Investigation of Technical Potentials for Load Shifting and Their Suitability to Compensate Forecast Errors of Wind Parks

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***Abstract*—Fundamental changes in the availability profile of electric power are expected due to the predominant feed-in share of renewable energy sources. In order to balance the differences between the regional generation and consumption, caused by forecast errors, the expansion of the power grid is currently being accelerated. However, a rational and resource-saving alternative constitutes the participation of consumers, which are capable of shifting load, in a Demand Side Management (DSM) concept. In the present work, the suitability of deploying existing consumers for compensating wind forecast errors in a German federal state is investigated. For the investigation, a survey regarding the structure and proportion of existing consumers in the domestic, industrial and service sector was conducted. Furthermore, the identification and quantification of their potentials of load shifting took center stage. A confrontation of expected positive, as well as negative forecast errors and technical potential of existing loads indicate that there is a high probability of successful elimination of unbalances, if a collaboration between wind parks and regional consumers was accounted.**

Keywords- Demand Side Management; forecast error; load shifting; wind parks.

I. INTRODUCTION

Future energy systems are prone to pass through a massive changeover from fossil to renewable energy generation as the German government decided to be one of the leading countries on the way to a more sustainable environment. However, renewable energy generation is often subject to uncertainties due to positive and negative forecast errors, consequently leading to high, dynamically-shaped availability profiles of the generated electric power.

Since generation and consumption in the electric power system has to be kept in balance, a resource-saving manner of providing the required balancing power is indispensable. Facing these uncertainties implies assuring that online power plants dispose of sufficient generation capacity, resulting in a permanent underutilization rate of power plants. By including load shifting consumers in a Demand Side Management (DSM) concept, the operating reserve of the power plants could be minimized or even replaced, increasing their utilization rate and their efficiency.

Up to now, several scientists researched this field. Main contributions were related to the benefits and challenges of DSM [1] and to the quantification of load shifting potential of different consumers [2][3]. Technical, as well as economic aspects with respect to developing a DSM concept were analyzed [2]-[5]. In [1], Strbac points out, the process of engaging consumers in a DSM concept was especially favorable and advantageous for grids with a great share of intermittent generation sources. Nevertheless, the slow development processes were a consequence of the lack of Information and Communication Technology (ICT) infrastructure, as well as the lack of understanding of the benefits of load shifting solutions.

A vast quantification of available load shifting solutions was presented by Klobasa in [2][3]. Klobasas publications, as well as the electric grid related report [4] refer to Germany, including the domestic, industrial and service sector. Further work related to the load shifting in industrial sectors was published by Ashok et al. [6] and Paulus et al. [7]. The impact of DSM on the domestic sector was investigated by Gottwalt et al. [8] and Schlomann et al. [9].

In addition to the publications mentioned above, this paper aims not only to present and quantify the load shifting potential of the three sectors but also to confront them to common forecast errors in the wind power generation. Load shifting potential, as well as the wind power generation data series correspond to the same German federal state, presenting an individual connection between the confronted values of load shifting potentials and expectable forecast errors. More specific information about typical density functions of occurring forecast errors are presented in [10]. In [10], the author gave an overview of the magnitude of forecast errors to be expected in different regions.

Following this objective, the paper is structured as follows: In Section II, the potentials of load shifting are presented and discussed. Hereby, a differentiation between the domestic, industrial, as well as service sector was made. Section II is followed by the evaluation of expected forecast

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errors corresponding to the investigated federal state. Subsequently, results were discussed in Sections IV and V and afterwards, main conclusions were drawn.

II. Evaluation of Technical Potential for Load Shifting

In order to accomplish the objective of this work, it was first necessary to identify the main consumers of the federal state that have the potential of short term load shifting and then to quantify them in terms of electric power. For this purpose, a survey was conducted implying the industrial commerce chamber, the federal state statistical office, as well as relevant industrial companies in the region. These delivered important information with regard to the technical potential of load shifting in the region including parameters, such as the annual energy consumption of different loads of the domestic, industrial and service sectors in the federal state. Specific market saturation rates, as well as average electric power of appliances corresponding to the domestic sector were made available. The appliance with the highest market saturation rate among households (hh) of the investigated federal state is the refrigerator, with 99.8 %, followed by the washing machine, with 96.65 %.

