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LOAD MANAGEMENT STRATEGY FOR INTEGRATION OF ELECTRIC VEHICLES IN DISTRIBUTION POWER SYSTEMS

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ABSTRACT

The discussion about substitute fossil driven vehicles by electros has opened questions from a system operation point of view. The focuses are distribution networks due to the expected impact electric vehicles have. The main problem will be load capacity of cables, transmission lines and transformers. Enhancing the grid is critical due to public acceptance and building costs. This Paper deals on the possible grid disturbance by additional charging load and a load management strategy to ease the situation.

Index Terms – Power flow analysis, Electric automobiles, Power distribution automation, Demand Side Management

1. INTRODUCTION

The focuses are distribution networks due to the expected impact electric vehicles have. They will be connected to the grid at low and mid voltages level. The charging of electro vehicles is concentrated in the evening due to user behavior [1,2]. This results in an additionally power peak, which stresses the distribution grid. The main problem will be load capacity of cables, transmission lines and transformers. Enhancing the grid is critical due to public acceptance and building costs. Application of Information and Communication Technologies (ICT) for demand side management purposes can ease the situation in the primary process and a platform for high level applications to get load the following the stochastic infeed of regenerative generation, especially wind or solar power, with respect to the power system limits[3].

2. APPROCH FOR CHARGING LOAD

On a first approach, there has to be a conclusion about changed grid load if the charging of electric vehicles is an autonomous procedure by users. It will be assumed that every car owner will start the charging process direct after using it at the evening hours from his power socket. With respect to a huge amount of cars the initial point of charging, will approximately fit to a normal distribution function. Previous publications showed such an accumulation [2]. The deviation of the resulting load curve is produced by the user's behavior. The sum of daily individual energy consumption cases the charge loads amplitude.

$$Q_{grid} = \sum_{i=1}^{n} Q_i \qquad (2.1)$$

$$Q_i = x_i * q(1 + (1 - \eta)) \qquad (2.2)$$

$$P_{charge} = F(x) * Q_{grid} \qquad (2.3)$$

$Q_{grid} - grid\ energy\ consumtion$

$Q_i - individual\ Energy\ Consumtion$

$x_i - individual\ daily\ driving\ distance$

$q - based\ car\ energy\ consumption$

$\eta - Battery\ efficiency$

$n - number\ of\ ecars$

$F(x) - prohability\ distribution\ function$

$P_{charge} - \ charging\ load$

The variables are dedicated to used technology, expect from x_i**,** which is a social determinant. Empiric studies [1] provide a x_i-distribution function, which can be reproduced by Rayleigh distribution function. Figure 1 shows cumulated charging load over 24 hours. Calculation variables where taken from the Mini-E test case [4].

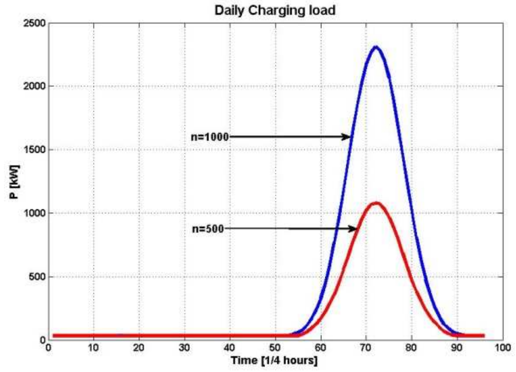

Figure 1 - estimated daily charging load

The Electric Vehicles maximum charging power has little impact on the amplitude of cumulated charging load. Due to German electric standards in households three charging levels are possible (20kW, 7,3kW, 3,6kW). The figure 2.1 was made for 20kW, which allows lowest charging time. The usage of the next lower power level will delay the amplitude and deform the graph. The following case studies will show the less influence of this secondary determinant for the Charging load.

3. LOAD MANAGEMENT STRATEGY

Previous section showed an approach for an uncontrolled charging. This will bring the distribution grid to its limits and decreases the grid efficiency which can be approximated through the load factor. As one result the responsible DSO has to repower his grid, which will extends the limits. A Strategy to avoid this and increase the grid efficiency at the same time will be the implementation of a load management system. Three main parts make this system capable. One is an appropriate ICT-infrastructure, which allows a remote control of the charging process and reports actual process parameters [5]. Second will be a detailed load forecast model. In residential areas this can be based on standard load profiles, as it was done in following case studies. Also there has to be a forecast of daily energy consumption by electric cars for every grid zone. Third will be the load management strategy, which will optimize the load flow. So there are two objective functions.

