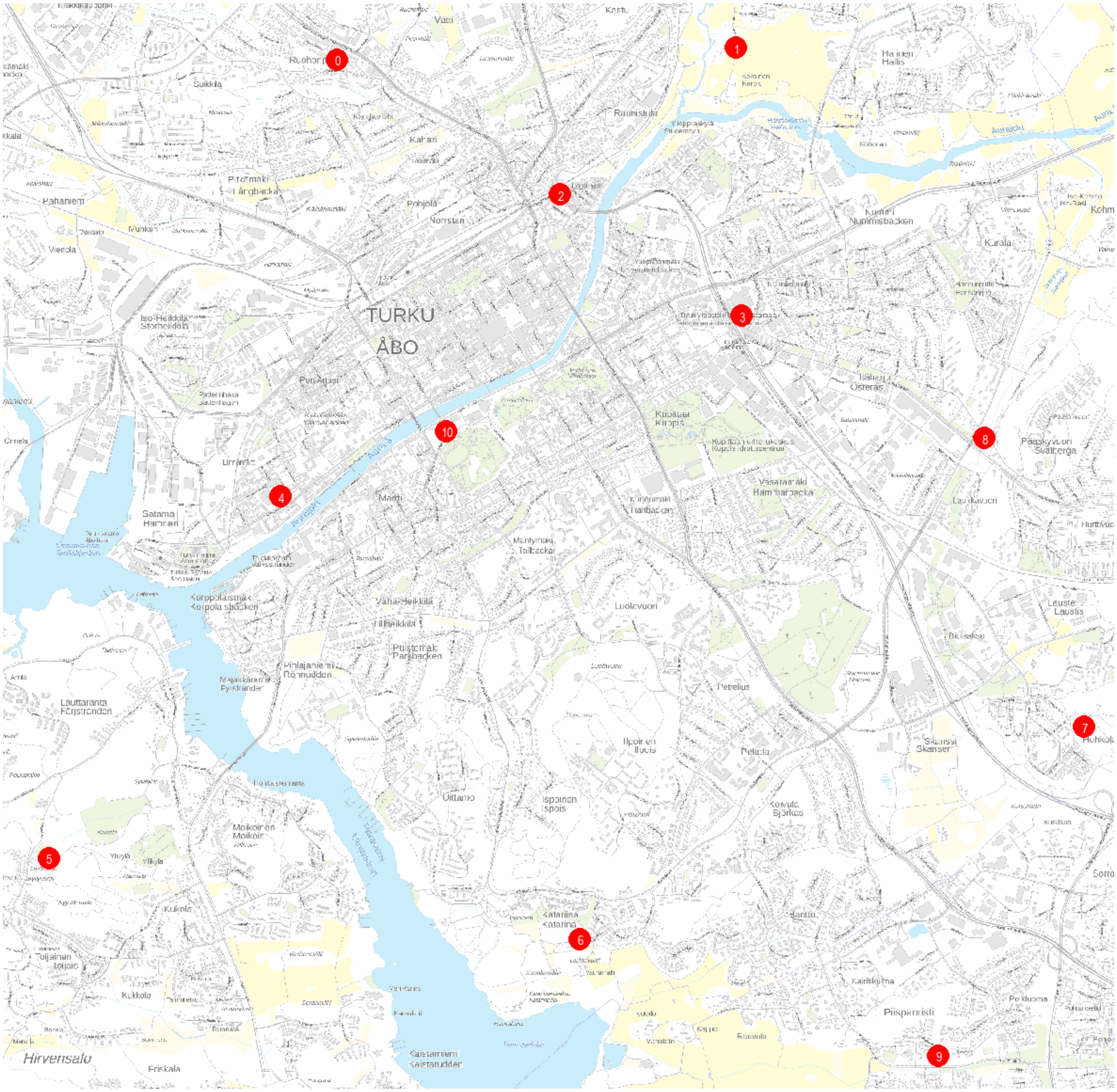

Figure 1 Planning area for 2023 assignment. Primary substation coordinates are ETRS89/ETRS-TM35FIN and are taken from the open-source map interface provided online by Fingrid (https://karttapalaute.fingrid.fi/#), Maan-Mittaus-Laitos (https://kartta.paikkatietoikkuna.fi/) and Google Maps

Task

Plan and cost (NPV) a radially operated network with appropriate switches and backup connections, and verify one aspect of your plan (e.g. one of the technical constraints) with an external software tool such as Matlab Simscape®