In case of industrial consumers, which are able to provide load shifting potential by interrupting their production, such as the steel industry, the annual production plays a major role in determining the load shifting potentials. In case of food industry, where load shifting can be made available by cooling houses and refrigeration compressors, the technical potential of load shifting is available at each time of day. Constraints are mostly given by the admissible duration of the load shifting process. Aiming to make a distinction between air conditioning and ventilation in different branches of the industry and the cooling houses, a category named cross-section technology has been added to the calculation. This category includes the ventilation and air conditioning of production and manufacturing halls, as well as machines.

With regard to the service sector, the individual character was given by the average annual consumption as well as in most of the cases information about the surface area and the working schedules of consumers. By knowing the surface area of supermarkets, discounters or even office buildings, the demand of air conditioning, ventilation of rooms and cooling or freezing of food products can be approximated. Furthermore, water heating processes are also to be taken into account. The technical potentials of the service sector are tightly connected to the weather conditions. For this work, consumption values, which correspond to the summer months and are therefore less significant for a DSM concept were considered. If winter months are assumed, the technical potential of air conditioning in the service sector will increase.

After acquiring these information, the power to be made available for load shifting was quantified by using the methodology and Load Management Factors (LMF) thoroughly presented in [2] and [4]. Hereby, the results listed in the tables I to III with respect to the domestic, industrial and service sector, respectively, were obtained.

Table I shows the technical potentials of one single household. These amount to 146 MW if a population of 2 million households was considered. Summing up the load shifting potential of the three sectors, a value of 533.3 MW was obtained. As shown in Table I, as well as in the publications [2]-[4][8] a considerable load shifting potential of the domestic sector could be provided by appliances with great market saturation, such as the refrigerator, or the washing machine. According to [8] the load of refrigerators can only be postponed for 30 minutes. A short duration of the load shifting process reduces considerably the available shifting power that might be used in a DSM concept. Appliances, such as the washing machine or the dishwasher are connected to possible comfort limitations of the inhabitants. Therefore, the utilization of the whole calculated technical potential seems to be rather unlikely.

A survey among the industrial consumers showed that the only industrial process to be possibly used in a DSM concept can be found in the steel production. Any other industrial branch would require an absolute changeover with respect to their processes in order to be eligible for a DSM concept. Nevertheless, the activation of the technical load shifting potential of the steel industry is tightly connected to the melting process and is therefore limited.

TABLE I. Load Shifting Potentials - Domestic Sector

Application	Energy Consumption	Market Saturation	Shifting Power
Washing machine	150 kWh/a	96.65 %	23 W/ hh
Dryer	280 kWh/a	23.8 %	11 W/ hh
Dishwasher	215 kWh/a	61.2 %	19 W/ hh
Refrigerator	200 kWh/a	99.8 %	29 W/ hh
Freezer	280 kWh/a	45.1 %	17 W/ hh

TABLE II. Load Shifting Potentials - Industrial Sector

Application	Energy Consumption	LMF	Shifting Power
Steel industry	1100 GWh/a	50 %	135 MW
Food industry	155 GWh/a	50 %	17.7 MW
Cross-section technology	519 GWh/a	11 %	16.6 MW

TABLE III. Load Shifting Potentials - Service Sector

Application	Energy Consumption	LMF	Shifting Power
Cooling Processes	128 GWh/a	63 %	169 MW
Ventilation	365 GWh/a	50 %	20 MW
Heating	238 GWh/a	25 %	7 MW
Air Conditioning	259 GWh/a	75 %	22 MW

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According to [2] an activation is only 40 times a year possible. A reduction of the consumption can be delayed for four hours. Cooling houses permit the load shifting up to a duration of two hours. In addition, cross-section technologies, such as cooling processes, ventilation or heating processes in the industrial sector might be available for participation in a DSM concept on daily basis with a maximum duration of two hours. The conducted survey confirmed that in the service sector only cross-section technologies can support shifting loads. A considerable amount can be provided by the consumption of cooling systems in supermarkets or discounters. The share of ventilation and air conditioning to the total technical potential is almost insignificant during the summer months.

III. EVALUATION OF EXPECTED FORECAST ERROR

The data series corresponding to the wind power generation was provided by a regional grid operator. These contain 15-minutes values describing the actual generation and the forecasted values during a year. Calculated forecast errors P_{FE} were defined as difference between the forecast generation P_F and the actual generation P_A:

$$P_F - P_A = P_{FE,} \tag{1}$$

with $P_{FE} < 0$ describing an underestimation and $P_{FE} > 0$ representing an overestimation of wind generation.

