IMPACT OF AN INCREASING PENETRATION OF URBAN PHOTOVOLTAIC SYSTEMS AND ELECTRIC CARS ON THE LOW VOLTAGE NETWORKS

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ABSTRACT

With the fast growing penetration of photovoltaic (PV) systems and future electric cars in the low voltage networks, the energy supply will be challenged and will need to be re-assessed or even upgraded. The aims of this study are to evaluate the acceptable penetration limit of photovoltaic systems and electric cars in the urban residential areas.

INTRODUCTION

A study of the photovoltaic potentials was carried out in the city of Cottbus that inhabits approximately 100.000 people in 2009. The results show that about 210 MWp PV-capacity could be installed, where 60% of the capacity is on household roofs. It could result in a maximum PV-power in-feed of 200 MW, which would clearly exceed the current peak load and highly stress the grids [1].

In this study the investigation should answer the question, whether the existing urban grids are sufficient for the integration of the theoretically installable PV-capacity or to what extent is the PV-capacity permissible?

The main concerns are thus focused on the voltage band and the tolerable utilization ratio of the existing networks, which are two crucial criterions for the determination of the permissible PV-capacity. Different network models were investigated for detached house settlements and apartment settlements, which are dominant in suburb areas and in the city center respectively.

CAPACITY OF THE NETWORKS

The maximum capacity of the low voltage networks is mainly dependent on the maximum carrying capacity of the cables and transformers as well as the voltage band along the cables. The limited values of these two criterions should not be exceeded by the integration of the PV-systems or the load of the electric cars.

The carrying capacity of the cable is determined primarily by the conductor material and its cross section. In practice the PVC aluminium cable with a cross section of 150mm^2 is widely used in the urban areas. Furthermore, the environmental conditions and the network status (load factor) should be taken into account as well. The load factor is determined by the given load curve and equals to 0.7 at the so-called “EVU”-load [2]. In the cases of decentralized PV-generations in the low voltage grid the “EVU”-load does not exist anymore, and as a result, the load factor differs from 0.7. Figure 1 shows the carrying capacity of different cables as a function of the load factor assuming that the cables are buried in the ground with the temperature of 20 ℃ and the ground thermal resistance of 1.0 Km/W. Due to the unavailable data for the load factors between 0 and 0.5, the dashed lines would be used as trend lines instead. The larger the load factor, the lower the carrying capacity of the cables.

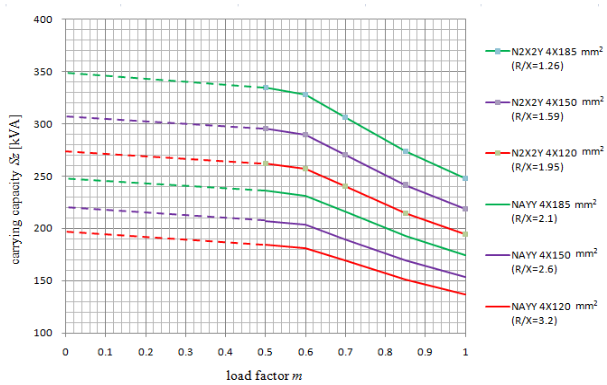

Figure 1: Carrying capacity of different cables as a function of the load factors

The carrying capacity of the transformers is another aspect for the determination of the network capacity. In the urban areas the transformers with a rated power of 630 kVA are mostly used. The capacity is severely dependent on the environmental conditions and can be temporarily overloaded to a certain extent. In general the overload factor is ranged between 1.2 and 1.5.

Moreover, the acceptable network capacity depends significantly on the tolerable voltage level. In the cases of distributed generations, the generated active power might be fed back through transformer to the upstream voltage level, resulting in a voltage rise along the cables. To ensure the safe operation of the network, certain requirements must be imposed on the voltages. According to the new VDE Guideline [3], the voltage band should not differ from the rated voltage by more than ±10% and the maximum voltage change ΔU at the worst node should be limited to 3%.

It must be noted, that the voltage drop across the transformer can not be neglected, because the current of all the PV-systems will be added to the transformer and leads to a correspondingly higher voltage drop.

MODELING

To analyse the impact of high penetration of PV and electric cars, the following factors in Figure 2 must be taken into account for the simulations.