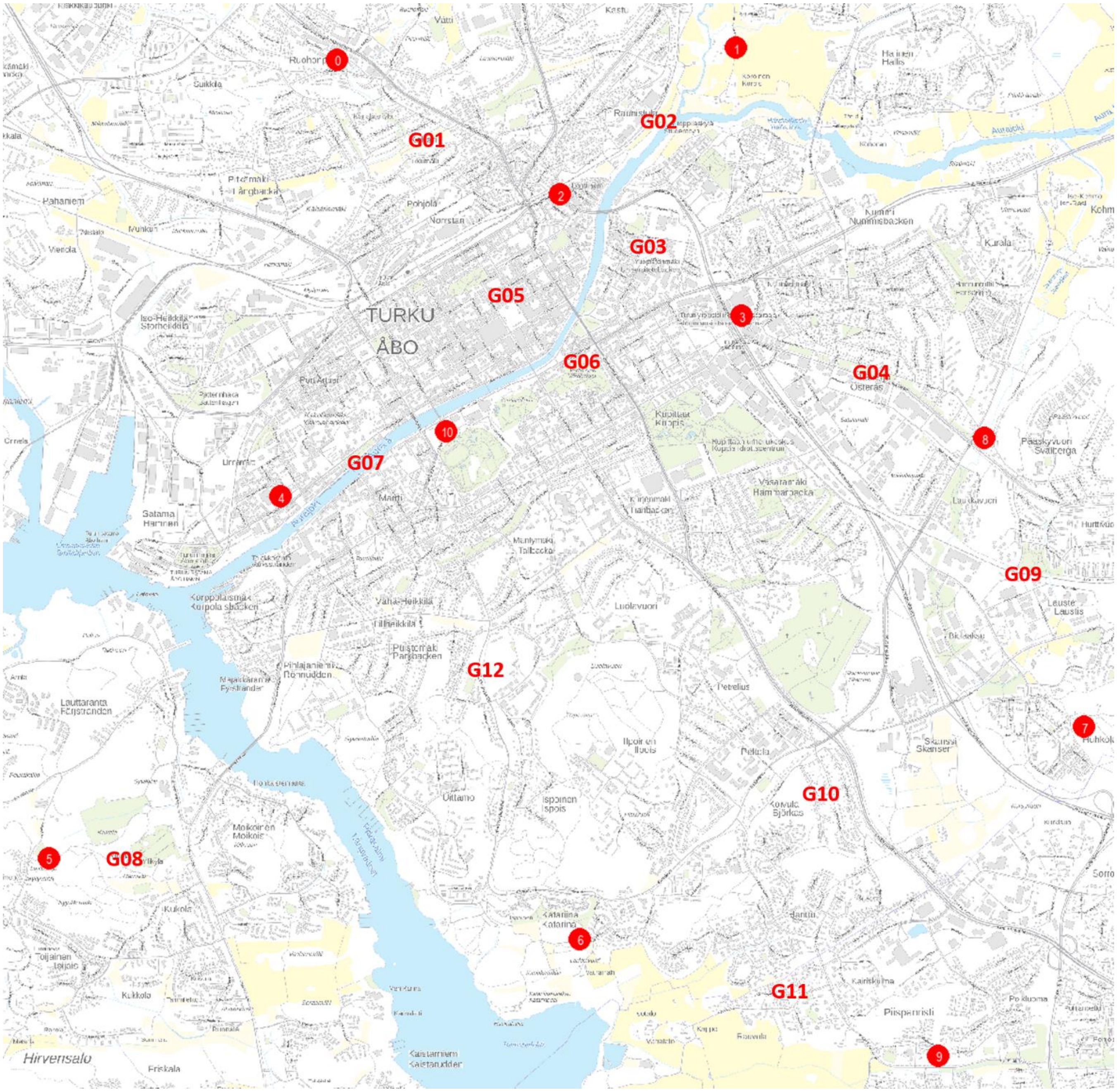

Figure 2 Regions between primary substations where each group should suitably locate their allocated secondary substations. Group 08 has only one primary substation

Plan and cost a distribution network that radially connects your group's allocated secondary substations to the feeding primary substation. These are listed in Table 2 in Appendix A. You can choose underground cables or bare overhead conductors in your network, or a combination of both. For switching, you can use manual and/or remote-operated load breaking switches, and even network circuit breakers, if appropriate. Use the fixed design parameters in Table 1.

- Assume a load growth of 3%/year for **20** years and a total review time of **40** years. Your costing should include:
    - investment costs (in the present)
    - the present value of the line ($3I^2R$) losses over the entire review period (**40** years)
    - the present value of the interruption costs from permanent faults.
- Line sections connected to the primary substations have circuit breakers, and each primary substation (main 20 kV feeder) connection has a cost.
- The network should be radially operated. Show where the open point(s) are. **You should be aware of the 6 h interruption limit for urban/suburban customers and plan accordingly if that's where your planning area is…**
- Your network plan should be technically viable, also during contingencies, and reasonably cost-effective!
- You should verify (at least) one of the technical constraints with an external tool, such as Matlab Simscape®

Appendix B gives a couple of useful map links and shows one way of calculating line route lengths. The data uses the coordinate system ETRS89/ETRS-TM35FIN.

Table 1 Fixed parameters for Task A

p	interest rate	4 %
r	load growth	3.0 % for 20 years
a & b	CIC values	1.23 €/kW & 12.3 €/kWh
c_l	Cost of energy losses	0.06 €/kWh

Other costs and parameters, e.g., for switches, feeder connections and lines, can be found in Appendix C. Interruption costs and other nodal data are given in Tables 2, 3 and 4.

Assume a voltage of **19.5 kV at every secondary substation** node in the network – that will push currents up and thus err on the safe side. You do not need to run a full load flow (unless you want to!), but use upstream summation of the active and reactive power components to calculate the load transfers in each line section assuming that there are no losses in the lines. The cost of losses, however, should of course be calculated, and for that, you will need the utilisation time for losses, $\boldsymbol{T_{\text{losses}}}$, related to the maximum (demand-related) power flow in each line section, which, to make things simpler, are assumed to be 3000 h/year for every node, as given in Table 4 in Appendix A. See Appendix D for the discount factors that you will need to convert the yearly loss-based costs and load-based costs to the net present value (NPV). **You should use higher than nominal voltages at the primary substations** for maximum 3-phase short circuit currents (**e.g. 20 kV + 10%**).

Submission instructions

Provide your final solution (one per group) for each part in a word-based report and your calculations in Excel. Make both documents as clear as possible – showing the methodology and results in the word document, and the numerical calculations in Excel. **Please have mercy on John!** Make your work easy to grade! Make sure all the data used on one sheet is visible on that sheet! Remember that you will have the chance to earn back 2 points if you correct 2 errors – so clear work will help you do this if needed!

Either submit the documents (the essays, the planning task and a power point presentation with the main conclusions from both) **via MyCourses**, or if there is a problem with that, email the documents to john.millar@aalto.fi before midnight on March 20, with the subject heading “**ELEC-E8406: Distribution Network Planning Assignment for group xx**”, where “xx” is your group number!

Appendix A: Nodal Data

Table 2 gives the substation node references for each group. HV grid and primary substation parameters are given in Table 3, and their coordinates are given in red in Table 4. You can also get the load data for each node (secondary substation) from Table 4. Please make sure that the load data for all your nodes are in Table 4. Let John know if there are any problems, missing data or you have a primary substation in the middle of a lake! You must locate the secondary substations yourselves by studying maps and using common sense. Note, you will have to make two load flow calculations, one for maximum demand / minimum generation (P_{max} and Q_{max}), and another for minimum demand /maximum generation (P_{min} and Q_{min}). Remember load growth for technical constraints!

