IMPROVED LOAD MANAGEMENT ALGORITHM FOR FUTURE NETWORK REQUIREMENTS

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ABSTRACT

With the expected charging characteristic of e-mobility a considerable load peak during the night is expected. Photovoltaic and small wind power systems will further increase the load fluctuations. The paper describes the application of a modified maximum rectangle algorithm to determine the optimal starting times for charging electric cars to realise a flat load curve. The load characteristic of electric cars is similar to night storage heating devices. This allows to use these currently widely spread devices as example for developing and testing methods for optimized load management in low and medium voltage networks. It is shown that the developed optimization algorithm finds solutions close to the global optimum even with a huge number of devices (≈15 000) with low requirements of calculation time (<1 min).

INTRODUCTION

Currently a large change in the electrical energy systems can be observed. There are a large number of photovoltaic and small wind power systems which are feeding in the low voltage (LV) and medium voltage (MV) networks. In the near future it is expected that many electric cars penetrate these networks. A replacement of other energy sources like oil and gas by electricity for heating purposes is also expected. Therefore the power flows through the LV and MV networks will become higher and more fluctuating in the future. For many cases a load management system can avoid network extension and additionally decrease fluctuations in power markets.

Thereby the load management system has to be able to handle a large number of units and it has also to be sufficiently flexible to react on changing infeed of photovoltaic and wind power systems.

Currently there are many night storage heating devices installed in the networks. These devices have similar load characteristic compared to e-mobility. After switching on these devices they consume a constant high power for several hours. The charging time of the night storage heating devices depends on the temperature, of the electrical cars on the load state. Therefore night storage heating devices can be used for testing and evaluating load management algorithms that later will be used for the load management of electric vehicles.

LOAD CHARACTERISTICS

Figure 1 shows typical load curves of different electric cars. It can be seen that the charging process consists of two different components. At first electrical cars charge with a constant power until they are nearly fully charged and then the charging power is reduced until the battery is fully charged. Since the charging with constant power is active for most time, the load characteristics can be simplified to a rectangle load characteristic with time and charging power as the two sides of the rectangle. Thereby the charging power is constant, depending on the type of the vehicle, and the charging time depends on the energy spent for driving the day before.

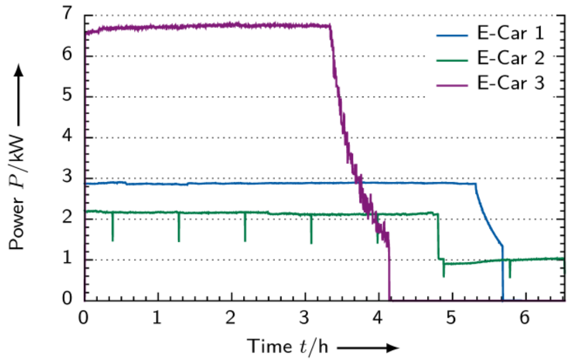

Figure 1 Load curves of different electric cars [1].

A similar charging characteristic can be found with night storage heating devices. These devices are able to store energy in form of thermal energy for many hours. The thermal storage is charged with constant electrical power until the desired temperature of the thermal storage is reached. Thus the load characteristics of a night storage heating device can also be described as a rectangle, with constant power depending on the type of the heating device and charging time depending on outside temperature as the both sides.

OPTIMIZATION METHOD

The aim of the load management system is to reduce the network stress due the charging of e-mobility and night storage heating devices during night and to maximize the utilization of wind power generation for the charging. Thus it has to schedule each device to achieve this goal.

The control of the night storage heating devices is currently implemented with a radio ripple control receiver and only a switch on signal is transmitted. The switch off time is determined by the control of the storage heating device depending on the charging state. This simple control concept should be maintained by the load management system. Thus the new optimization algorithm only has the switch on time of the devices as degree of freedom.

Algorithm

In general the optimization problem corresponds to a power plant scheduling. These types of problems are often solved by an integer linear programming. Integer linear problems belong to the complexity class NP-hard. This term refers to classes of problems that are unlikely to be solved efficiently. This results in particular with a large number of variables to a high computer storage and computational complexity. With the high number of night storage heating devices and electrical cars, which should be optimized by load management systems a high computational effort is required. Thus integer linear programming is not the method of choice for a practical implementation.

In addition to the linear approach a variety of heuristic methods exist for power plant scheduling [2]. Heuristic approaches have the advantage that they are very fast. However, they do not necessarily lead to the optimal solution. In practice, the solutions found are usually sufficiently accurate, since they have only a slight deviation from the actual optimum.

For this optimization problem it makes sense to use a 2D rectangle packing algorithm. As described before the load of an electrical car or a night storage heating device can be represented as a rectangle with time and power on each side. The objective of the algorithm is to "pack" all the load rectangles optimally in a given area. This given area depends on the residual load and wind generation forecast of the next day as well as the expected charging time of each electrical vehicle and night storage heating device. The positions of the load rectangles after the optimization correspond to the switch on time of each device.

