Distribution assignment

Analysis of electric power Systems, 10c

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Task 1

In this task the suitable loading conditions for the simulations is determined.
First the peak power of a group of customers (households) was estimated using Velanders formula

$$P = K_1 W + K_2 \sqrt{W}$$

and the minimum power is estimated to be 20% of the peak power.

The reactive loads of the cables were calculated assuming a constant power factor of 0.9
High-load and low-load cases for both active and reactive power is shown in *Table 2.*

Figure 1. Residential middle-voltage distribution grid.

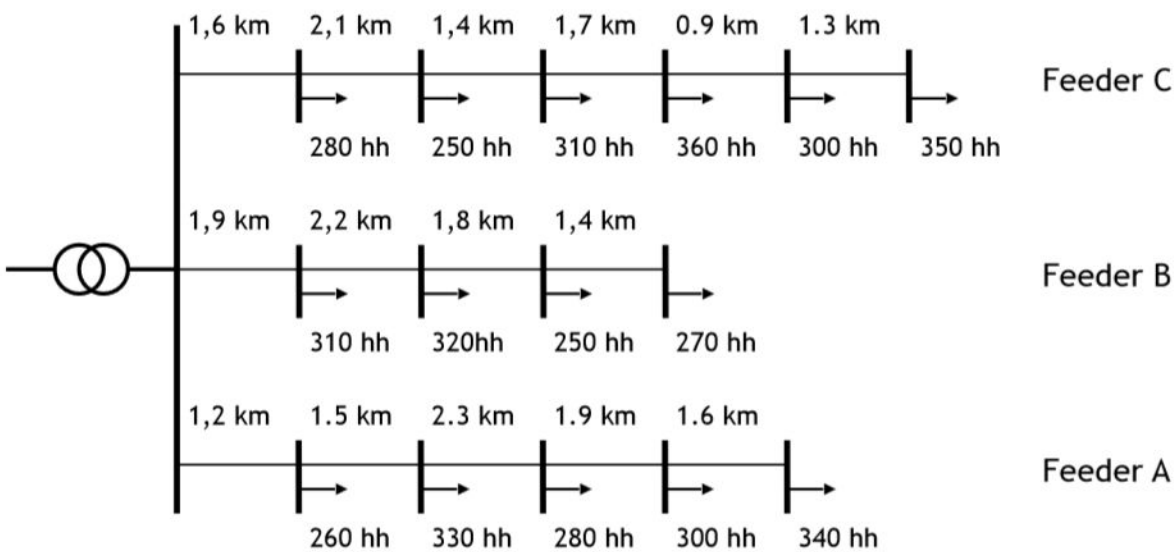

Figure 2. Model built in Power world for the low load case with defined bus numbers

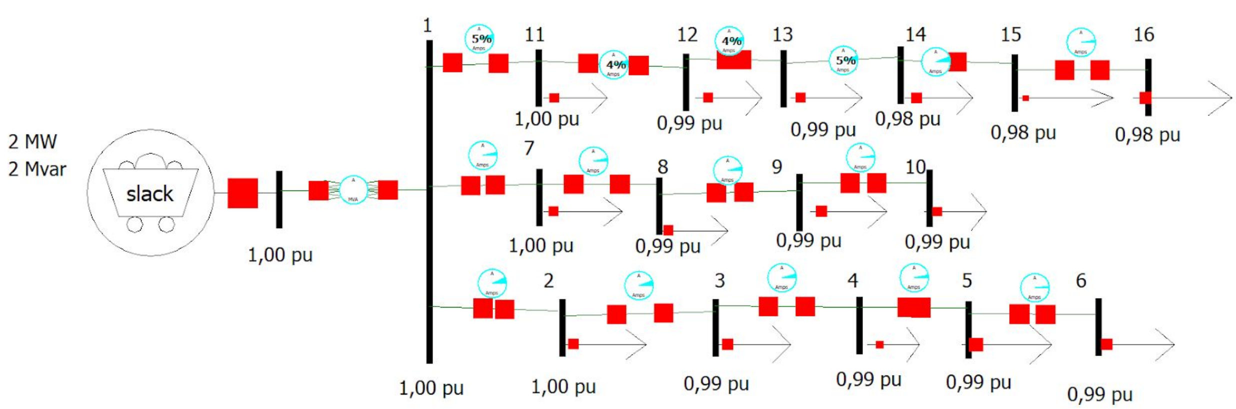

Table 1. Customer data and Velander coefficients.