$$\boldsymbol{min}\sum_{i=1}^{l}(P_{i,max}) = f[\sum_{j=1}^{n} P_{j,charge}(t)] \qquad (3.1)$$

$$\boldsymbol{max}\sum_{i=1}^{l} k_i = \boldsymbol{max}\sum_{i=1}^{l}\frac{P_{i,mean}}{P_{i,max}} \qquad (3.2)$$
$$= f[\sum_{j=1}^{n}(P_{j,charge}(t)]$$

$l - number\ of\ grid\ nodes$

$n - number\ of\ ecars$

$k_i - grid\ load\ factor$

Expect from other demand side management strategies electric cars subjects with a weak predictable usage, so the amount of possible charging cars will not constant. But empiric investigations showed that there is cumulative pattern [1], which takes part in the load management. Following load strategy assumes from the previous mentioned forecasts and has to handle with these constraints.

$$m = F(t) \le n \qquad (3.3)$$

$$\sum_{j=1}^{n} P_{j,charge}(t) = Q_{grid} \qquad (3.4)$$

$m - number\ distributable\ ecars$

In a distribution system with hundreds of nodes there will be no need to control every charging power continuously. This would increase the requirements for the ICT-infrastructure and complexes the load management without any gain. A continuous charging power control would only make sense in grid zone, which are operated at their limits already. Equation 3.5 shows the transformation to a discrete load control.

$$\sum_{i=1}^{n}\int_{0}^{T} P_i(t)dt = \Delta T * \sum_{i=1}^{n}\sum_{t=0}^{T}\left\{\begin{matrix}P_{max}\\ \mathbf{0}\end{matrix}\right\}(i,t) \qquad (3.5)$$

$P_{max} - Power\ charge\ controller$

Figure 2 illustrates the typical parallel stream structure for a distribution grid. Optimize every node for its own seems not be useful, due to complementary results and weak predictable loads. For a stream structure a sequential optimization from the lower to the higher voltage level uses the physical coupling and gets best optimization results. Low voltage grid zones are often designed with more limits reserve, due to a lower amount of accumulated loads and therefore a higher utilization factor, which is used for grid design. Therefore peak shaving in the mid voltage areas has higher priority.

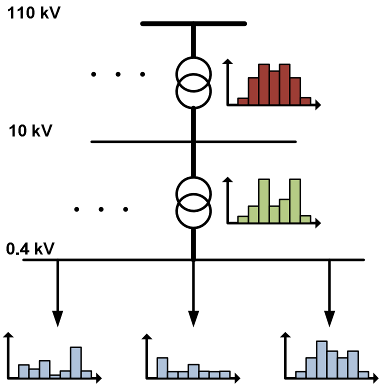

Figure 2-typical structure of distribution grid

4. CASE STUDIES

The test case is defined from a middle town distribution grid for the following investigations. Previous described charging load was implemented in a power flow calculation. Measured and normalized load data were added to the estimated charging loads on every grid level. Following figures show the dependency of grid disturbance from the quota of electric vehicles, which means the quota of households with electric vehicles charged from their power socket. Left axis displays the estimated load maximum, while the right axis displays the load factor (eq. 3.2).

4.1. **base scenario without Load Management**

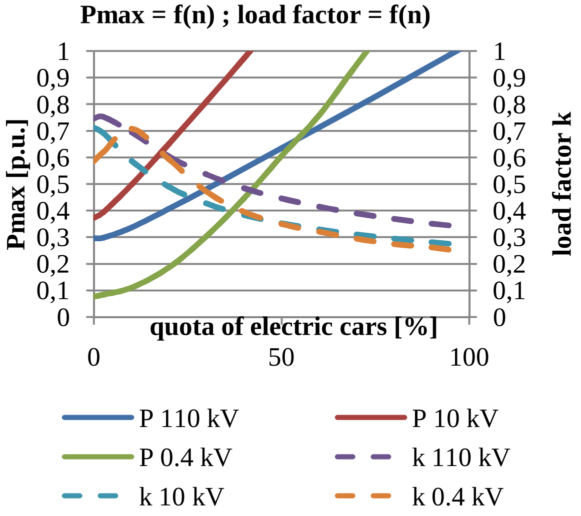

figure3 - base scenario

In Figure 3 there can be seen the near linear coherence between rising quota of electric vehicles and maximum load power. Concurrent the load factor is falling. The graphs slope for lower grid levels is higher than for the 110 kV ones. By reason charging load effects the low voltage grid zones direct and increases rapidly the less peaks. Due to the lower designed security load margin the 10 kV level will be the first limiting the home charging of electric vehicles. Utilities design their cables and transformer with a security margin of 30% typical, so this limit will enter at a quota of 20% followed up by a 55% limit quota for the 0.4 kV grid level. A variation of the charging loads parameter (eq. 2.2) for the 10 kV grid level is displayed in table 4.1

q[kWh/km]	P charge [kW]	Quota of max electric cars
0,15	20	40%
0,15	7,3	42%
0,15	3,6	50%
0,20	20	30%