In the literature, a variety of different 2D rectangle packing algorithm is described [3–7]. For the solution of this problem the maximum rectangles algorithm [3] is in principle suitable. After the first placement of a rectangle (rectangle 1 in fig. 2 up) all maximum rectangles are determined in the remaining free space (rectangle A and B). The next rectangle will now be placed in the most appropriate maximum rectangle (see Figure 2 bottom).

After the placement of the first rectangle the shapes A and B result as maximum rectangles in the remaining free space. The placement of the next rectangle is according to the selection criteria in A or B. If the best fitting length is used as selection criteria then the rectangle 2 is placed in B (see Figure 2). For the next step the maximum rectangles are A', B' and C'.

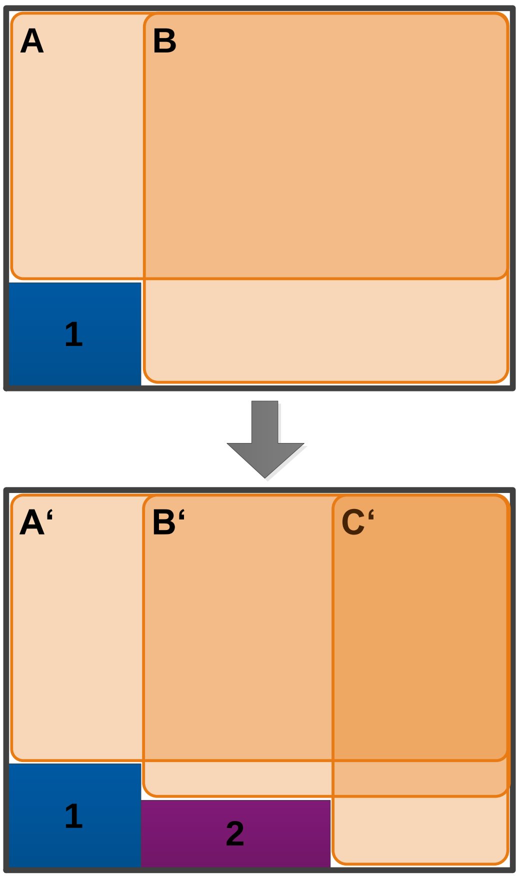

Figure 2 Maximum rectangles algorithm

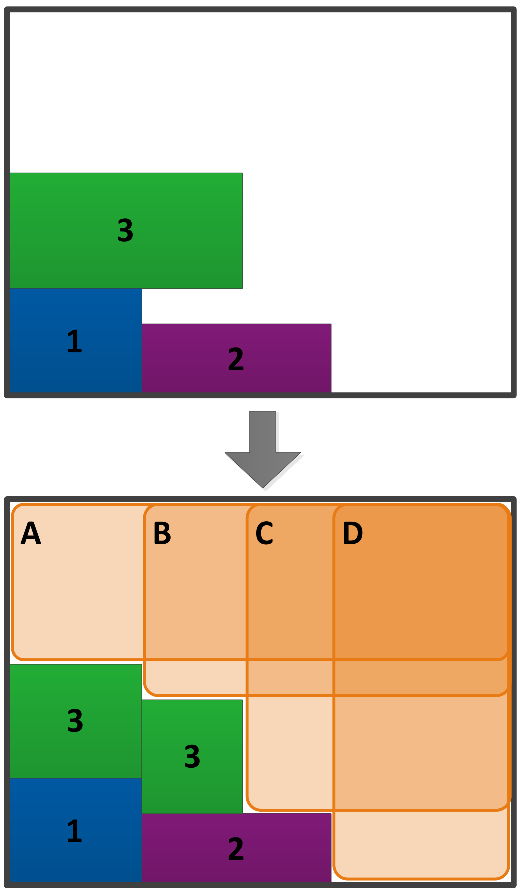

Figure 3 Modified maximum rectangles algorithm

For this optimization problem only the x position of each rectangle is relevant, since it defines the switch on time of the device. The y position of the rectangles is irrelevant. For the optimization only the remaining space in y direction has to be stored. Thus it is possible to divide the rectangles parallel to the y-axis. With this modified maximum rectangles algorithm the remaining free space after the optimization is reduced, thus a solution close to the global optimum is found (see Figure 3).

Further minimization of the remaining free space at the end of optimization could be achieved by choosing the best sorting for the rectangles and the best selection method for the maximum rectangle. In this case the best results could be realized if the rectangles are sorted in descending order of power (size in y direction). For selecting the maximum rectangle for the next device it is the best by evaluating the y-axes [8].

Calculating the optimization area

To achieve the optimization goal a suitable optimization area has to be calculated. To accomplish minimal network stress and maximized utilization of wind power generation the resulting load at the substation has to minimal in the optimization period which was chosen from 8:00pm to 8:00am.

First the substations load without the charging load of e-mobility and night storage heating devices has to be calculated. This could be done by sum up the load and the wind forecast. Next the total charging energy in the optimization period has to be estimated. For the night storage heating devices this depends on the outside temperature. For e-mobility this depends on the state of charge of the battery of each car. Therefore each car has to submit this information to the load management system.