Table 2 Substation node references, a column for each group. Note that the **second and third rows (in red)** are the node references for your primary substations. The rest of the rows in your column give the node references for the secondary (20/0.4kV) substations.

G 1	G 2	G 3	G 4	G 5	G 6	G 7	G 8	G9	G10	G11	G12
0	**1**	**2**	**3**	**2**	**3**	**4**	**7**	**5**	**6**	**6**	**10**
2	**2**	**3**	**8**	**10**	**10**	**10**	**8**		**7**	**9**	**6**
11	27	43	59	75	91	107	123	139	155	171	187
12	28	44	60	76	92	108	124	140	156	172	188
13	29	45	61	77	93	109	125	141	157	173	189
14	30	46	62	78	94	110	126	142	158	174	190
15	31	47	63	79	95	111	127	143	159	175	191
16	32	48	64	80	96	112	128	144	160	176	192
17	33	49	65	81	97	113	129	145	161	177	193
18	34	50	66	82	98	114	130	146	162	178	194
19	35	51	67	83	99	115	131	147	163	179	195
20	36	52	68	84	100	116	132	148	164	180	196
21	37	53	69	85	101	117	133	149	165	181	197
22	38	54	70	86	102	118	134		166	182	198
23	39	55	71	87	103	119	135		167	183	199
24	40	56	72	88		120					
25	41	57	73	89		121					
26	42	58	74	90		122					

Note, it may be that I've got something wrong in the table above, so if you find that you have a primary substation in the middle of nowhere, shift it to a more sensible location, but make sure you give John the new coordinates! It is your job to place your secondary substations appropriately!

Table 3 HV grid and primary substation parameters

Node IDs	110 kV grid	Main transformer	
	S_k (MVA)	u_k (p.u.)	S_N (MVA)
0 to 10	2400	0.1	2x40

Table 4 Network nodal parameters – select the ones relevant for your group planning task. Nodes **0** to **13** are feeding primary substations

Node ID	Coordinates, ETRS89/ETRS-TM35FIN		Load						CIC-parameters	
	X (East) (m)	*Y* (North) (m)	P_{max} (kW)	P_{min} (kW)	Q_{max} (kvar)	Q_{min} (kvar)	T_{losses}[1] (h/a)	$f_{coincidence}$	*a* (€/kW)	*b* (€/kWh)
0	238504.04	6712910.74	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
1	241345.64	6712993.94	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
2	240091.24	6711950.74	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
3	241384.04	6711085.14	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
4	238100.84	6709798.74	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
5	236449.64	6707225.94	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
6	240232.03	6706649.94	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
7	243822.44	6708160.34	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
8	243112.03	6710214.74	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
9	242785.64	6705817.94	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
10	239281.12	6710264.74	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
11	233326.44	6711009.94	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
12	233460.84	6712269.14	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
13	235668.84	6712048.34	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
14			902	-1330	227	2	3000	1	1.23	12.3
15			757	-1176	116	26	3000	1	1.23	12.3
16			470	461	45	25	3000	1	1.23	12.3
17			613	395	42	0	3000	1	1.23	12.3
18			632	-80	20	8	3000	1	1.23	12.3
19			341	-182	79	22	3000	1	1.23	12.3
20			429	-1236	133	23	3000	1	1.23	12.3
21			328	-12	124	17	3000	1	1.23	12.3
22			305	-223	185	11	3000	1	1.23	12.3
23			615	-402	114	10	3000	1	1.23	12.3
24			708	159	21	16	3000	1	1.23	12.3
25			613	-966	51	15	3000	1	1.23	12.3
26			483	-879	50	17	3000	1	1.23	12.3
27			989	323	132	2	3000	1	1.23	12.3
28			494	36	100	7	3000	1	1.23	12.3
29			647	-329	193	6	3000	1	1.23	12.3
30			649	476	64	14	3000	1	1.23	12.3
31			442	-380	130	7	3000	1	1.23	12.3
32			801	-133	72	29	3000	1	1.23	12.3
33			828	-269	149	4	3000	1	1.23	12.3
34			689	-988	109	20	3000	1	1.23	12.3
35			505	-424	47	6	3000	1	1.23	12.3
36			569	215	111	2	3000	1	1.23	12.3
37			604	-937	139	13	3000	1	1.23	12.3
38			969	-1245	222	2	3000	1	1.23	12.3

[1] Loss utilisation time is the number of hours at maximum power that would yield the same losses that occur in a year of normal operation. To make things easier (since we are not giving you time series data), we assume loss times are the same (3000 h) and coincidence is 1.