Table 1 - variation of electric vehicles parameter

As there can be seen in the charging power of the individual electric vehicle has less impact on the grid as the vehicles energy consumption. A three time lower charging power results only in less increased maximum quota of electric car. On the other hand a variation of energy consumption form 0,15kWh/km to 0,20kWh/km decreases the maximum quota up to 30%. Concluding the dominating parameter for charging load is the vehicles energy consumption cased by the electrics car's drivetrain- and battery management efficiency.

4.2. **Scenario with Load Management**

The Load Management was described in previous section, already. Figure 4.2 points out the advantage of a controlled charging compared to the base scenario without any control of charging load

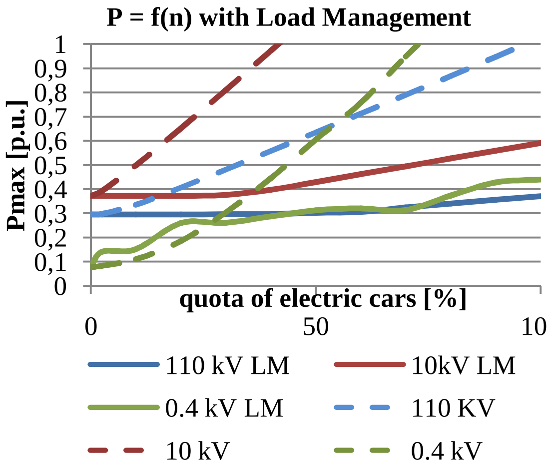

figure 4- grid disturbance with load management

With respect to the constraints (eq. 3.3) a load management system can operate a distribution grid up to a 100% quota of electric vehicles without reaching its limits. The non linear graph slope of the 0.4 kV zone results from the described minima search for higher grid level. Figure 5 shows the dependence of load factor k to the electric car quota also compared to the base case

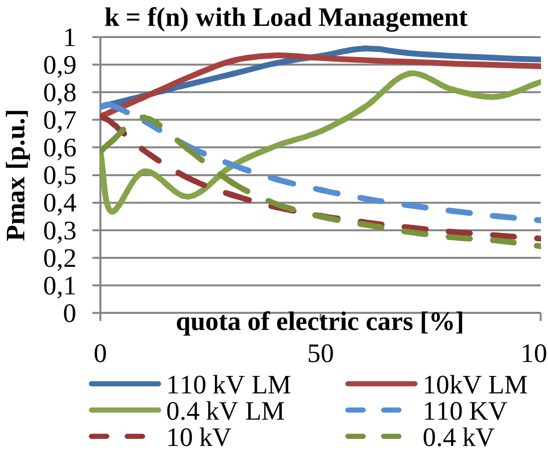

figure 5- load factor with load management system

The display load factor is a well benchmark for the efficient use of the distribution grid. A flat graph of load means the optimum of k=1, which could not be reached caused by the car usage constraint (eq. 3.3). The Comparison to the base scenario demonstrates the benefit of a load management system.

5. CONCLUSION

So far there are no experiences with electric vehicles and their impact on distribution grids. It can be assumed that the charging at home will be the only wise solution to handle with the charging time. The quick charging technology is not fully developed up to now, which would be necessary for an infrastructure similar to the gasoline stations. So for a first step there was estimation of the uncontrolled charging load in all grid levels. Calculations showed the mid- and low voltage level as the bottlenecks. Anyhow the grid will not crash with the introduction of the first electric cars as it was shown in this paper. In case of rising amount of electric vehicles by a market share of approximately 20% the additional charging load would bring first cables or transformers to overload. At this point a load management system will be unavoidable for a sustainable power supply. On the other hand by using a fully integrated peak shaving load management strategy the distribution grid could supply more electric cars than necessary. Concluding only the weak grid zones have to be equipped with an ICT-infrastructure to make the load management strategy available for them.

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