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Electric Vehicles Impact to the Low Voltage Distribution Network

Abstract

The electric vehicles (EVs) are aimed to be a permanent substitute for the combustion engine powered vehicle in the foreseeable future. The aim of this study is to examine the effects of the charging processes of electric vehicles on the existing low voltage distribution network. In order to examine the effects of the charging process, four similarly built areas of detached houses and terraced houses were chosen for a deeper investigation and electro technical calculation. The calculations were made both by using network information system (NIS) and by using index data. According to the index data calculation the average increase of peak load is 35 %. According to the network information system calculation the average increase of peak load is 27 % and the average transition of the transformer load rate is 26 %. The index data calculation indicated that the peak load was shifted by an hour from 22.00 o´clock to 23.00 o´clock by the effect of the charging process. The current strength of the cables proved not to be a limiting factor. On the other hand, the average of voltage reduction turned out to be 1,7 %. Even though the calculations assume that the existing car fleet is instantaneously replaced by the electric vehicles and therefore represents the worst case analysis, the four low voltage distribution networks seem to withstand the increased peak load comparatively well, especially when the progressive redesigning of the existing network is taken into consideration.

Introduction

It is predicted that the present combustion engine powered vehicle fleet will be replaced by electric vehicle in the foreseeable future in order to reduce the amount of CO_2 emissions and the consumption of fossil fuels albeit the precise market penetration time remains still unknown. The range of operation of a plug-in type electric vehicle (PHEV) depends to a great extent on the batteries. On that account, to be able to utilize the EV in everyday life the batteries of the PHEV will require periodic charging daily. Since the weather in Finland is cold during the winter time, vehicles need to be preheated in order to avoid the motor damages caused by the cold weather. For that reason, the infrastructure of car preheating electric networks is already commonly available. Since it can be assumed that the vehicle is most of the time at home excluding the journey to and from the work, the charging process of the PHEV is most probably carried out by using the existing low voltage networks at home. Therefore, it is reasonable to examine the effects of the charging process on the low voltage feed area of the secondary substation and the probability of reinvestments. In the review the concentration is on the areas of electrically heated detached houses that are heavily loaded especially during the winter season. The calculations are carried out by using the Fortum's network information system and the spreadsheet program Excel.

Definition for Electric Vehicle load

In order to define the required year energy of the electric vehicle, the average annual driving distance of the chosen residential area has to be determined. In addition, the average energy consumption of the electric vehicle per kilometre has to be measured. According to the latest national travel survey which was carried out for the Finnish Rail Administration, the Finnish National Road Administration and the Ministry of Transport and Communication during years 2004 and 2005 in Finland illustrates that the average annual driving distance per car is 20 900 km. [1] Therefore, the average daily driving distance per car becomes 57 km.

Since the cold weather in Finland requires noticeable amounts of energy for heating purposes, the energy consumption of the electric vehicle at winter time is assumed to be considerable. The actual energy consumption of the electric vehicle in Finland at winter time has lately been measured by a Nordic company. According to the measurements, the average energy consumption of the electric vehicle in Finland at winter time is approximately 0,20 - 0,25 kWh/km. [2] The batteries of the electric vehicle are presumed to be 30 kWh/car. By using the before mentioned information the outcome of energy required by the electric vehicle is approximately 11,5 kWh/day. Hereby, the annual energy consumed by the electric vehicle is circa 4,2 MWh.

In order to simulate the effects of the electric vehicle charging process on the low voltage (LV) feed area of the secondary substation, the concentration is on four comparable low voltage feed areas in this review. All of the chosen LV feed areas are situated outside of city. In addition, all the four LV feed areas consist of electrically heated detached houses, terraced houses and low-rise buildings that are built in the eighties. The network structure of the low voltage feed areas is composed both of cables and overhead lines. An example of the network structure is shown in figure 1.