39			927	-696	220	18	3000	1	1.23	12.3
40			844	734	50	29	3000	1	1.23	12.3
41			502	232	70	23	3000	1	1.23	12.3
42			468	-777	89	2	3000	1	1.23	12.3
43			953	-35	165	12	3000	1	1.23	12.3
44			434	-939	2	7	3000	1	1.23	12.3
45			387	254	71	10	3000	1	1.23	12.3
46			786	270	7	29	3000	1	1.23	12.3
47			477	-698	53	17	3000	1	1.23	12.3
48			401	-963	46	17	3000	1	1.23	12.3
49			420	-542	201	26	3000	1	1.23	12.3
50			662	90	81	24	3000	1	1.23	12.3
51			941	-1356	31	9	3000	1	1.23	12.3
52			827	-1497	69	22	3000	1	1.23	12.3
53			673	-466	107	7	3000	1	1.23	12.3
54			423	-919	176	8	3000	1	1.23	12.3
55			594	457	98	4	3000	1	1.23	12.3
56			780	-608	73	28	3000	1	1.23	12.3
57			336	-805	156	18	3000	1	1.23	12.3
58			964	-1211	10	29	3000	1	1.23	12.3
59			674	89	17	16	3000	1	1.23	12.3
60			527	444	129	28	3000	1	1.23	12.3
61			1007	-847	25	13	3000	1	1.23	12.3
62			426	-1120	69	19	3000	1	1.23	12.3
63			458	-79	102	11	3000	1	1.23	12.3
64			306	240	207	2	3000	1	1.23	12.3
65			351	-39	205	8	3000	1	1.23	12.3
66			400	-673	124	0	3000	1	1.23	12.3
67			962	617	229	20	3000	1	1.23	12.3
68			775	-1114	52	26	3000	1	1.23	12.3
69			421	-423	90	29	3000	1	1.23	12.3
70			643	643	94	21	3000	1	1.23	12.3
71			336	-1090	67	6	3000	1	1.23	12.3
72			634	-131	189	5	3000	1	1.23	12.3
73			807	-14	28	6	3000	1	1.23	12.3
74			768	550	54	2	3000	1	1.23	12.3
75			538	-200	95	16	3000	1	1.23	12.3
76			642	163	203	7	3000	1	1.23	12.3
77			305	-1393	10	9	3000	1	1.23	12.3
78			1020	475	186	29	3000	1	1.23	12.3
79			548	-167	85	8	3000	1	1.23	12.3
80			977	-172	141	19	3000	1	1.23	12.3
81			717	-1101	186	15	3000	1	1.23	12.3
82			656	-991	189	8	3000	1	1.23	12.3
83			651	338	163	24	3000	1	1.23	12.3
84			467	-1289	69	26	3000	1	1.23	12.3
85			392	-1380	117	11	3000	1	1.23	12.3
86			957	848	123	19	3000	1	1.23	12.3
87			1017	-495	29	12	3000	1	1.23	12.3

88			316	-525	22	29	3000	1	1.23	12.3
89			327	-1061	136	2	3000	1	1.23	12.3
90			656	260	154	15	3000	1	1.23	12.3
91			904	230	201	11	3000	1	1.23	12.3
92			689	-1022	6	16	3000	1	1.23	12.3
93			820	-938	70	19	3000	1	1.23	12.3
94			330	110	140	18	3000	1	1.23	12.3
95			709	-418	54	0	3000	1	1.23	12.3
96			782	-1272	145	27	3000	1	1.23	12.3
97			952	-1475	132	0	3000	1	1.23	12.3
98			775	-337	214	26	3000	1	1.23	12.3
99			628	-1395	195	11	3000	1	1.23	12.3
100			893	-1453	135	8	3000	1	1.23	12.3
101			488	-1431	191	11	3000	1	1.23	12.3
102			576	-757	134	24	3000	1	1.23	12.3
103			508	-215	174	12	3000	1	1.23	12.3
104			411	-510	64	27	3000	1	1.23	12.3
105			856	220	8	26	3000	1	1.23	12.3
106			865	-415	136	24	3000	1	1.23	12.3
107			673	547	121	23	3000	1	1.23	12.3
108			923	-880	82	19	3000	1	1.23	12.3
109			494	-653	179	7	3000	1	1.23	12.3
110			363	-264	153	23	3000	1	1.23	12.3
111			870	736	163	4	3000	1	1.23	12.3
112			748	-605	102	10	3000	1	1.23	12.3
113			741	686	112	7	3000	1	1.23	12.3
114			327	-1380	177	28	3000	1	1.23	12.3
115			488	-174	86	17	3000	1	1.23	12.3
116			782	-137	11	28	3000	1	1.23	12.3
117			821	-295	211	11	3000	1	1.23	12.3
118			458	-1030	120	20	3000	1	1.23	12.3
119			715	110	33	14	3000	1	1.23	12.3
120			847	765	107	10	3000	1	1.23	12.3
121			918	-609	174	21	3000	1	1.23	12.3
122			862	572	71	21	3000	1	1.23	12.3
123			948	-1475	51	21	3000	1	1.23	12.3
124			339	104	193	8	3000	1	1.23	12.3
125			441	-930	38	26	3000	1	1.23	12.3
126			620	597	104	17	3000	1	1.23	12.3
127			310	-1144	210	21	3000	1	1.23	12.3
128			932	179	184	6	3000	1	1.23	12.3
129			641	496	17	9	3000	1	1.23	12.3
130			587	-240	153	19	3000	1	1.23	12.3
131			550	542	35	3	3000	1	1.23	12.3
132			376	-90	170	3	3000	1	1.23	12.3
133			325	-465	124	4	3000	1	1.23	12.3
134			386	334	211	1	3000	1	1.23	12.3
135			398	-750	135	25	3000	1	1.23	12.3
136			852	-907	218	24	3000	1	1.23	12.3

