Abstract — In this paper, the effect of a Demand Side Management (DSM) on the residual load in Germany is shown. The used Demand Side Management model is focused on controlling heat pumps, electrical vehicles and white goods. The aim is to analyze the use of DSM regarding the increasing fluctuating power feed-in which is a result of the growing renewable energy sources (e.g., wind turbines and photovoltaic installations). The target function of the used model is to plane the residual load curve. To evaluate the influence on the German system load, the residual load curve will be analyzed with two key parameters: the shift potential and the volatility change factor. The shift potential expresses the maximum, simultaneous reduction of the peak of the residual load curve. The volatility change factor describes the relation between the diversity of the maximum and the minimum power before and after using the DSM. The effectiveness of the DSM by the used model is estimated and the outstanding points are declared.

Index Terms—Demand Side Management (DSM), residual load, increasing renewable energy, electrical vehicles, heat pumps, white goods, volatility change factor, shift potential

I. INTRODUCTION

The residual load is defined as the difference between the system load profile and the feed-in from renewable energy sources, already regarding the imports and exports of electrical energy [1]. In other words, the residual load describes the system load which still has to be covered by conventional power plants.

The DSM is applied successfully to help reducing the peak demand and filling the demand curve valleys [2]. Due to the increasing renewable energy sector, the decreasing of conventional power plants and the current discussion around nuclear power plants in Germany, a Management system to shift the customer’s demand seems as one means to deal with the situation. The main idea is to shift demand devices into times with a high feed-in of renewable energy. Concerning the residual load curve, this means shifting a part of the peak load to the off-peak load valleys.

There are two mechanisms to influence the customer’s demand behavior. The first one is that the customer responds to appropriate incentives and changes his consumption behavior. The second mechanism requires an automatic load control system. In this case, the shift potential does not depend on the customer’s reaction because the declared customer devices are operated automatically.

Several political conditions are already implemented to affect the customer’s demand. According to § 40 (3) EnWG, suppliers of electrical energy must provide a tariff with an energy-saving incentive1, as long as it is technically and economically reasonable. This could mean a variable tariff in time or load (e.g., a two-part-pricing model).

The customer has therefore the possibility to take a flexible rate with different prices at different times or loads. This impulse is just one opportunity to influence the customer’s demand. Due to the fact that the effect by variable tariffs depends on the unpredictable customer’s reaction and adaption, the predicted customer’s load curve is an insecure parameter.

On the contrary, an automatic load control system may provide a more confident short time prediction of the customer’s load curve and is therefore considered in this paper.

To simulate such a DSM, a model is developed to give answers to the following central questions:

• Which technical appliances will be primarily suitable to balance the residual load?
• How much of the residual load curve can be planned and what are the essential factors?
• What is the maximum shift potential?

The shift potential of the residual load can be used to analyze the impact of the DSM on the residual load curve. It describes the maximum, simultaneous reduction of the peak load. This means the amount of the system load that can be mobilized at a time when only a minimum of renewable energy is available.

The primary aim of this paper is to plane the residual load curve by using a developed Demand Side Management model. The focus of using the DSM is to analyze the shift potential and the volatility change factor by controlling electrical devices in households.

II. COORDINATION OF DSM

The management of controllable electrical devices is simulated by using a heuristic model. In addition to the statistical

1 latest till the 30th of December 2010.
data about the appliances of interest, the input data of the DSM model are the residual load profiles of Germany for 12 characteristic days (a typical weekday, Saturday and Sunday of winter, summer and transitional time).

The target function of the used DSM model is to plane the residual load curve. The DSM model contains a prioritization for the controlled appliances, which means that according to the chosen order the management system is shifting the load iteratively. After each iteration step, the resulting residual load curve will be the new basis for the target function.

One iteration step always includes the whole group of each selected appliances, which means that their usage probability function reaches its minimum at the time frame of the peak of the residual load. The whole energy consumption of this group will be shifted to other time frames. That leads to the assumption that every household possessing at least one controllable device participates in the load management.