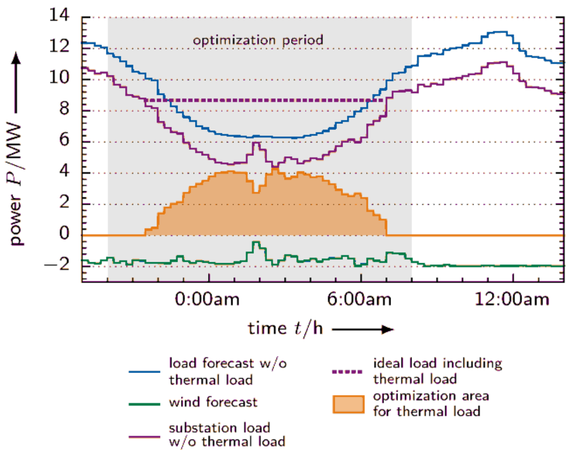

Figure 4 Optimization area in the night from 16. to 17.01.2010

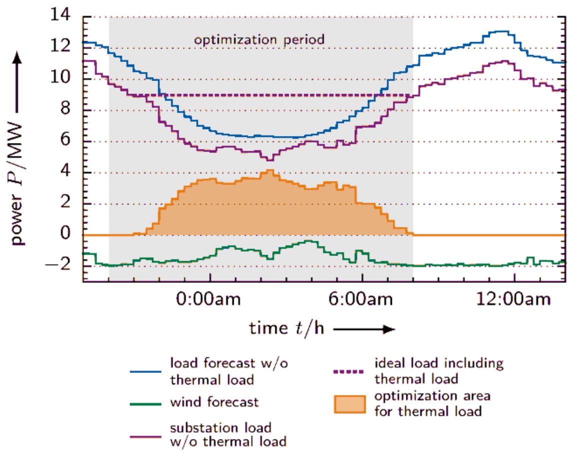

Figure 5 Optimization area in the night from 29. to 30. January 2010

With this data the optimization area for next day can be calculated. Figure 4 and **Figure 5** present the calculated optimization area for two example days at one substation in the network on ENSO NETZ GmbH. About 500 night storage heating devices are installed in the network of this substation. The total power of these devices is about 11 MW

Optimization Results

Figure 6 and Figure 7 show the optimized load curve at the substation compared to the load without optimization for the two example days. It can be observed that the load profile at the substation is almost flat after the optimization during the selected period. Compared with the load curve without optimization the peak load of the network during the chosen optimization interval is reduced.

Nevertheless the theoretical global optimum is not reached by the described heuristic optimization method. But for practical applications the results are sufficiently good. The main advantage of this algorithm is the low requirement of computational time. In the scenario with approximately 15 000 night storage heating devices in the network of ENSO NETZ GmbH the computation time is less than 1 minute. The calculation was done on a normal Workstation PC (Intel Core i5 CPU 650 @ 3,2GHz, 4GB RAM).

Another advantage is that the computation time increases only linearly with the number of devices. Thus this algorithm is also suitable for a much larger number of devices.

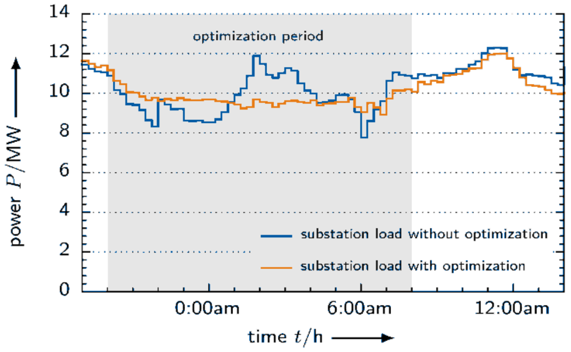

Figure 6 Optimization result in the night from 16. to 17.01.2010

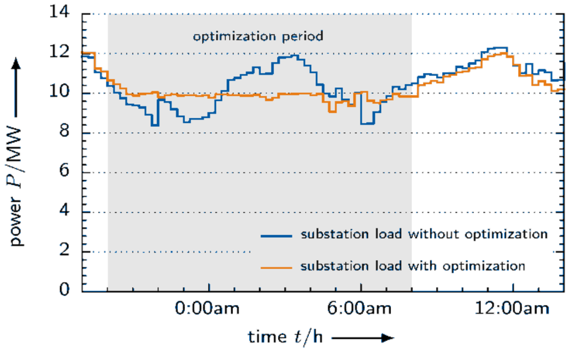

Figure 7 Optimization result in the night from 29. to 30.01.2010

CONCLUSION

In this paper an optimization algorithm for load management of e-mobility and night storage heating devices has been presented. With the heuristic approach it is possible to optimize a large number of devices to reduce the network stress, reduce the peak load and maximize the utilization of wind-power. Thereby the communication requirements are minimal. The algorithm optimizes only the switch on time of each device. As information for the algorithm the electric cars have to transmit only there state of charge and after the optimization only the switch on time is transmitted.

In a test scenario with approximately 15 000 night storage heating devices it could be demonstrated that the resulting substation load is near to the ideal load profile. The remaining error is lower than 5 %. With some further adjustments the algorithm can also be applied to other devices like heat pumps.

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