137			991	-746	224	21	3000	1	1.23	12.3
138			343	-370	199	4	3000	1	1.23	12.3
139			409	-1404	153	22	3000	1	1.23	12.3
140			467	-487	156	9	3000	1	1.23	12.3
141			987	791	166	14	3000	1	1.23	12.3
142			791	-254	39	7	3000	1	1.23	12.3
143			877	-599	217	23	3000	1	1.23	12.3
144			882	-658	204	0	3000	1	1.23	12.3
145			539	-141	201	0	3000	1	1.23	12.3
146			856	-1253	22	15	3000	1	1.23	12.3
147			901	-480	4	18	3000	1	1.23	12.3
148			470	-513	114	19	3000	1	1.23	12.3
149			632	400	213	2	3000	1	1.23	12.3
150			435	3	211	22	3000	1	1.23	12.3
151			577	427	17	9	3000	1	1.23	12.3
152			713	692	122	23	3000	1	1.23	12.3
153			696	-256	127	6	3000	1	1.23	12.3
154			989	-656	8	11	3000	1	1.23	12.3
155			573	-1310	172	18	3000	1	1.23	12.3
156			359	-266	216	5	3000	1	1.23	12.3
157			652	-1053	172	16	3000	1	1.23	12.3
158			466	317	3	18	3000	1	1.23	12.3
159			964	-172	226	5	3000	1	1.23	12.3
160			627	-1423	73	9	3000	1	1.23	12.3
161			538	-141	73	11	3000	1	1.23	12.3
162			598	-1033	109	27	3000	1	1.23	12.3
163			459	-517	73	29	3000	1	1.23	12.3
164			1005	-1127	60	12	3000	1	1.23	12.3
165			665	80	102	24	3000	1	1.23	12.3
166			563	-158	65	7	3000	1	1.23	12.3
167			450	-460	88	20	3000	1	1.23	12.3
168			537	-552	30	15	3000	1	1.23	12.3
169			1012	991	66	9	3000	1	1.23	12.3
170			889	-1254	173	22	3000	1	1.23	12.3
171			838	692	178	4	3000	1	1.23	12.3
172			323	297	199	9	3000	1	1.23	12.3
173			456	-1400	106	14	3000	1	1.23	12.3
174			537	-378	11	27	3000	1	1.23	12.3
175			927	-76	1	1	3000	1	1.23	12.3
176			520	-115	151	13	3000	1	1.23	12.3
177			335	185	142	2	3000	1	1.23	12.3
178			644	206	131	22	3000	1	1.23	12.3
179			970	-926	11	0	3000	1	1.23	12.3
180			811	-1128	203	18	3000	1	1.23	12.3
181			710	-407	208	12	3000	1	1.23	12.3
182			512	186	65	24	3000	1	1.23	12.3
183			555	-1343	43	8	3000	1	1.23	12.3
184			621	-1058	82	24	3000	1	1.23	12.3
185			464	-196	181	5	3000	1	1.23	12.3

186			684	618	32	27	3000	1	1.23	12.3
187			624	62	32	28	3000	1	1.23	12.3
188			697	-1246	160	9	3000	1	1.23	12.3
189			691	-930	3	23	3000	1	1.23	12.3
190			871	-72	41	8	3000	1	1.23	12.3
191			656	-727	66	27	3000	1	1.23	12.3
192			492	-994	133	0	3000	1	1.23	12.3
193			403	-86	87	3	3000	1	1.23	12.3
194			704	-597	34	16	3000	1	1.23	12.3
195			446	-498	156	18	3000	1	1.23	12.3
196			952	-593	185	20	3000	1	1.23	12.3
197			568	-847	207	28	3000	1	1.23	12.3
198			416	-795	173	20	3000	1	1.23	12.3
199			329	-1415	224	23	3000	1	1.23	12.3
200			794	357	95	12	3000	1	1.23	12.3
201			621	-1079	227	15	3000	1	1.23	12.3
202			902	458	100	24	3000	1	1.23	12.3
203			372	260	173	8	3000	1	1.23	12.3
204			499	-1123	23	13	3000	1	1.23	12.3
205			630	-672	194	9	3000	1	1.23	12.3
206			381	-1430	102	23	3000	1	1.23	12.3
207			688	-190	151	12	3000	1	1.23	12.3
208			990	-1355	164	16	3000	1	1.23	12.3
209			702	-445	52	22	3000	1	1.23	12.3
210			323	-1326	80	9	3000	1	1.23	12.3
211			358	-1354	135	14	3000	1	1.23	12.3
212			814	-10	91	24	3000	1	1.23	12.3
213			785	-789	82	9	3000	1	1.23	12.3
214			524	-775	169	19	3000	1	1.23	12.3
215			898	-521	93	21	3000	1	1.23	12.3
216			782	184	131	22	3000	1	1.23	12.3
217			372	-872	39	15	3000	1	1.23	12.3
218			389	-1353	176	13	3000	1	1.23	12.3
219			810	-1032	116	26	3000	1	1.23	12.3
220			920	-1306	229	22	3000	1	1.23	12.3
221			423	-439	104	23	3000	1	1.23	12.3
222			888	-821	194	12	3000	1	1.23	12.3
223			915	813	96	20	3000	1	1.23	12.3
224			736	80	85	13	3000	1	1.23	12.3
225			748	-704	155	9	3000	1	1.23	12.3
226			786	-1342	125	6	3000	1	1.23	12.3
227			985	819	186	18	3000	1	1.23	12.3
228			386	-1494	119	1	3000	1	1.23	12.3
229			761	-70	35	10	3000	1	1.23	12.3
230			728	-157	68	16	3000	1	1.23	12.3
231			494	-376	208	16	3000	1	1.23	12.3
232			534	-1306	94	24	3000	1	1.23	12.3
233			851	-1228	76	12	3000	1	1.23	12.3
234			775	-1350	112	18	3000	1	1.23	12.3