An analysis of technical appliances revealed that the appropriate devices should have a high consumption of electrical energy and the customer accepts the shifting process. Particularly suitable for these requirements are the electrical heat pumps, because the majority of the consumers will not notice any interference into the usual operating sequence and the electrical consumption is significant. Furthermore, electrical vehicles provide a fairly high load capacity and the customer’s acceptance for shifting the charging process is predicted to be quite high, at least during specific time frames (e.g. night time). From the typical electrical devices in households, the white goods, meaning washing machines, laundry dryers and dish washers generally offer flexibility in time of a few hours. Their electrical energy consumption is significant in comparison to other loads in households, but in order to use this flexibility in an automatic load management the customer is to accept an interference of their daily schedule. These three types of appliances are used as controllable devices in the DSM model. The way they are modeled is described in detail in the subsequent paragraphs.

A. Heat Pumps

The increasing demand for heat pumps and the comparable high power consumption make the implementation of heat pumps indispensable.

The heat pumps are included in the Demand Side Management model to plane the residual load curve because the consumer’s acceptance of controlling heat pumps is expected to be very high in comparison to the remaining applications. The only thing the customer requires is to have his individual heat demand covered at all times.

To simulate the consumption characteristic in the DSM model, load profiles are used, which are standardized at a consumption of 1,000 kWh per year and reflect seasonal variations. The profiles for the winter time (01.11.-20.03.) and the transitional periods (21.03.-14.05. and 15.09.-31.10.) assume the heat pumps running 24 hours a day. In the summer time (15.05.-31.10.), they are only active from 6 am to 10 pm every day. Since the German distribution system operators (DSO) already use a type of load management in terms of the heat pumps, the DSM algorithm is based on these procedures. Customers with a heat pump currently pay lower fees for the network access and the DSO gets the possibility to interrupt the operations of the heat pump 2-3 times a day for two hours. The time zone for each interruption is previously set by the DSO so that a two-hour intermediate time is assured. In the DSM model, three time slots each over two hours are set flexible to the times of the peak of the residual load curve on the basis of the daily situation in the system. During these time slots all the modeled heat pumps will shut down and the energy that should be consumed during this time will be consumed in the following ¼-h-periods.

The basis for the statistical input data for the model is provided by a study of 2009 from the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). Figure 1 displays the predictions for the annual electrical energy consumption of the heat pumps in Germany for the decades 2020 till 2040 [3].

**Assumptions for heat pumps:**

- Prediction of the annual electricity consumption of the heat pump sector in Germany [3]
  - 2020: 4.4 TWh
  - 2030: 6.1 TWh
  - 2040: 6.2 TWh
- annual electricity consumption of one heat pump: 6,000 kWh
- installed capacity of a heat pump: 2.0 kW

Figure 1: Assumptions for heat pumps

In contrast to other studies, the BMU predicts a lower increase of the consumption of the heat pump sector up until 6.2 TWh per year in 2040 and even a decrease afterwards. The reason is that after 2020 the technology of local heating systems will be established so that great parts of the heat requirement of households will be supplied by solar and geothermal energy. The fossil energy sources and therefore the single heating systems in each household will be pushed back [3]. For the simulation, an installed capacity of 2.0 kW and an average electricity consumption of 6,000 kWh per year is taken for a heat pump, which means that around one million heat pumps are considered in the DSM model.

B. Electrical Vehicles

With regard to the enlargement of electrical vehicles, the influence on the energy supply structure will be significant. To evaluate the potential of the DSM, the widespread introduction of electrical vehicles planned by the German government is essential. The plans are to have one million electrical vehicles included in the German energy system by 2020 (cf. Figure 2). On this basis and considering a successful market introduction procedure, it is assumed that 8 million electrical vehicles will be integrated in Germany in 2030 and 20 million in 2040.

Since the DSM model is focused on the household sector, the electrical vehicles are charging at a connected load of 3.7 kWh. Using the Demand Side Management in this context
means to shift the necessary time frame of charging into other periods of the day.