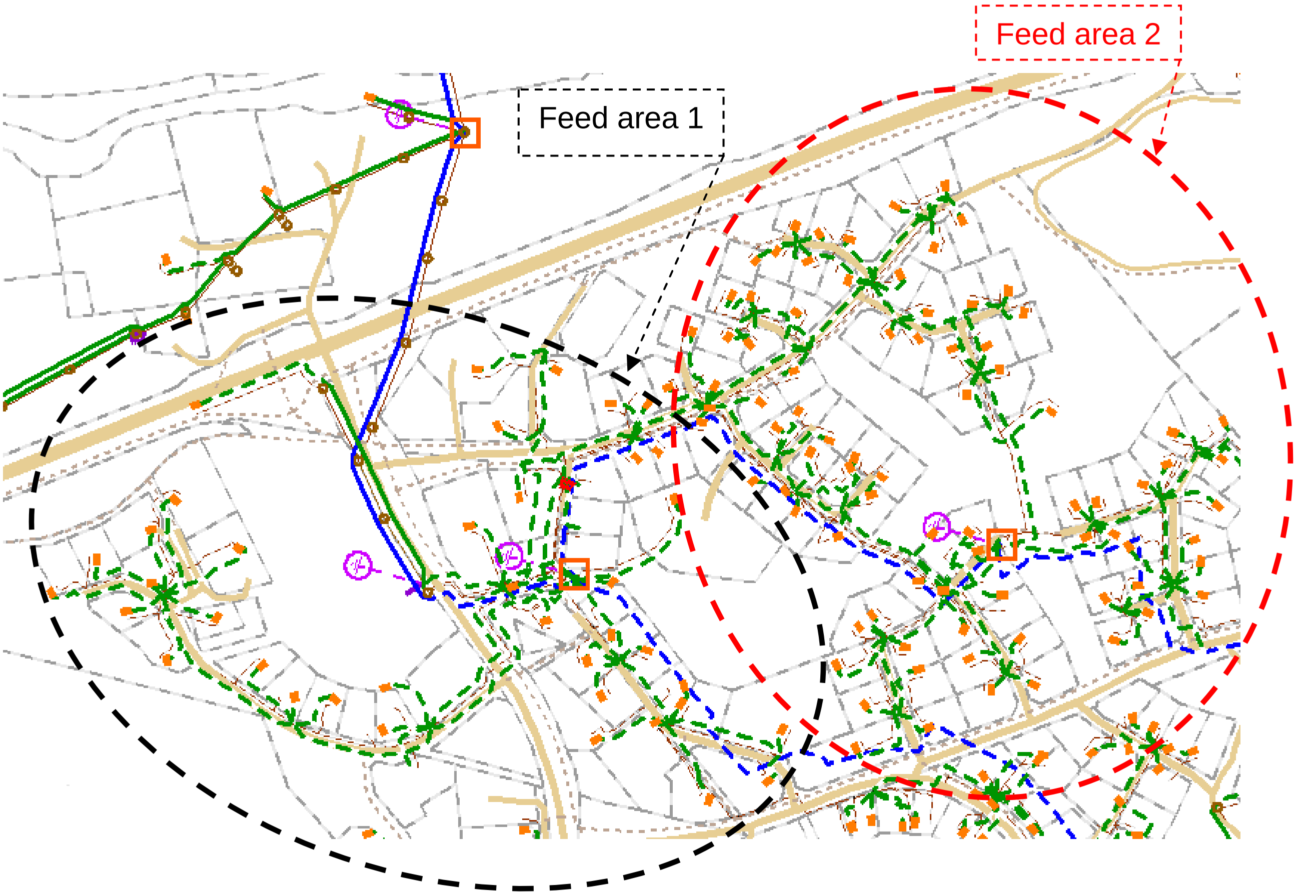

Figure 1. An example of a network structure employed in the review.

The blue colour in the figure represents medium voltage (MV) network (20 kV) and the green colour represents the low voltage network (0,4 kV). Underground cables can be recognized from dashed lines and overhead cables are drawn by using coherent lines. Even though the four feed areas have close to similar settlement, the network structures of the feed areas are different which complicates the comparison of the results. The network structures of the low voltage feed areas 1 and 2 have been designed in the eighties by using only underground cables. Correspondingly, the low voltage feed areas 3 and 4 have been designed by using overhead lines which have been replaced by the underground cables during the years. The overhead lines cover approximately 45 households (87 %) in the feed area 3 and 16 households (37 %) in the feed area 4.

The average quantity of cars for every household can be defined separately for each LV feed area, since the amount of households and the amount of registered cars are known. By using the information given in the table 1, it turns out that the average amount of cars per household is approximately 1,60 – 2,25 depending on the LV feed area of the substation. Therefore, the calculations of the effects of the charging process are done by using parameters 1,6 car/hh, 1,7 car/hh and 2,0 car/hh.

Table 1. The amount of registered cars and households for each low voltage feed areas of the secondary substation.

	Feed area 1	Feed area 2	Feed area 3	Feed area 4	Average
Households [pcs]	67	74	52	43	59
Amount of registered cars [pcs]	110	120	117	69	104
Cars per household	1,64	1,62	2,25	1,60	1,78

To find out the influences of the charging process on the networks of the feed areas, the networks were electro technically calculated at the present state by using the NIS. After finding out the current electro technical states of the four feed areas, a specified load curve for electric vehicles were added on each measuring point. The annual energy consumed by each household after 100 % penetration of the electric vehicles was defined by using the amount of cars per household and the annual energy consumed by the EV. The load curve employed in the network information system calculation can be seen in the figure 1. It is assumed that the most of the people leave their houses for a work day in the morning around eight o'clock and arrive home in the evening around eight o'clock.