An evaluation of the given data series showed, the positive forecast error totaled up to 109 GWh/ a, while the negative forecast errors equaled -127 GWh/ a. The maximal values of the positive and negative forecasted errors were 210.58 MW and -239.66 MW, respectively, while the reference installed power of the wind turbines amounted to 1112 MW. Nevertheless, a positive median forecast error of 16.3 MW is to be assumed in case of overestimation. The median underestimation forecast error lied at -21.2 MW.

In order to get a better overview of the type and magnitude of forecast errors in the evaluated wind data series, the error magnitudes were analyzed by means of the frequency of their occurrence in the data series. The obtained histogram showed in Figure 1, indicates that great values of underestimation errors are more frequent than great values of overestimation errors. On the other hand, the majority of the forecast errors, which are positive, lie within a band of 2 MW to 6 MW. Forecast errors due to overestimation greater than 65 MW proved to be rather unusual.

For a better understanding of the character of forecast errors with respect to the magnitudes of the actual feed-in wind power, these were divided into three groups. Each of the three groups consist of 2928 elements and represent values of low, medium or high feed-in power. In accordance with the evaluated data series the low feed-in values range from 1.2 MW to 73.49 MW. The high feed-in power values lie within a band of 196.5 MW to 840 MW.

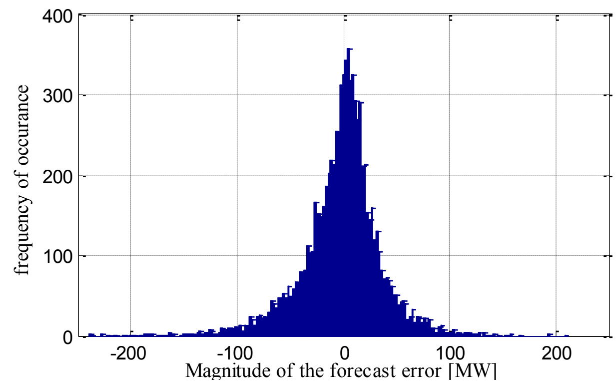

Figure 1. Relative Frequency of Forecast Errors over a year.

The tendency of overestimation or underestimation depending on the magnitude of the feed-in values was following analyzed by means of the distribution function for each of the three groups, as it can be seen in Figure 2. The average values corresponding to the three density functions differ from zero, meaning that there are certain tendencies of the three groups for overestimation or underestimation. In the area of the high feed-in power values, 196.5 MW to 840 MW, the average value of the forecast error, equal to -17.29 MW, is negative, thus preponderantly describing underestimation errors. In contrast to the high feed-in group, the density functions of the other two groups are defined by positive average values. The average value of the normal distribution of the group represented by middle feed-in power values between 73.5 MW and 196.49 MW is equal to 2.89 MW, meaning that most of the forecast errors were positive. Still, the number of overestimation and underestimation errors are almost equal for this power interval. The forecast errors of low feed-in power show a clear tendency to overestimation. Further information related to the forecast errors of the three groups, can be obtained by calculating their absolute median values. The median absolute values of the forecast errors that correspond to the three groups of high, medium and low feed-in power are 32.6 MW, 19.5 MW and 10.3 MW, respectively.

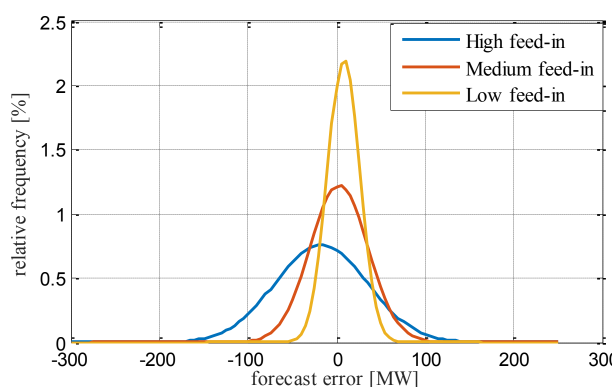

Figure 2. Normal distribution of Forecast Errors over a year of different feed-in levels.