Feeder	House type	Avg. electricity use per house and year	K_1	K_2
A	Single family house with electric heating	13 MWh	0.000300	0.0250
B	Single family house without electric heating	7 MWh	0.000161	0.1170
C	Single family house without electric heating	7 MWh	0.000161	0.1170

Table 2. Real and Reactive power for the buses.

Feeder A		**P max [kW]**	**P min [kW]**	**Q max [kVAr]**	**Q min [kVAr]**
	Bus 2	1059,96	211,99	513,36	102,67
	Bus 3	1338,78	267,76	648,40	129,68
	Bus 4	1139,70	227,94	551,98	110,40
	Bus 5	1219,37	243,83	590,57	118,11
	Bus 6	1378,56	275,60	667,67	133,53
Feeder B					
	Bus 7	521,72	104,34	252,67	50,54
	Bus 8	535,75	107,15	259,48	51,90
	Bus 9	436,53	87,31	211,42	42,28
	Bus 10	465,14	93,03	225,28	45,06
Feeder C					
	Bus 11	479,36	95,87	232,16	46,43
	Bus 12	436,53	87,31	211,42	42,28
	Bus 13	521,72	104,34	252,68	50,54
	Bus 14	591,45	118,29	286,45	57,29
	Bus 15	507,62	101,52	245,87	49,17
	Bus 16	577,58	115,52	279,74	55,95

Task 2

In this task a 10 kV residential middle-voltage (MV) distribution grid, as shown in *figure 1,* is designed. The resulting model made in Power World can be seen in figure 2.

The simplified voltage drop equation $V_d = \frac{P}{V_s} \cdot (R + X_s tan\ \phi)$ is used to calculate the voltage drop between two points.

When selecting a cable, all bus voltages must be within 0.95 and 1.05 p.u.

The voltage drops over all cables are calculated and then summed and cables are chosen such that the total voltage drop from the feeder to the last bus is not more than 0.05 p.u.

The final grid in terms of cable types and operational characteristics such as bus voltages, losses etc is shown in *Table 3.* The low load characteristics are presented in parenthesis.

Table 3. Voltage drop for different lines with different cable types [V].

Line/Cable	**A**	**B**	**C**	**D**
1-2	805	511	217	144
2-3	833	528	225	149
3-4	940	596	254	168
4-5	540	342	146	96
5-6	241	153	65	43
1-7	407	258	110	73
7-8	346	219	93	62
8-9	178	113	48	32
9-10	71	45	19	13
1-11	545	346	147	97
11-12	605	384	163	108
12-13	337	214	91	60
13-14	312	198	84	56
14-15	107	68	29	19
15-16	82	52	22	15

The voltage drops according to table 3 determined the selected cable types for the different lines that can be seen in table 4. These cables minimizes the voltage drop without over sizing the cables which is assumed to result in a greater cost.

Table 4. Cable selection and cable parameters for high load and low load*. Low load case is shown in parenthesis.*

	Section	Cable Type	Voltage drop [p.u]	Cable loadings [%]	Active power losses [MW]	Reactive power losses [Mvar]
Feeder A						
	Line 1-2	D	0.0144	33,9 (6,9)	0,027 (0,001)	0,164 (0,007)
	Line 2-3	D	0.0149	28,2 (5,7)	0,016 (0,001)	0,094 (0,004)
	Line 3-4	D	0.0168	20,9 (4,2)	0,020 (0,001)	0,119 (0,005)
	Line 4-5	D	0.0096	14,6 (2,9)	0,008 (0,000)	0,048 (0,002)
	Line 5-6	D	0.0043	7,8 (5,1)	0,002 (0,000)	0,011 (0,000)
Feeder B						
	Line 1-7	C	0.0101	14,3 (2,9)	0,013 (0,001)	0,026 (0,001)
	Line 7-8	B	0.0160	28,2 (3,2)	0,028 (0,001)	0,022 (0,001)
	Line 8-9	A	0.0147	20,1 (4,0)	0,016 (0,001)	0,007 (0,000)
	Line 9-10	A	0.0060	10,4 (2,1)	0,003 (0,000)	0,001 (0,000)
Feeder C						
	Line 1-11	D	0.009731	16,9 (4,9)	0,009 (0,001)	0,056 (0,005)
	Line 11-12	D	0.008666	14,4 (4,5)	0,009 (0,001)	0,053 (0,005)
	Line 12-13	D	0.006013	12,0 (4,0)	0,004 (0,000)	0,024 (0,003)
	Line 13-14	C	0.008416	12,2 (4,7)	0,008 (0,001)	0,017 (0,003)
	Line 14-15	B	0.006775	11,9 (6,0)	0,006 (0,002)	0,005 (0,001)
	Line 15-16	A	0.008212	12,7 (2,6)	0,005 (0,000)	0,002 (0,000)