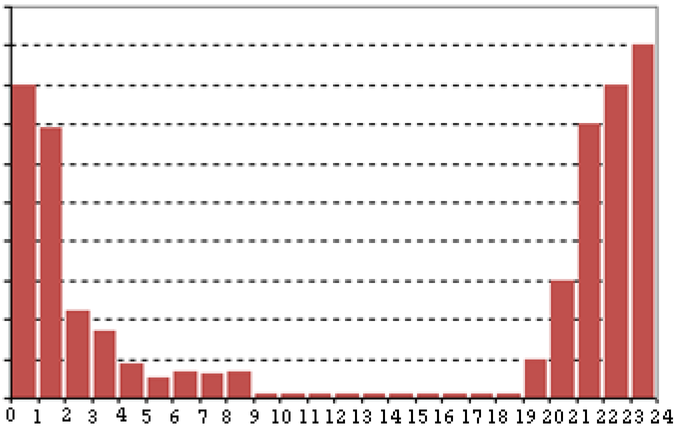

Figure 2. Household charging curve.

After executing the network information system calculation, the electro technical states of the feed areas were calculated by using the index data as well. The calculation was carried out by using the spreadsheet program Excel. Since the index data was at hand, a specific load curve for every feed area could be composed. An example of the load curve generated by the index data calculation can be seen in figure 3. The variation of the load curve with respect to the four seasons is clearly visible in the figure 3.

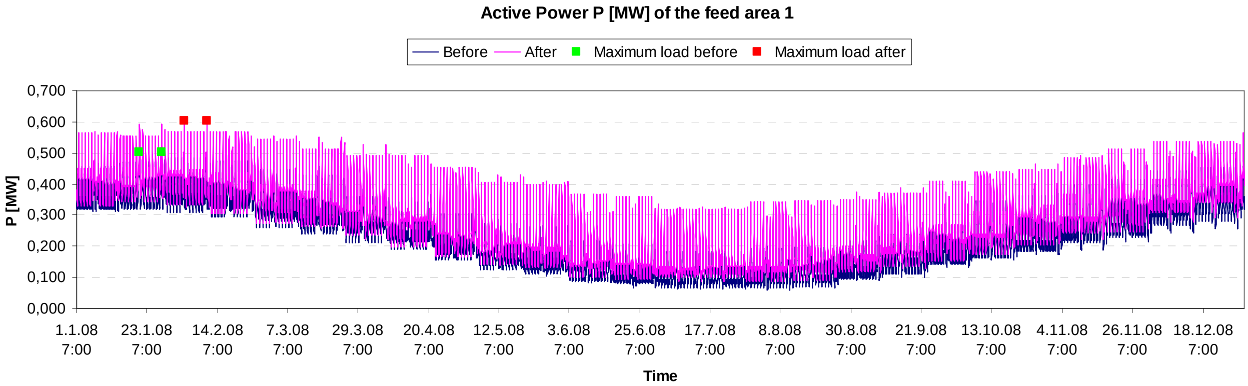

Figure 3. An example of a load curve generated by the index data calculation.

Results

As mentioned before, the results were gathered by calculating the electro technical states of the feed areas in two different ways. In order to simulate the dispersion of the results, the network information system calculation employs a statistical safety factor which could not be simulated in the index data calculation. Therefore, the results calculated by using the index data do not include dispersion which has to be taken into consideration in the analysis of the results. The load curves generated by employing the index data calculation are presented in figure 4. In order to differentiate the present electro technical state of the network and the electro technical state of the network affected by the charging process of the electric vehicles, expressions "before" and "after" are employed in the figures. The expression "before" stands for the present electro technical state of the network. Correspondingly, the expression "after" stands for the state of the network after 100 % penetration level of the electric vehicles.