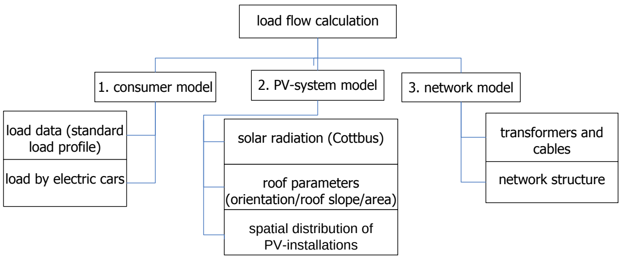

Figure 2: Overview about the modeling

1. Consumer model: The consumer model is formed using the so-called standard load profile, which consists of a set of daily load curves with a resolution of 15 minutes [4]. The used standard load profile was provided by the Stadtwerke Cottbus and is thus very representative for the simulations in Cottbus.

Furthermore, the load of electric cars, as an additional load, is not negligible in the future. A representative charging profile for electric cars is currently not available. The dominant charge capacity per car is also unclear due to the diverse future battery technologies. The first generation of electric cars will be hypothetically charged uncontrolled by direct house connection. In the Simulation, two scenarios were carried out.

2. PV-system model. The PV-system model is based on the measured global radiation data in Cottbus. The values were collected in 2008 on a horizontal surface and could be converted for roofs with any roof pitch and roof orientation [1]. In addition, the roof parameters and the spatial distribution of the PV-systems should be specified for the simulation. The roof parameters include roof areas, roof pitches and roof orientations. The spatial distribution of the PV-systems is geographically dependent on the settlement structures.

Figure 3 shows the load profile for one household with consumption of 3900 kWh/a and the feed-in PV-profile for a south oriented PV-system of 3 kWp with a roof pitch of 35 °.

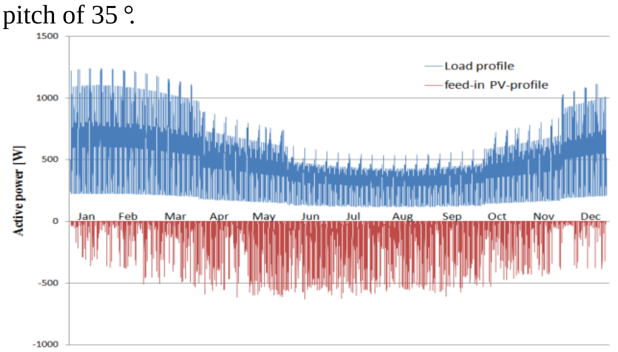

Figure 3: Load profile and feed-in PV-profile

3. Network model. The network model mainly depends on the types of the supplied settlements. In the urban low voltage networks, pure radial networks without cross-connections or ring-circuits are favoured. Some networks are designed as meshed grids but will be operated as radial networks by disconnecting at the separation points. In this context, the radial networks were investigated for the simulations.

SIMULATION

Based on the criterions and parameterized models, the detailed procedure for the determination of the permissible installable PV-capacity is shown in Figure 4.

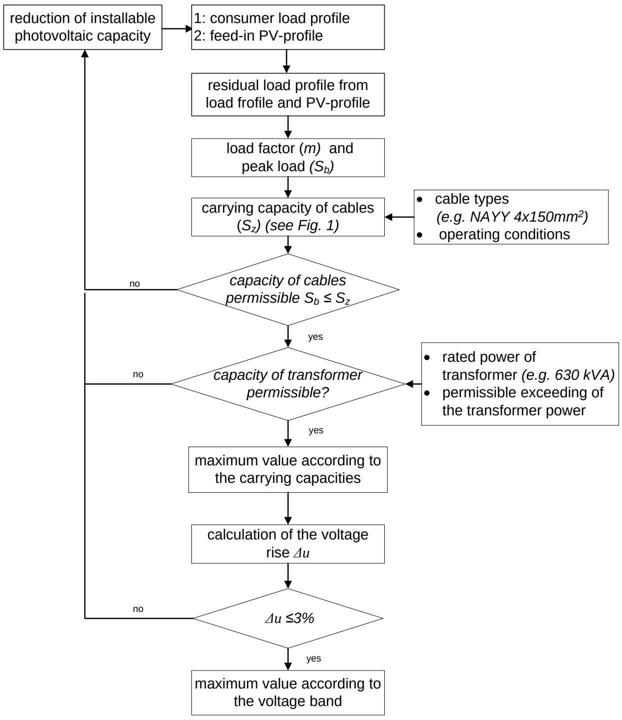

Figure 4: Procedure for determination of the maximum permissible installable PV-capacity

The calculations of the permissible installable PV-capacity were carried out in "worst case", namely on the most critical day with the largest feed-in PV-capacity and the lowest consumer load. To ensure the plausibility of the investigation procedure, the simulations were implemented in three reference networks.