235			656	452	95	2	3000	1	1.23	12.3
236			453	-310	183	8	3000	1	1.23	12.3
237			930	-31	163	24	3000	1	1.23	12.3
238			363	-564	20	26	3000	1	1.23	12.3
239			362	246	213	28	3000	1	1.23	12.3
240			600	-1017	151	4	3000	1	1.23	12.3
241			935	717	212	22	3000	1	1.23	12.3
242			510	-1147	94	4	3000	1	1.23	12.3
243			431	221	50	23	3000	1	1.23	12.3
244			515	309	145	6	3000	1	1.23	12.3
245			915	-1169	211	13	3000	1	1.23	12.3
246			644	-1261	11	10	3000	1	1.23	12.3
247			1016	-531	187	16	3000	1	1.23	12.3
248			999	-1455	215	8	3000	1	1.23	12.3
249			498	-1478	210	14	3000	1	1.23	12.3
250			789	-1337	127	18	3000	1	1.23	12.3
251			913	-623	73	21	3000	1	1.23	12.3
252			580	-1176	210	7	3000	1	1.23	12.3
253			1001	-474	34	29	3000	1	1.23	12.3
254			965	358	93	2	3000	1	1.23	12.3
255			434	-1454	184	1	3000	1	1.23	12.3
256			788	-748	118	11	3000	1	1.23	12.3
257			889	824	67	14	3000	1	1.23	12.3
258			993	126	28	11	3000	1	1.23	12.3
259			389	-1192	143	26	3000	1	1.23	12.3
260			649	-1454	175	22	3000	1	1.23	12.3
261			954	624	142	10	3000	1	1.23	12.3
262			450	-1258	134	19	3000	1	1.23	12.3
263			455	-1034	11	7	3000	1	1.23	12.3
264			973	892	100	18	3000	1	1.23	12.3
265			543	-941	9	26	3000	1	1.23	12.3
266			818	-1124	145	13	3000	1	1.23	12.3
267			459	-1358	193	25	3000	1	1.23	12.3
268			1003	-934	227	7	3000	1	1.23	12.3
269			733	-1273	75	6	3000	1	1.23	12.3
270			987	944	80	27	3000	1	1.23	12.3
271			662	-1097	64	6	3000	1	1.23	12.3
272			530	-1167	142	6	3000	1	1.23	12.3
273			1003	-624	93	29	3000	1	1.23	12.3
274			599	-1258	55	13	3000	1	1.23	12.3
275			659	504	27	5	3000	1	1.23	12.3
276			485	361	95	2	3000	1	1.23	12.3
277			774	-1118	228	7	3000	1	1.23	12.3
278			538	-1259	208	22	3000	1	1.23	12.3
279			366	-1264	185	3	366	-1264	185	3
280			485	-98	215	27	485	-98	215	27
281			926	-1447	162	18	926	-1447	162	18
282			945	423	211	27	945	423	211	27

There are two types of nodes in the network: primary substations (110/20 kV) that serve as feeding points for your network and secondary substations (20/0.4 kV). Secondary substations represent the demand and, in many cases, distributed generation, including the lumped demand/generation of the substations outside the planning task area.

Appendix B: Geography

When you select the line types for each of the internodal (substation-to-substation) connections, use your engineering rationale to judge where lines should be located. Your network areas are mostly suburban or rural, and so you could investigate which is more suitable, underground cable or overhead line, noting that lake crossings of more than 200m should be cabled (underwater). Your network sections are close to the primary substations, so that may also influence your decision about line type, not to mention the increasing frequency of unusual weather events and changing legislation about long interruptions...

The methodology for viewing your network area and calculating distances shown below in Figs. 3 and 4 is based on the website: http://kansalaisen.karttapaikka.fi, but you might find http://www.paikkatietoikkuna.fi easier to work with. Note that your coordinate system is ETRS89/ETRS-TM35FIN.