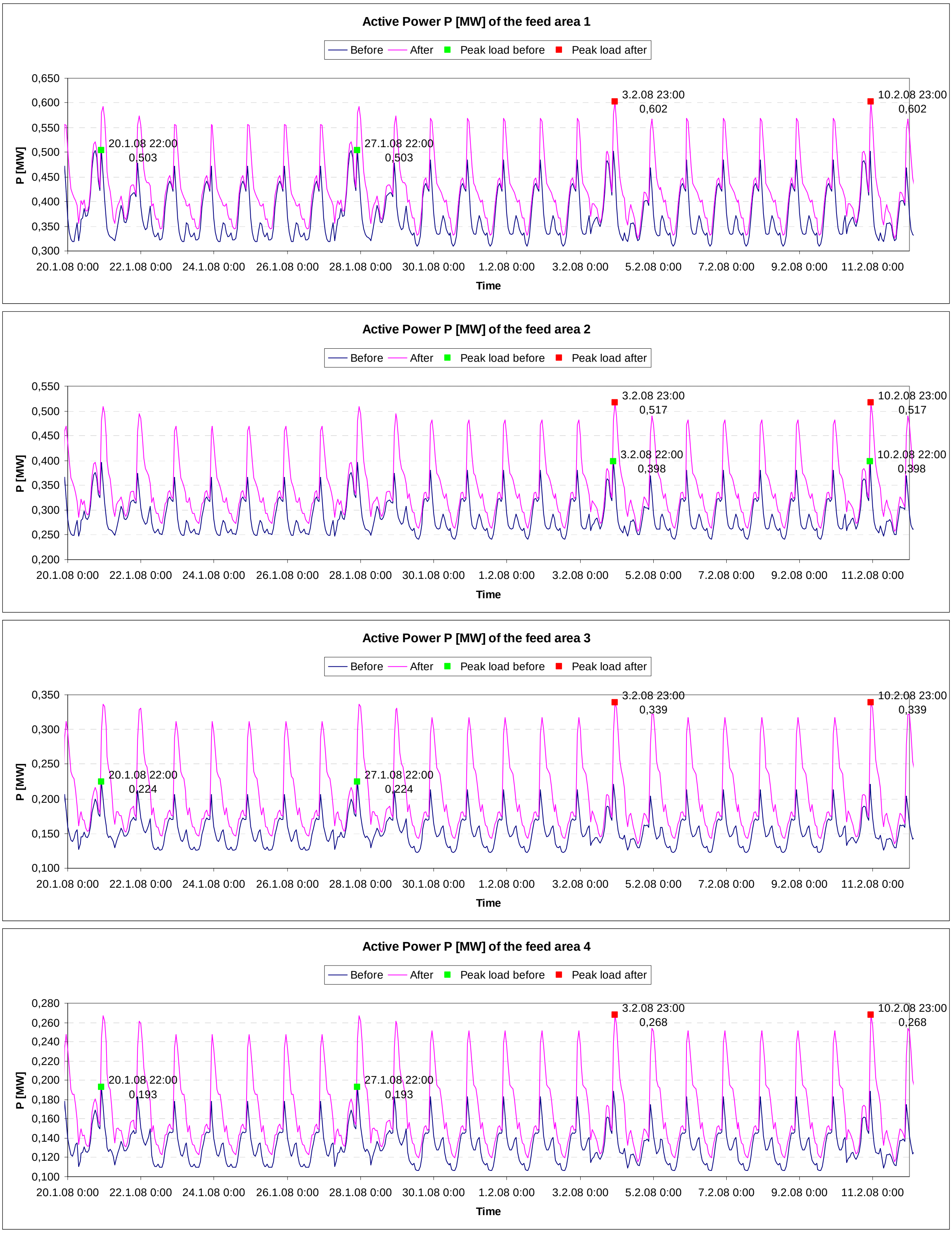

Figure 4. Transition of load curves according to the index data calculation.

It can be seen that the effects of the charging process are significant since the peak load has been shifted not only by days but by minutes as well within a day. If the load curve is reviewed at day level, it can be seen that the peak load has been shifted by one hour. The old peak load can be found at 22.00 o'clock and correspondingly, the new peak load caused by the charging process of the electric vehicles reappears at 23.00 o'clock. This is most probably due to the overlapping of the old and the new load curve. The old peak load is caused by the hot water boilers that turn on every day exactly at 22.00 o'clock in the evening. Even though the difference between the old and the new peak load can be measured in days, the new peak load is shifted by one hour in every feed area if the load curve is reviewed at day level. The day level load curves can be seen in figure 5 which illustrates the difference between the old and the new peak load.