In the high load simulation a transformer tap ratio of 0,95 was utilized to achieve satisfactory bus voltages within the range of 1,05 and 0,95 p.u. whereas in the low load simulation the tap ratio was set to 1,00; this resulted in bus 1 voltages of 1.05 and 1.00 p.u. respectively.

The impedance for the transformer was set to 0,04 p.u which seems like a normal value for a commercial transformer of the same size.

In table 4 the bus voltages in the Power World simulation can be seen. Bus 1 is defined as the bus connected to the transformer. Buses 2-6 is defined as the buses in feeder A. Bus 7-10 is defined as the buses for feeder B. Bus 11-16 is defined as the buses for feeder C. See figure 2 for definition of bus numbers.

Table 5. Bus voltages low load and high load cases

	High load bus voltage [p.u.]	**Low load bus voltage [p.u.]**
Bus 1	1,05	1,00
Bus 2	1,04	1,00
Bus 3	1,02	0,99
Bus 4	1,01	0,99
Bus 5	1,00	0,99
Bus 6	0,99	0,99
Bus 7	1,04	1,00
Bus 8	1,02	0,99
Bus 9	1,00	0,99
Bus 10	0,99	0,99
Bus 11	1,04	1,00
Bus 12	1,03	0,99
Bus 13	1,02	0,99
Bus 14	1,02	0,98
Bus 15	1,01	0,98
Bus 16	1,00	0,98

Task 3

In this task the case of every house being nearly-zero energy buildings (NZEBs) when PV generation is implemented. Each house generates 900 kWh per year per installed kW_p. Different degrees of PV integration and different distribution of PV systems along the feeders are simulated. All simulations are done for the low-load case since it is more interesting.

For all simulations the low load case was used together with the following data:

- Total yearly energy needed: 40 630 MWh /yr
- PV: 45 144 KW_P for 100% integration
- PV: 33 858 KW_P for 75% integration
- PV: 22 572 KW_P for 50% integration

Case 1-3: All the PV generation is installed on bus 6

Table 6. All PV integration installed on bus 6.

Case			**50% PV integration**	**75% PV integration**	**100% PV integration**
System losses [MW]			*3,13*	*6,11*	*9,74*
		PV Gen.	**Bus voltage [p.u.]**	**Bus voltage [p.u.]**	**Bus voltage [p.u.]**
	Bus 1		*0,99*	*0,99*	*0,99*
Feeder A					
	Bus 2	0	*0,93*	*0,93*	*0,94*
	Bus 3	0	*0,87*	*0,88*	*0,91*
	Bus 4	0	*0,81*	*0,87*	*0,98*
	Bus 5	0	*0,79*	*0,92*	*1,11*
	Bus 6	100%	*0,80*	*1,0*	*1,26*
Feeder B					
	Bus 7	0	*0,99*	*0,99*	*0,99*

	Bus 8	0	*0,98*	*0,98*	*0,98*
	Bus 9	0	*0,98*	*0,98*	*0,98*
	Bus 10	0	*0,98*	*0,98*	*0,98*
Feeder C					
	Bus 11	0	*0,99*	*0,99*	*0,99*
	Bus 12	0	*0,98*	*0,98*	*0,98*
	Bus 13	0	*0,98*	*0,98*	*0,98*
	Bus 14	0	*0,98*	*0,97*	*0,97*
	Bus 15	0	*0,97*	*0,97*	*0,97*
	Bus 16	0	*0,97*	*0,97*	*0,97*

Case 4-6: The total PV generation is divided among the last buses of the feeders

Case 4-6: The total PV generation is divided among the last buses of the feeders, i.e. a third each is placed on bus 6, 10 and 16. Again integration of 50%, 75% and 100% is tested. The results are shown in *Table 5.*

Table 7. The PV generation is evenly distributed among last buses of the feeders.