The simulation according to Figure 4 was carried out using the example of the network 1 (Figure 5), which consists of three outgoing feeder cables of NAYY 4x150mm^2. 50 houses are connected along each cable with an average cable length of 15 m between adjacent nodes. The capacity of the transformer is 630 kVA and the permissible overload factor could reach 1.2. The voltage on the transformer side was set to 230 V constantly.

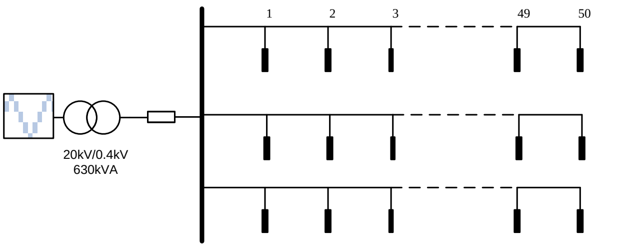

Figure 5: Structure of the network 1

The following procedure was carried out:
1). Start with an initial value of the installable PV-capacity and adjust it slightly until the permissible carrying capacity of either the cables or the transformer is reached. Thus 5.5 kWp PV-capacity per household can be installed.
2). Check the voltage rise at the end of the cables and limit it lower than 3% of the rated voltage. In this way only 2 kWp PV-capacity per household is installable.
As a result every household can install approximately 2 kWp PV-capacity for the network 1.

REACTIVE POWER SUPPLY

As for the real cases, in the detached house settlements the roof potential for the PV installation is positively higher than 2 kWp per household. Therefore, the carrying capacity of the low voltage network must be increased. This can be realized by the reactive power supply from all the inverters.
Figure 6 shows the voltage rise along the cable with different power factors until the limit value of 3% is reached. At cosφ=0.95 the permissible PV-capacity for the network 1 was increased to 2.8 kWp per household, which corresponds to 40% capacity increase. At cosφ=0.90 almost 80% correspondingly.

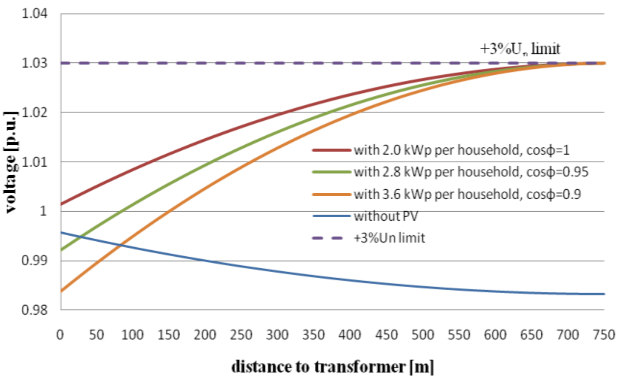

Figure 6: Voltage rise along the cable with different shift factors on the day 17.06.2008 at 12:30

The simulations for the other two networks were carried out with the same procedures. The network 2 used cable type N2X2Y 4x150mm^2 instead; the other simulation conditions were set the same as the network 1. The network 3 was simulated in the apartment settlement using cable NAYY 4x150mm^2. The results are shown in Table 1.

network	**installable PV-capacity *[kWp per household]***		
	cosφ = 1.0	cosφ = 0.95	cosφ = 0.90
network *1*	2.0	2.8	3.6
network *2*	2.8	5.4	5.7
network *3*	4.5	4.2	3.9

Table 1: Comparison of the permissible installable PV-capacity for three reference networks

The results show that, by using cable type of N2X2Y, a higher PV-capacity around 3 kWp per house could be installed. In the apartment settlement (network 3) this value could reach (4-5) kWp.
By generating reactive power by the inverters of the PV-generators (cosφ=0.95), the permissible PV-capacity can be increased by 40% using cable type of NAYY and by 90% using N2X2Y.
In real networks, the PV-systems with different capacities are available according to the roof surface potentials. A statistic about the roof potentials was carried out according to different types of settlements in Cottbus. The results are shown in Table 2.

type of settlement	**possible installable PV-capacity per household / average**
detached house settlement	(5-15) kWp / 8.7 kWp
apartment settlement	(0.6-5) kWp / 2.1 kWp

Table 2: The possible installable PV-capacity per household according to different types of settlements

Compared to Table 1, the installed PV-capacity for the detached house settlements must be limited due to its relatively larger roof potential per household. Conversely, a complete coverage of the roofs with PV-systems is permissible in the apartment settlements.