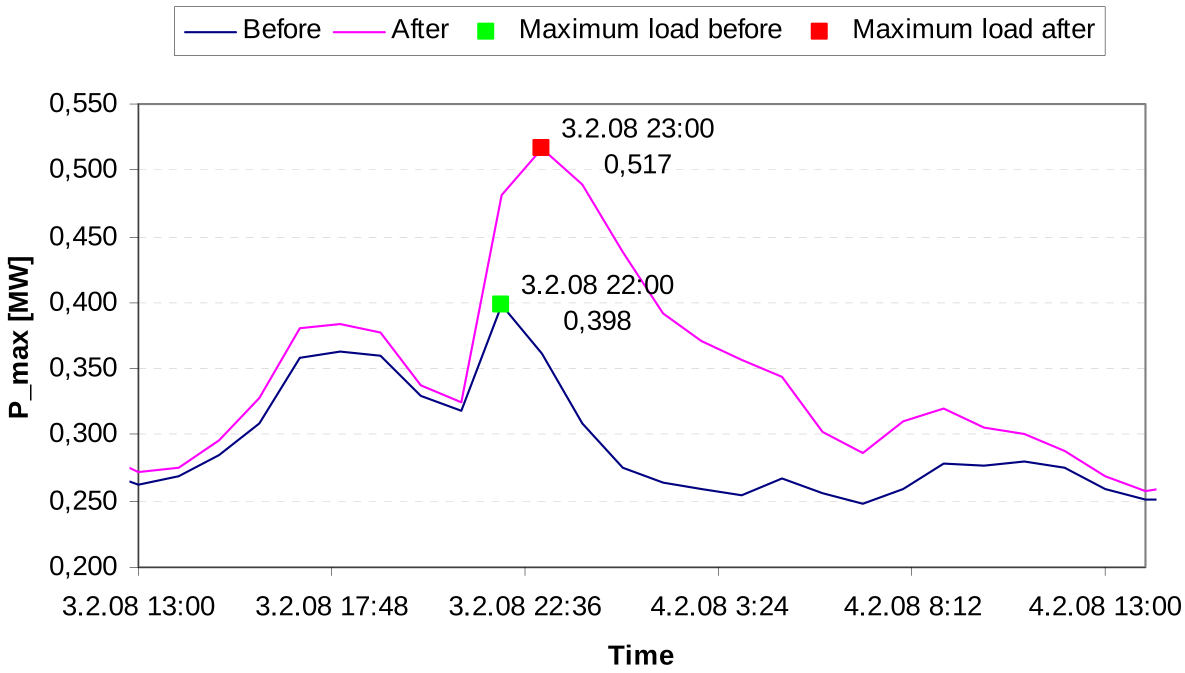

Figure 5. Transition of peak load (feed area 2) reviewed at day level.

If the charging process of the electric vehicle is scheduled to start for example couple of hours after the old peak load caused by the hot water boilers, the transition of the peak load would not be as big as in the results. However, an optimal charging process would require energy storages that could be charged during the day when the overall load is low. Since the batteries of the vehicle are charged at work as well, it can be assumed that the batteries of the vehicle are practically never empty.

Since the network topologies of the four feed areas are different, it is logical that the transitions of peak loads act differently as well. The dispersion between peak loads is represented in figures 6 and 7. Figure 6 illustrates the results which are calculated by using the network information system. Correspondingly, the transitions of the peak loads according to the index data calculation are illustrated in figure 7. The red line in the upcoming figures 6, 7 and 8 represents the transition of the peak load in terms of percent and the green line represents the average transition of the peak load in terms of percent. The figures 6 and 7 have two y-axes, the left one for the effective power in kilowatts and the right one for the percentual variation. In the figure 8 the left y-axis is for the load rate and the left y-axis is for the percentual variation.

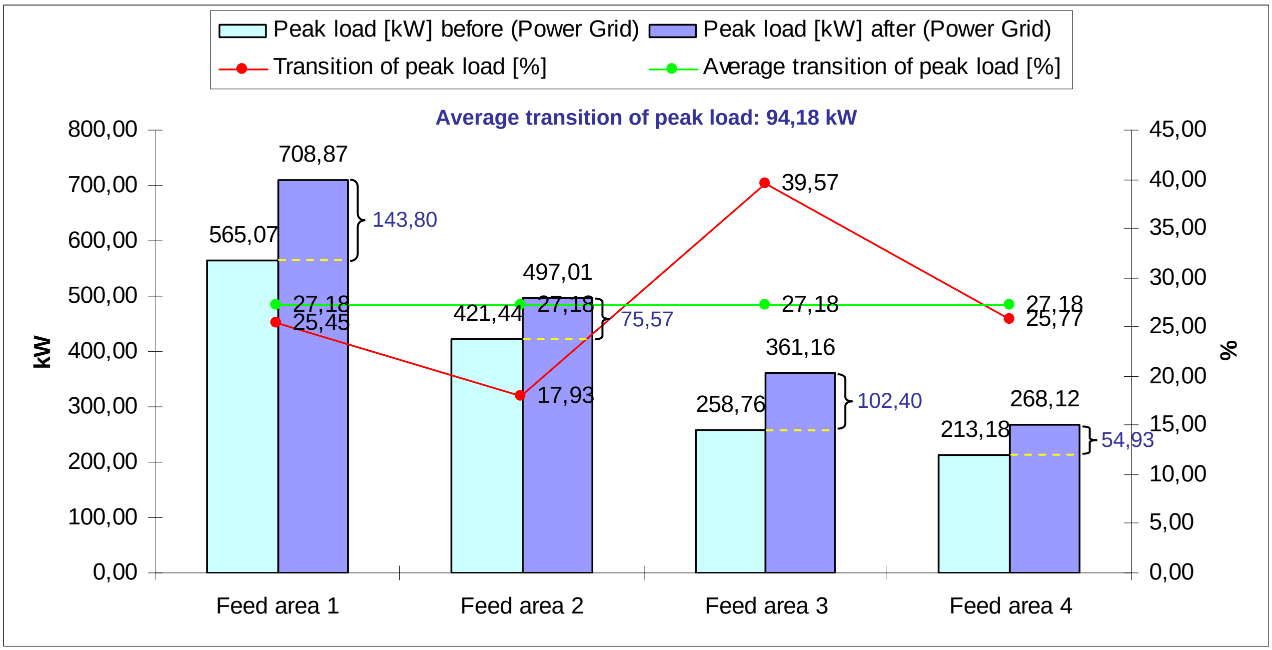

Figure 6. Transition of peak load according to the network information system calculation.

It can be seen from both figures that the biggest change in peak load (in terms of percent) occurs in the feed area 3. The most probable reason behind the biggest transition of peaks loads in the feed area 3 is the biggest amount of cars per household which can be discovered from table 1.