Case			**50% PV integration**	**75% PV integration**	**100% PV integration**
System losses			**2,66**	**5,46**	**9,12**
		PV Gen. [p.u]	**Bus voltage [p.u.]**	**Bus voltage [p.u.]**	**Bus voltage [p.u.]**
	Bus 1		*1,00*	*1,00*	*0,99*
Feeder A					
	Bus 2	0	*1,00*	*0,99*	*0,98*
	Bus 3	0	*0,99*	*0,98*	*0,97*
	Bus 4	0	*1,00*	*0,98*	*0,96*

	Bus 5	0	*1,00*	*0,99*	*0,96*
	Bus 6	⅓	*1,00*	*0,99*	*0,97*
Feeder B					
	Bus 7	0	*1,01*	*1,01*	*1,01*
	Bus 8	0	*1,07*	*1,09*	*1,10*
	Bus 9	0	*1,16*	*1,22*	*1,27*
	Bus 10	⅓	*1,24*	*1,32*	*1,40*
Feeder C					
	Bus 11	0	*0,99*	*0,99*	*0,98*
	Bus 12	0	*0,99*	*0,98*	*0,96*
	Bus 13	0	*0,99*	*0,98*	*0,96*
	Bus 14	0	*1,00*	*0,99*	*0,97*
	Bus 15	0	*1,03*	*1,03*	*1,03*
	Bus 16	⅓	*1,10*	*1,14*	*1,17*

Case 7-9: The total PV generation is divided among the first buses of the feeders

Case 7.9: The total PV generation is divided among the first buses of the feeders, i.e. a third each is placed on bus 2, 5 and 11. Again integration of 50%, 75% and 100% is tested. The results are shown in *Table 6.*

Table 8. The PV generation is evenly distributed among the first buses of the feeders.

Case			**50% PV integration**	**75% PV integration**	**100% PV integration**
System losses [MW]			**0,21**	**0,48**	**0,86**
		PV Gen. [p.u]	**Bus voltage [p.u.]**	**Bus voltage [p.u.]**	**Bus voltage [p.u.]**
	Bus 1	0	*1,00*	*1,00*	*1,00*

Feeder A					
	Bus 2	⅓	*1,00*	*1,00*	*1,00*
	Bus 3	0	*1,00*	*1,00*	*1,00*
	Bus 4	0	*0,99*	*1,00*	*1,00*
	Bus 5	0	*0,99*	*0,99*	*0,99*
	Bus 6	0	*0,99*	*0,99*	*0,99*
Feeder B					
	Bus 7	⅓	*1,02*	*1,03*	*1,03*
	Bus 8	0	*1,01*	*1,02*	*1,03*
	Bus 9	0	*1,01*	*1,02*	*1,03*
	Bus 10	0	*1,01*	*1,02*	*1,03*
Feeder C					
	Bus 11	⅓	*1,00*	*1,00*	*1,00*
	Bus 12	0	*1,00*	*1,00*	*1,00*
	Bus 13	0	*0,99*	*0,99*	*1,00*
	Bus 14	0	*0,99*	*0,99*	*0,99*
	Bus 15	0	*0,99*	*0,99*	*0,99*
	Bus 16	0	*0,98*	*0,99*	*0,99*

Task 4

Some general conclusion or observation regarding NZEBs are that integration of PV systems require thoughtful consideration because distributed generation alters the power flow of the entire system and in many cases will overload the distribution lines - the thermal limitations of the lines may be exceeded. Moreover the voltage profile of the lines are too altered in such a way that it can result in overvoltage at the buses, especially in the low-load case. It can also be very beneficial and prevent undervoltage in the most distant buses. When the PV-production was concentrated on the last bus for each feeder the low capacity lines of each feeder became overloaded.

The optimal case would probably be to have the PV-production evenly distributed over the buses.