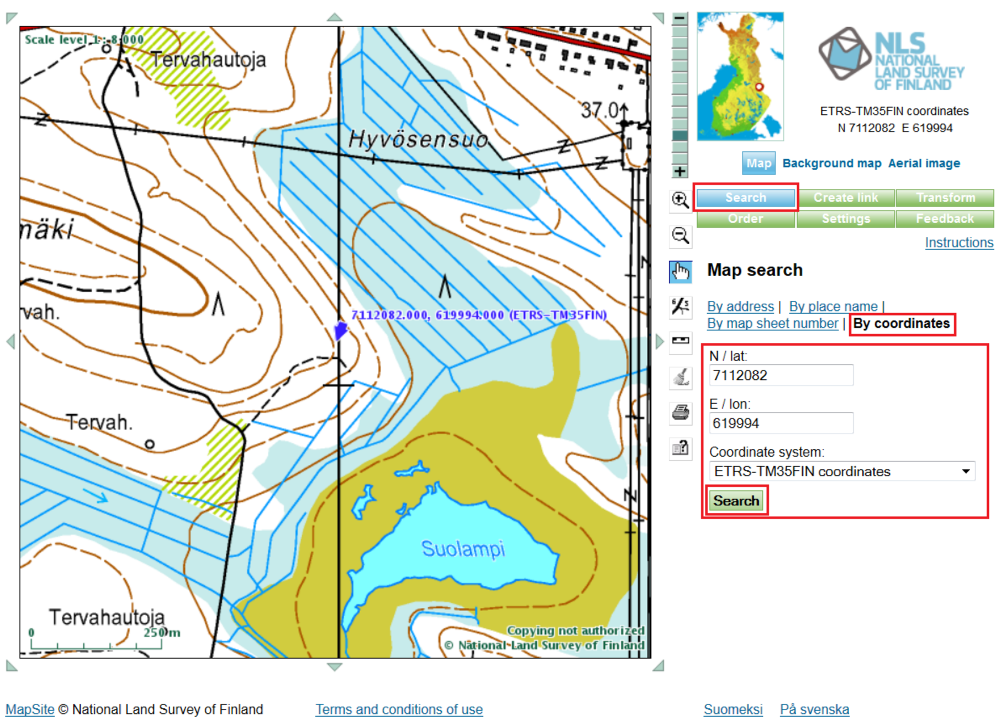

Figure 3 One way to locate nodes

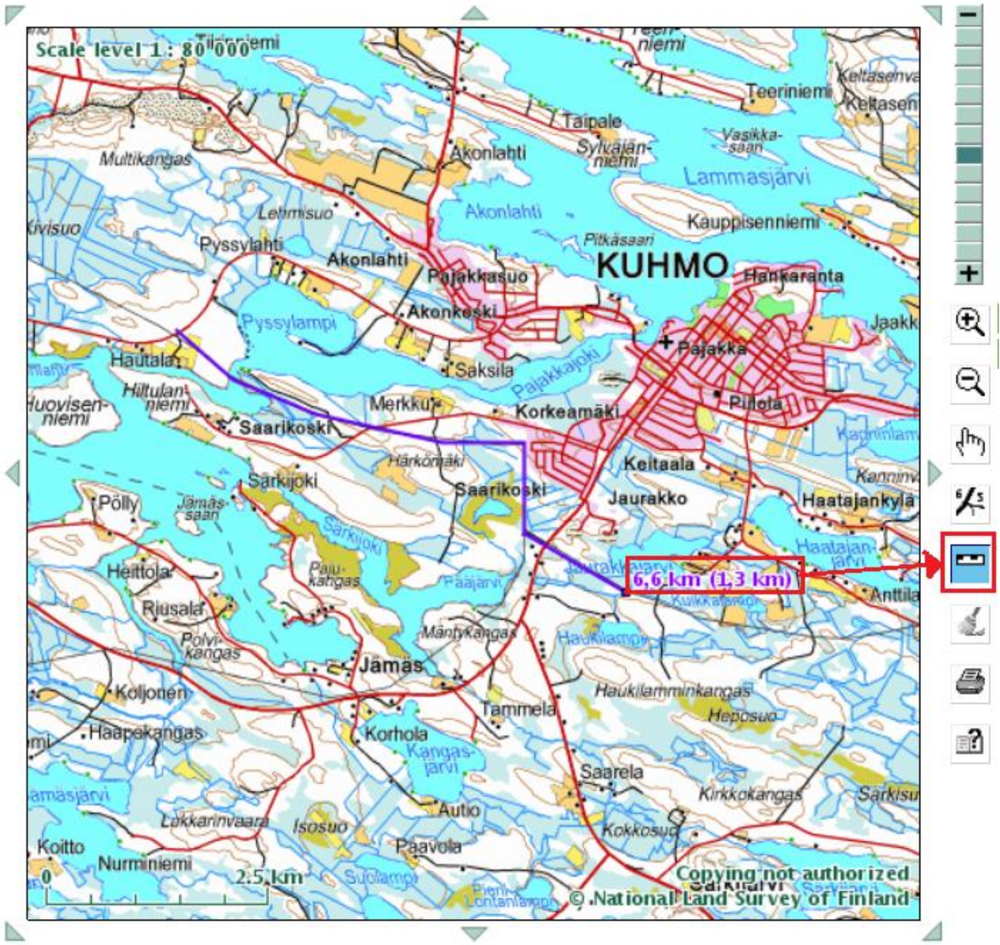

Figure 4 One way to calculate distances

Appendix C: Cost Data, reliability and time parameters

Table 5. Network cost data. Note that remote switches and circuit breakers need one master station at each location (node).

manual switches	switch	6100 €
remote switches	master station	800 €
	switching device	11600 €
field circuit breakers	master station	1000 €
	circuit breaker	25700 €
primary substation MV feeder connections (including main circuit breaker)		50000 €

Table 6. Switching times

Manual switch	1 h
Remote switch	0.08 h (~5 min)
Circuit breaker (substation and field)	0.00015 h (~0.5 sec)

Table 7. Line type data

	OHL	UGC
fault rate (1/100km/a)	7	1
repair time (h)	4	12
Allowable max. normal/contingency Voltage Drop	7% / 10%	3.5% / 7%

Allowable max. normal/contingency Voltage Rise	3.0% / 6.0%	3.0% / 6.0%

The line cost and technical data for underground cables (UGC) and bare conductor overhead line (OHL) are given in Tables 9 and 10. Advice on how to construct cost functions can be found in Appendices D and E, but note, for logistic reasons, try to avoid using too many cable sizes if you choose underground cables.

Table 9. OHL costs and parameters

	Fixed cost (€/m)	**Resistance** (Ω/km)	**Reactance** (Ω/km)	I_{max} (A)	$I_{k,1s}$ (kA)
Al/Fe 54/9 (Raven)	22.75	0.535	0.368	280	5.3
Al/Fe 85/14 (Pigeon)	24.56	0.337	0.354	360	8.4
Al/Fe 106/25 (Suur-Savo)	27.66	0.279	0.344	430	10.5
2 x Al/Fe 106/25	55.32	0.140	0.172	860	21.0

Table 10. UGC costs and parameters (use these costs for underground and underwater cables)

	Fixed cost (€/m)	**Resistance** (Ω/km)	**Reactance** (Ω/km)	I_{max} (A)	$I_{k,1s}$ (kA)
AHXAMK 50 mm2	72.94	0.641	0.145	155	4.7
AHXAMK 150 mm^2	82.04	0.250	0.123	300	14.5
AHXAMK 240 mm^2	90.24	0.150	0.110	385	22.6
2 x AHXAMK 240 mm^2	130.48	0.075	0.055	770	45.2
Overhead line to underwater cable connection [2]	6000.00€ per connection				
Underground cable T-joint	3000.00€ per T-joint				

Appendix D: Discount factors, i.e., capitalization factors

Because of the effect of load growth and interest rates, the present value of costs over the review period is not just the number of years in the review period times the annual costs. This would only be the case if there were no interest rate and no load growth! For this assignment you need to be able to assess the present value of the network(s) in this assignment.

The total costs C_{LCC} of each network will be (see Appendix E for some hints on conductor choice):

$C_{LCC} = C_I + C_L + C_F$

- C_I, the investment costs
- C_L, the cost of losses over the review period
- C_F, the cost of outages over the review period

You need the following formulae:

$$\gamma = \frac{(1+r)}{(1+p)}, \quad \gamma_1 = \frac{(1+r)^2}{(1+p)} \quad \text{and} \quad \gamma_2 = \frac{1}{1+p} \qquad \text{(1), (2) and (3)}$$

[2] Includes cable (pole) termination, surge arrestors, microtunneling, etc.

$$\kappa_{losses} = \gamma_1 \frac{\gamma_1^{t'} - 1}{\gamma_1 - 1} + \frac{(1+r)^{2t'}}{(1+p)^{t'}} \gamma_2 \frac{\gamma_2^{T-t'} - 1}{\gamma_2 - 1} \qquad (4)$$

$$\kappa_{load} = \gamma \frac{\gamma^{t'} - 1}{\gamma - 1} + \frac{(1+r)^{t'}}{(1+p)^{t'}} \gamma_2 \frac{\gamma_2^{T-t'} - 1}{\gamma_2 - 1} \qquad (5)$$

where

r is load growth
p is interest rate
T is review period and
t' is load growth period.