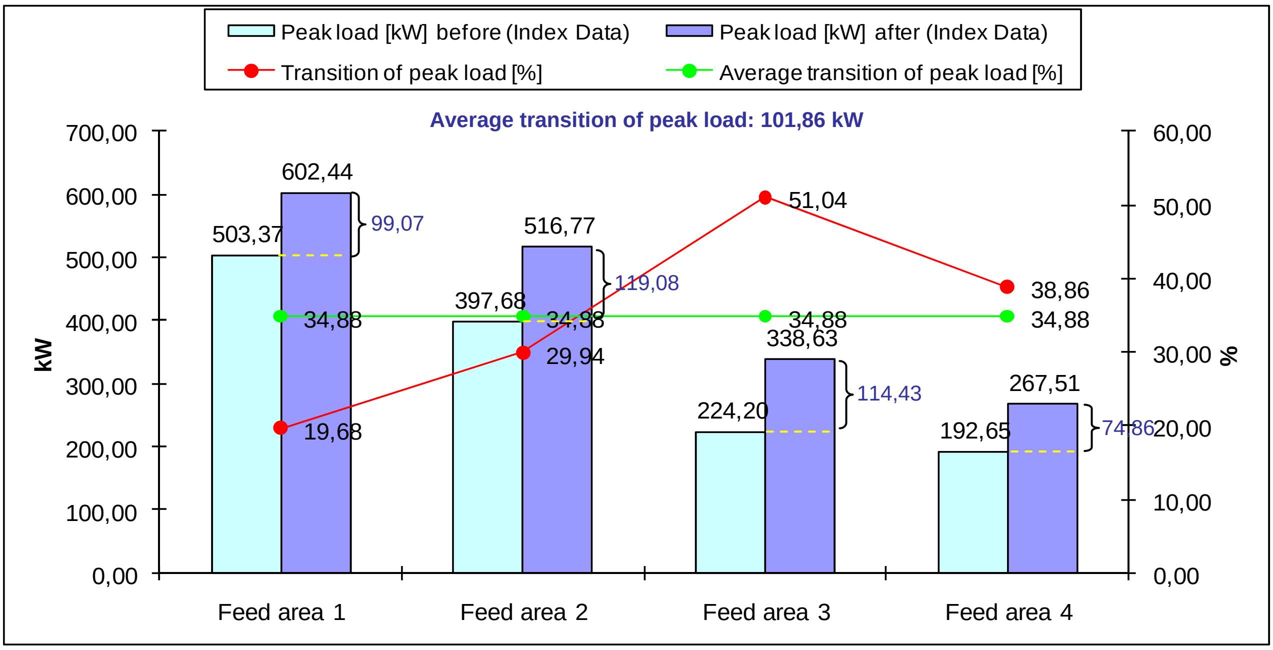

Figure 7. Transition of peak load according to the index data calculation.

According to the network information system calculation the average transition of peak load is 94 kW which corresponds to an average transition of 28 %. By reviewing the results of the index data calculation it can be seen that the average transition of the peak load is 102 kW which corresponds to an average transition of 35 %. As can be seen from the figures 6 and 7 the results between the network information system and the index data calculation differ from each other. The difference originates from the lack of safety factor in the index data calculation.

Although the feed areas include housing and heating systems of the same kind, the results between the feed areas seem to differ considerably. The differences between the transitions of peak loads are most probably due to the alternation between the average amounts of cars per household, the network structures and the transformers. However, the charging process of the electric vehicle seems to increase the peak load approximately by a third. The reason for the increase of the peak load originates from the overlapping of the load curves.

The charging process has an effect also on the transformers. The effects of the charging process can be seen in figure 8 which illustrates the transition of the transformer load rates. As can be seen the effect varies greatly depending on the apparent power and the previous load rate of the transformer. Again the biggest relative growth in the load rate occurs in the feed area 3. On the whole, the average growth of the load rate seems to be approximately 26 % depending on the apparent power of the transformer. The load rate of the transformer increases over 100 % in the feed areas 1 and 2 which means that the transformers will have to be replaced in order to withstand the effects of the charging process. On the other hand, the load rate of the transformer remains under 100 % in the feed areas 3 and 4.