INTEGRATION OF ELECTRIC CARS

In this study the charging profile of the electric cars was investigated in residential areas only. Thus, it is assumed that charging the electric cars is possible at home only.
It is assumed that each household has one electric car. The daily covered journey is 25 km, which corresponds to an energy consumption of 5 kWh (0.2 kWh/km). The capacity of the battery is 10 kWh, which means the charging of the electric cars takes place every two days. The cars were charged by a single phase connection (230V, 16A) with a charging capacity of 3.7 kW for 3 hours.

Two scenarios were investigated:
1) Uncontrolled charging: the cars were charged after the last trip at the charging point,
2) Controlled charging: the cars were charged at off-peak time between 23:00 and 6:00.
In Figure 7 the uncontrolled and controlled charging profiles of the electric cars are shown schematically in a network with 50 households.

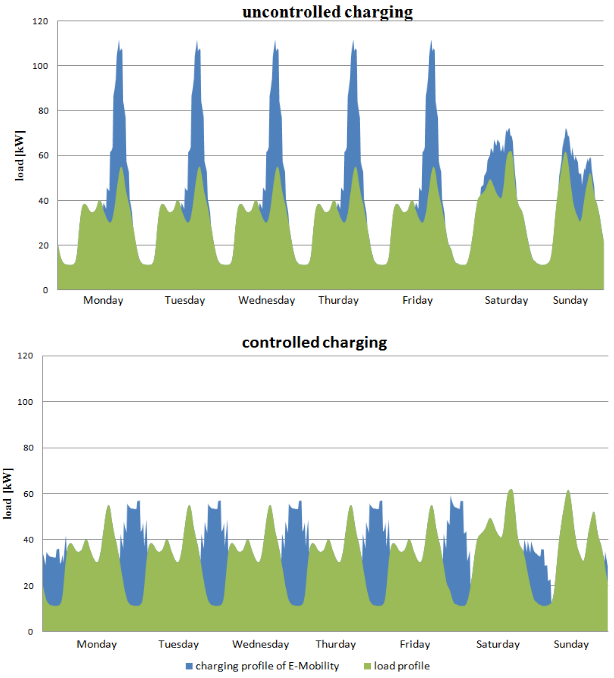

Figure 7: Charging profiles of the electric cars in the uncontrolled and controlled charging cases

In the uncontrolled case, a significant increase of the load profile occurs and should be avoided by intelligent or controlled charging.
One approach is to combine the solar energy and the load of the electric cars using a battery, which could store the solar energy in the daytime and charge electric cars during the peak load time. Therefore, not only the stress of the network caused by the electric cars can be decreased, but the acceptable PV-capacity rises as well.

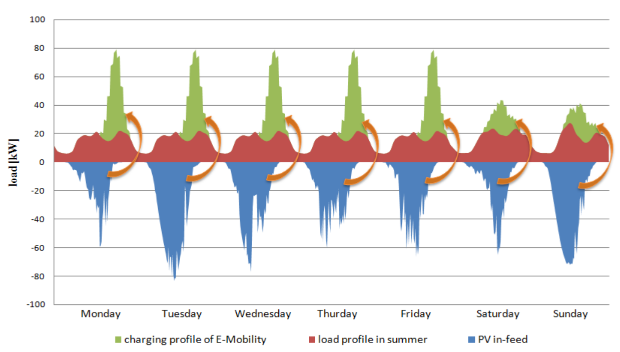

Figure 8: Comparison between PV profile and charging profile of the electric cars in summer

Figure 8 shows the comparison between the feed-in PV-profile and the scenarized charging profile of the electric cars. With a PV-capacity of 3 kWp per household, the demand for electric cars can be met by the solar energy completely in summer.

CONCLUSION

This study aims to find out the penetration limit of PV-capacity for different settlements. In the detached house settlements only (2-3) kWp per house is permissible. The installed PV-capacity must be limited to guarantee the network quality. In the apartment settlements the roof surface can be covered with PV-systems completely.
By generating reactive power by the inverters of the PV-generators (cosφ=0.95), the permissible PV-capacity can be increased by (40-50) % using cable type of NAYY.
Unfortunately in reality the already installed PV-capacity cannot be limited anymore and only pure active power generated by PV-systems is permissible, consequently, the network extension is inevitable.
Furthermore, in the future the uncontrolled charge of the electric cars will lead to a much higher peak load. This can be avoided by shifting the charging time or using batteries, which could store the solar energy in the daytime and charge electric cars during the peak load time. Hence, not only the stress caused by the electric cars for the network can be decreased, but the acceptable PV-capacity rises as well.
The next step is to analyse the impact on the real networks in the city of Cottbus.

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