**Assumptions for electrical vehicles:**

Prediction of the number of electrical vehicles in Germany:
- 2020: 1 million electrical vehicles
- 2030: 8 million electrical vehicles
- 2040: 20 million electrical vehicles

Figure 2: Assumptions for modeling the electrical vehicles

C. White Goods

White Goods need around 15% of the total consumption of electricity in a household depending on the customer’s habits and behavior. In the DSM model average values for the property of white goods are used. In Figure 3 the equipment, the frequency of use and the power consumption for white goods are pointed out.

**Assumptions for white goods:**

- Portfolio of washing machines, laundry dryers and dishwashers
- Facility level of households in the years 2020, 2030 and 2040:
  - 93% washing machine
  - 38% laundry dryer
  - 62% dishwasher
- Use of the Equipment in households per day for the years 2020, 2030 and 2040:
  - 48% washing machine
  - 25% laundry dryer
  - 40% dishwasher
- Power consumption of each program sequence [4]:
  - 0.9 kWh washing machine
  - 2.5 kWh laundry dryer
  - 0.7 kWh dishwasher
- No switch-off during the program

Figure 3: Assumptions for white goods

These values are assumed to be constant for the time frame of interest. To demonstrate the DSM model, the used load profiles of white goods are illustrated in Figure 4.

D. Key Parameter

To evaluate the potential of the DSM, heat pumps, electrical vehicles and white goods are implemented in the model as described. The selected key parameters to analyze the potential of the DSM are the maximum shift potential and the volatility change factor. The maximum shift potential $\Delta P_{\text{max}}$ expresses the maximum, simultaneous reduction of the peak of the residual load. The volatility change factor $\Delta g$ is described by the following formula:

$$\Delta g = 1 - \frac{|P_{\text{max, DSM}} - P_{\text{min, DSM}}|}{|P_{\text{max}} - P_{\text{min}}|}$$  \hspace{1cm} (1)

The parameters of the volatility change function are the maximum and the minimum load capacity ($P_{\text{max}}$ and $P_{\text{min}}$) before and after the DSM ($P_{\text{max, DSM}}$ and $P_{\text{min, DSM}}$). The volatility change factor is determined by the relation between the diversity of the maximum and the minimum load capacity before and after using the Demand Side Management.

These two characteristic parameters form the basis for the evaluation of the results.

III. RESULTS

The DSM model is applied on two different scenarios. The first one emphasizes the installation of renewable energies and at the same time the nuclear withdrawl. That means that this scenario considers an increasing funding of renewable energies (EE). The second scenario is developed by the BMU and predicts an even higher installation capacity of the renewable energies for the decades till 2040. Whereas in the EE scenario the increase of renewable power plants is still moderate, the BMU scenario describes an extreme situation in which even negative residual load becomes probable. This means that times occur when the feed-in of renewable power plants exceeds the demand.

For each scenario, two different strategies for the Demand Side Management are carried out.
**Version A:**

The loads can be shifted without any constraints in regard to time and capacity and the customers accept the shift of their use of the electrical appliances. So the shifting potential is available 24 hours per day.

**Version B:**

The use of the electrical devices is limited in time and therefore the shifting potential is only available in a special time frame. This version represents the situation that there are times in which the probability is very low that the consumer would agree to a Demand Side Management.

The use of washing machines and laundry dryer is limited to the time frame between 6 am and 10 pm in this version. This corresponds to some of the current regulations for rented accommodation. The dish washer usually produces less noise so it can still be used any time of the day. Since the electrical vehicles are mainly expected to be charged at home or during working time, the time slots between 5 am and 9 am and between 2 pm and 6 pm.

In order to compare the results for a different prioritization of the controllable appliances, two different strategies were analyzed. The first strategy takes the order from the customer’s acceptance assumption: (1) heat pumps, (2) electrical vehicles and (3) the shifting of the examined white goods. The second strategy considers a possible incentive for flexible owners of electric vehicles. The order is: (1) electrical vehicles, (2) heat pumps and (3) white goods. The results display that the prioritization does not have a significant impact so in the following only the results for the first strategy (the most probable) are described.

Figure 5 shows the load pattern and the feed-in by renewable energies in Germany for the BMU scenario in 2040. The different curves show the different load pattern of the considered controllable loads for every 15 minutes.