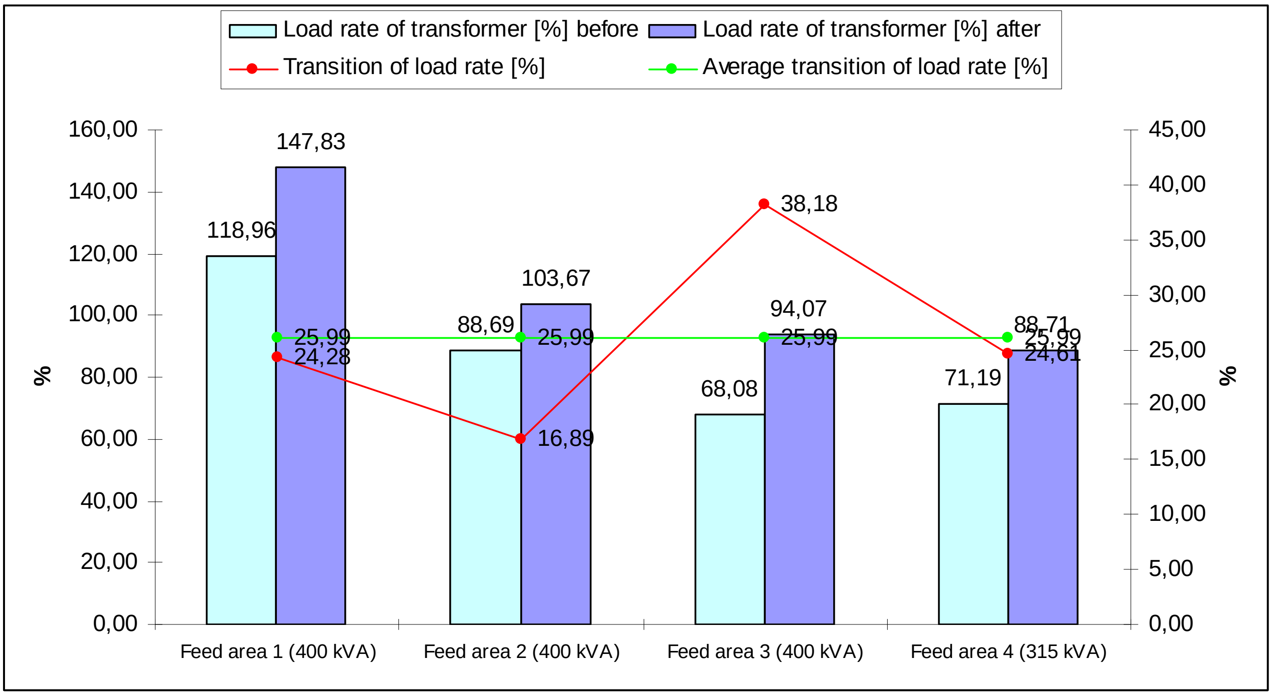

Figure 8. Transition of transformer load rate according to the information system calculation.

Since the voltage of the low voltage feed areas will not change, the increased power means increased current as well. Table 2 represents the features of the cable outlets in every low voltage feed area. It seems that the cable outlets can mainly withstand the increased current.

Table 2. Table of features for the cable outlets of the secondary substation. The results have been calculated by using the network information system software Power Grid.

	Type of cable	Cross-sectional area [mm^2]	Length [m]	Fuse [A]	Current strength [A]	Current [A] before	Current [A] after	Growth of current [A]	Growth of current [%]	Voltage reduction [%] before	Voltage reduction [%] after	Growth of voltage reduction [%]
Feed area 1	AMC120	120	63,0	250	255	129,0	131,7	2,7	2,1	1,0	1,1	10,0
	AXC185	185	94,0	400	375	158,1	178,4	20,3	12,8	1,3	1,5	15,4
	2xAXC185	185	136,0	630	375	113,0	165,9	52,9	46,8	0,7	1,0	42,9
	2xAXC185	185	85,0	630	375	324,1	448,6	124,5	38,4	1,2	1,7	41,7
	AX185	185	220,0	315	330	64,6	70,0	5,4	8,4	1,3	1,4	7,7
	AX185	185	220,0	315	330	64,4	69,7	5,3	8,2	1,3	1,4	7,7
	MC10	10	90,0	80	77	22,6	22,8	0,2	0,9	1,8	1,8	0,0
	AXC120	120	140,0	250	295	86,0	103,9	17,9	20,8	1,6	1,9	18,8
Feed area 2	2xAXC185	185	78,0	630	375	326,7	370,2	43,5	13,3	1,1	1,3	18,2
	AXC185	185	147,0	250	375	193,1	218,5	25,4	13,2	2,5	2,9	16,0
	AXC185	185	81,0	400	375	146,9	173,8	26,9	18,3	1,1	1,3	18,2
	MC10	10	51,0	63	77	21,1	21,3	0,2	0,9	0,9	0,9	0,0
Feed area 3	AXM185	185	100,8	250	330	77,3	107,1	29,8	38,6	0,8	1,0	25,0
	AXM185	185	98,3	250	330	79,7	110,3	30,6	38,4	0,8	1,0	25,0
	AXM185	185	44,7	100	330	81,2	105,8	24,6	30,3	0,4	0,5	25,0
	AXM240	240	88,4	315	375	193,8	264,5	70,7	36,5	1,3	1,7	30,8
	AXM35	35	43,8	63	125	13,9	14,7	0,8	5,8	0,3	0,3	0,0
Feed area 4	AXM185	185	147,2	250	330	64,3	77,9	13,6	21,2	0,9	1,1	22,2
	AXM185	185	66,2	100	330	113,3	133,8	20,5	18,1	0,7	0,8	14,3
	AXM185	185	106,1	250	330	73,8	93,3	19,5	26,4	0,7	0,9	28,6
	AXM185	185	103,3	250	330	76,0	96,0	20,0	26,3	0,7	0,9	28,6
	AXM16	16	29,4	63	78	16,4	16,6	0,2	1,2	0,5	0,5	0,0
	AXM16	16	14,0	63	78	54,1	54,7	0,6	1,1	1,4	1,4	0,0
	AXM16	16	16,1	63	78	15,2	16,8	1,6	10,5	0,1	0,2	100,0
Average								23,2	18,3			20,7