One principle in the above formulae is that resistive line loss ($3I^2R$) related costs vary quadratically with load growth, whereas load related costs (e.g. outage costs) rise linearly with load growth. The fact that money tends to lose value going into the future lessens the effect of these increases – the interest rate expressions are in the denominators...

For example, using the above formulae for a load growth *r* of 3% for a load growth period *t'* of 20 years, an interest rate *p* of 4 % over the full review period *T* of 40 years, you should get: κ_{losses} = 45.04 and κ_{load} = 29.3. If *r* = 0.12 % for 40 years and *p* = 4 %, then κ_{losses} = 20.55 and κ_{load} = 20.17. **Note, these are only examples, the load growth and interest rate for your assignment planning task may be different…**

Appendix E: Conductor cost curves for each line type

For each line type there are a number of conductor sizes (conductor family), whose parameters are given in

Table 10. You will need to assess the appropriate conductor sizes when assessing the costs. For this, you need to consider the investment cost plus the loss related costs as a function of power transfer for each conductor size. The best thing to illustrate this is a graph; see Figure 2 below. However, for logistic reasons, the same conductor size would probably be used for all line sections in a given section of distribution network, especially with underground cables.

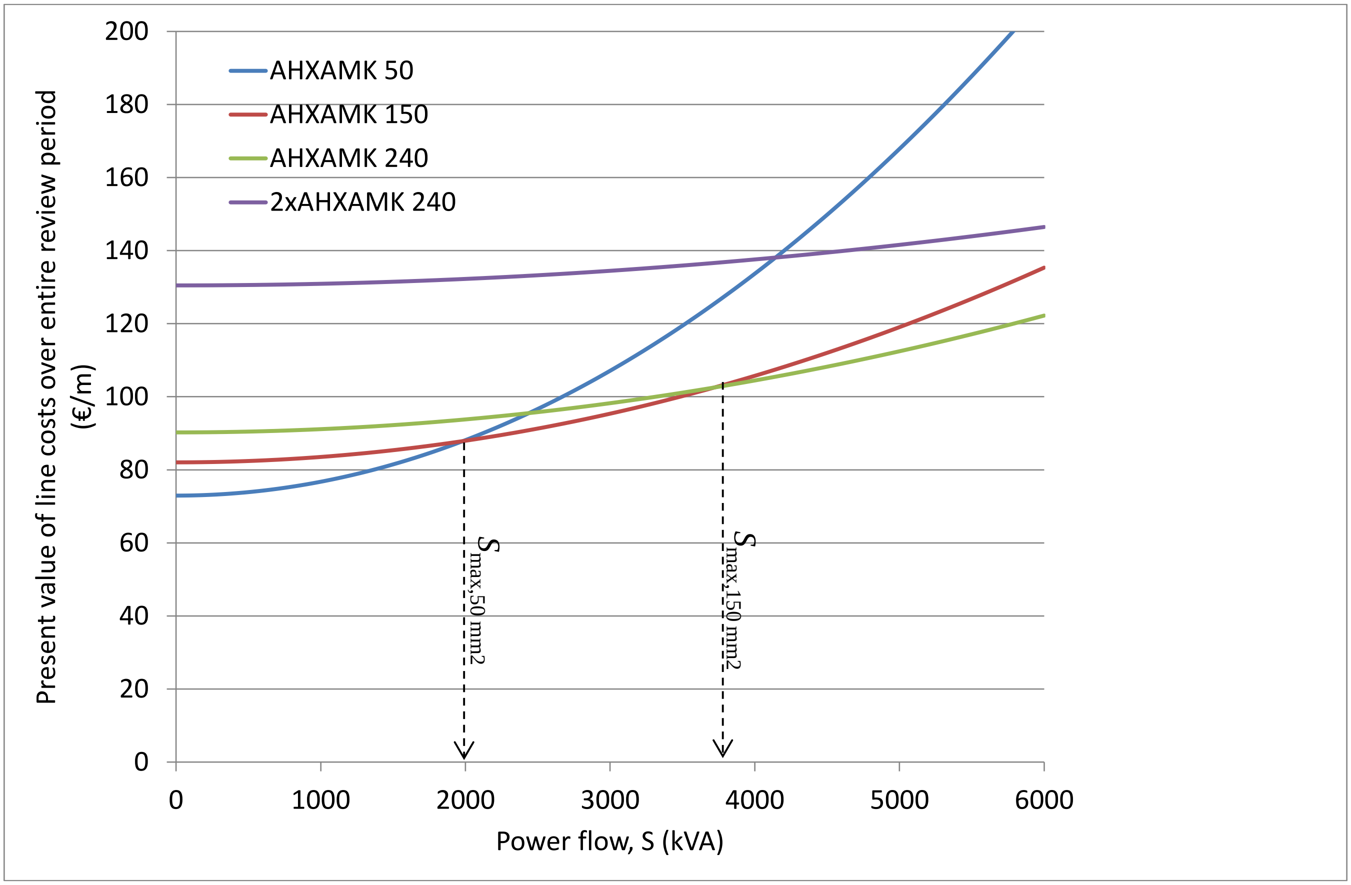

Figure 5. A typical cost curve for an underground cable conductor family (although you may prefer to find the best single-size for all sections if you have a suburban cable network)

The economic upper limit for the apparent power through a given conductor cross-section can be calculated using the equation:

$$S_{\max} = U\sqrt{\frac{c_{Ib} - c_{Ia}}{\kappa_{losses} c_l (r_a - r_b) \cdot T_{losses}}}$$ You should be able to derive this formula!

where

- U is the main voltage,
- c_{1a} is the investment cost (€/km) for the given conductor size,
- c_{1b} is the investment cost (€/km) for the next larger conductor size,
- c_l is the cost of losses (€/kWh)
- r_a is the resistance (Ω/km) for the given conductor size and
- r_b is the resistance (Ω/km) for the next larger conductor size.