Due to the fact that the BMU scenario assumes a very high penetration of the renewable energies in 2040 the feed-in of renewable energies exceeds the total capacity load.

In Figure 6 the result of the DSM for version A (no limit in time and capacity) is exposed. Compared to Figure 5, the DSM model shifts the loads from off-peak times of renewable energies in high-peak times of the feed-in of renewable energies. It is noticeable that the volatility can be decreased. The figure shows that despite of using the DSM model a difference exists between the maximum feed-in by renewable energies and the total capacity load. This means that even in times of maximum feed-in by renewable energies, storages has to be filled or energy has to be exported. In case of the storages being already filled there are only two possibilities left. Either it is still possible to export the electrical energy or feed-in of renewable power plants has to be limited.
In Figure 7 and Figure 8, the results for the maximum shift potential $\Delta P_{\text{max}}$ of the DSM and the volatility change factor $\Delta \sigma$ are demonstrated for both scenarios and both versions. One main effects of using the DSM model is that from 2020 to 2040 the shift potential $\Delta P_{\text{max}}$ increases from 2.5 GW to 7.9 GW. This occurs due to the increasing use of electrical vehicles and heat pumps in 2020. In addition to that the volatility change factor indicates the improvement of the residual load’s volatility. In all scenarios and versions the residual load curve can be planned. The greatest improvement is in the renewable energy scenario in 2030 with a volatility change factor of 59%.

IV. CONCLUSION

Technical appliances with a high consumption of electrical energy and an independent use regarding time could be integrated into a Demand Side Management system to plane the residual load. The customer’s acceptance is an important factor since he will only agree to a shift of his electrical devices if there is no lack of comfort. According to that, the DSM model shifts the energy of the heat pumps first by allocating three two-hour time frames for closing down. Afterwards the charging procedure of the electrical vehicles is shifted to peak load times of the residual load curve. In the last step of the iteration, the energy consumption of white goods is shifted into the remaining valleys of the residual load curve.

In the two analyzed scenarios BMU and EE, the shift potential increases with the rising feed-in of renewable energies and of course with a higher amount of controllable devices in households. Analog, the volatility change factor increases and the volatility of the residual load can be more planned.

V. FUTURE PROSPECTS

The gained results provide new starting points for analyzing the impact of new tariff-models and automation systems for the customers. It has to be analyzed how different restrictions in time and capacity of the usage of the electrical devices influence the shift potential and the volatility change factor.

In addition to that, the DSM model has to be adjusted to operate more iteratively. That means that one iteration step should not always mean the shift of 100% of the group’s electrical consumption but it should be possible to decide on shifting a lower percentage. This is according to the fact that not every household possessing a controllable electrical item will offer it to be included in a Demand Side Management system. In the future, it has to be evaluated how these changing influence the achieved results.

Furthermore, it has to be mentioned, that the customer’s acceptance for shifting the load has to be studied in detail. It is seen as an input data, that the customer is willing to shift the load from the peak times into the off-peak times of the residual load. In this paper the focus is investigating the maximum of the potential in shifting and balancing the load of the residual load curve, so the maximum shift potential and the maximum volatility change factor are presented. The possible realistic data need a closer look on the customer’s behavior in view of the socio-economic factors.

The influence of the heat pumps, electrical vehicles and white goods, which is described in this paper, requires new energy market roles and new energy market processes to ensure a sustainable development. To analyze other influencing factors on the residual load through the customer the combine heat and power plants and other decentralize energy conversion plants also have to be regarded.

VI. REFERENCES


VII. BIOGRAPHIES

Hans-Jörg Belitz was born in Herne, Germany, in 1984. He received the Diploma degree in industrial engineering with the focus on European energy management from the Technical University of Dortmund, Germany, in 2009. Since 2009, he is working on his Ph.D. degree at the Institute of Power Systems and Power Economics at the Technical University of Dortmund. His research focus is on the electricity industry and smart grids. His research focus is the electricity industry and smart grids in conjunction to the usage combined heat and power plants.

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