Table 3 shows the alternation of the lowest voltage levels for each feed area. It can be seen that the average voltage decrease is 3,8 V which corresponds to 1,7 %. The biggest decrease can be found in the feed area 3 which can be explained by the biggest amount of overhead cables. The network structures of the feed areas 1 and 2 consist only of underground cables, and the average decrease of voltage level is 1,9 V and 0,8 %. The voltage reduction seems to be greater in the areas of overhead lines where the cross-sectional area of the cable is small. The increased power consumption increases also the value of current which correspondingly have a reducing effect on the voltage levels.

Table 3. Alternation of the lowest voltage level in each low voltage feed area of the secondary substation. The results have been calculated by using the network information system software Power Grid.

	Voltage before [V]	Voltage after [V]	Voltage reduction [V]	Voltage reduction [%]
Feed area 1	213,5	211,6	1,9	0,8
Feed area 2	215,7	213,8	1,9	0,8
Feed area 3	192,0	182,0	10,0	4,3
Feed area 4	206,1	204,5	1,6	0,7
Average			3,8	1,7

Conclusions

According to the calculations the old peak load appeared at 22 o'clock and the new peak load seems to appear at 23 o'clock. This means that the new peak load is shifted by an hour. If the load curve of the charging process was totally controlled to fill the periods of low load rate of the previous load curve, the overlapping could probably be avoided. In that case the charging process should be scheduled by an intelligent control system to be executed at times when the overall load is low. In practice, the overall charging process is difficult to control optimally because the lowest load rate appears at noon when the biggest part of the electric vehicle users are presumed to be at work. On the other hand, it can be assumed that the batteries of the electric vehicle are never empty, since the electric vehicles are mainly used for short distance driving. Therefore the required time for the charging process can be shorter than the assumptions made in the calculations. However, in order to fully control and schedule the charging process of the electric vehicles, the usage of energy storages should be taken into consideration.

The average increase in the peak load is approximately 27 % according to the network information system calculation. If the calculations are made by using the index data, the average increase of the peak load is 35 %. The low voltage feed areas 1 and 2 do not include overhead lines because both feed areas are designed in the eighties by using only underground cables. According to the results it seems that the feed areas 1 and 2 will withstand the effects of the increased peak load. However, the increased transformer load rate seems to be the most acute problem. Even though the cold weather in Finland allows the transformers to be overloaded without cooling problems, the overloaded transformers will have to be replaced by more effective transformer. Moreover, when all cable outlets of the four feed areas were calculated, it turned out that the current strength of the cables will not set a limit for the charging process of electric vehicles. All four low voltage feed areas have increased voltage reduction values due to the charging processes of the electric vehicles. In order to reduce the harm caused by the low voltages, the network structure of the feed areas will have to be redesigned for example by dividing the low voltage distribution network and adding a new distribution transformer.

The network structures of the low voltage feed areas 1 and 2 have been designed in the eighties by using only underground cables. Similar principles for the network design have been used ever since for similar neighborhoods. Therefore it can be assumed that similar neighborhoods to the low voltage feed areas 1 and 2 will also have near to an identical response for the charging process of the electric vehicles. Even though the network structures of the feed areas 3 and 4 include mainly underground cables, inevitably some minor areas of overhead lines still remain. This is due to the fact that the feed areas have originally been designed by using overhead lines, but the replacement of the overhead lines has been carried out progressively in the course of time. The strengthening of the low voltage distribution network is usually considered to be easier by using overhead lines since the overhead lines do not need be dug into the ground such as underground cables. On the other hand, the underground cables tend to have less faults and interruptions due to weather conditions which make the usage of the underground cables more profitable in the long run. According to the calculations, it seems that the major electro technical issues of the feed areas 3 and 4 appear only in the network areas that still include overhead lines. Therefore, the remaining overhead lines should be replaced by the underground cables, in order to enhance the durability of the network

Even though, it is assumed in the calculations that the existing car fleet is instantaneously replaced by the electric vehicles, in reality the replacement is carried out progressively. Therefore the results of the calculations represent only the worst-case analysis. In order to fulfill the requirements of the increasing consumption of electricity, the low voltage distribution networks are constantly redesigned. Since the durability of the low voltage distribution network is increasing progressively in the course of time, it can be assumed that the low voltage distribution network will probably be durable enough to withstand the load caused by the charging process of the electric vehicles.

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