The calculated median values support the proposition that the absolute magnitude of forecast error arises with increasing magnitudes of the actual feed-in power. Furthermore, the investigated data series showed that forecast errors are likely to occur in the afternoon and in the late evening hours, as calculated forecast errors correspond to the day-ahead forecast method. By making use of another forecast method, lower values regarding the forecast error could be achieved.

IV. CONNECTION BETWEEN TECHNICAL POTENTIAL OF LOAD SHIFTING AND FORECAST ERRORS

The connection between overestimation and underestimation and the required countermeasures are described by the diagram in Figure 3. A positive forecast error resulting from overestimation would therefore be followed by a demand of positive balancing power. Positive balancing power can be provided by consumers that are able to postpone their regular consumption cycles or reduce these. This type of procedure can lead to an additional consumption at a later point of time, since most of the consumption cycles still has to be executed. Still, a short term error compensation can be achieved, if positive forecast error are balanced out by deploying the right amount of positive balancing power. In case of underestimation, negative balancing power is required. Appliances that have not been yet in operation are collectively switched on with the purpose of collecting the superfluous power available. The load that has been procured earlier may result in a reduced load profile at a later point in time. By matching the appropriate amount of negative balancing power to the occurring negative forecast error, a short term compensation of negative forecast error will result. In this way, a short term compensation of forecast errors and therefore an improvement of the electric grid by balancing supply and demand will be reached.

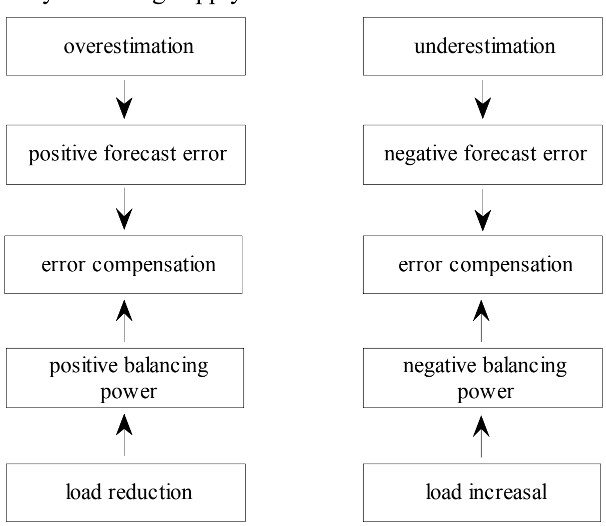

Figure 3. Connection between the type of forecast error and suitable countermeasures.

V. INTERPRETATION OF RESULTS

In accordance to the objective of this work, a confrontation between the technical potential and the expectable forecast error in wind power generation corresponding to the federal state is indispensable. Evaluating the results on regional base aims to provide an additional share of plausibility and applicability. The assumption that an ample participation of regional consumers to a DSM concept is able to face forecast errors could be consolidated, if it was shown that technical potential for shifting loads exceeds the expectable forecast error in most of the cases. This assumption has also been considered in the work of Stötzer et al. [11]. In this work, the authors analyzed the load shifting potential in Germany and predicted the future development of the German energy system.

Developing a DSM concept requires in the first step the identification and quantification of regional technical potential. For this purpose, consumers have to be divided into two categories, providers of positive or negative balancing power. According to the regional industrial processes, an utilization of the load shifting operation is permitted only 40 days a year and is straightly oriented to steel production. For a time interval up to 4 hours, 135 MW can be made available as positive balancing power in case of overestimation. The participation of industrial consumers to compensate for positive wind forecast errors is therefore only possible to a limited extent, although to be encouraged. Cooling houses as part of the food industry could be engaged in a DSM concept based on direct or indirect control. Cooling processes of industrial sector can be activated on daily basis.

All technical potentials that are related to cross-section technologies, such as cooling processes, ventilation or air conditioning can be made available every day of a year at least once a day for a time interval up to two hours. These can be aggregated and then utilized in order to provide positive, as well as negative balancing power, offering a secure source of technical potential for load shifting. As already stated in the work of Stötzer et al. [11], these are associated to a very low limitation of comfort for each consumer in different sectors due to their inherent storage function.

Technical potential of the domestic sector resulting from appliances, such as washing machines or dishwashers are mostly available during the day. Additionally, they imply the active participation of the inhabitants to the DSM concept. Given the high market saturation of this appliances, it might be realistic that part of the available households engage in a DSM concept. Every source of load shifting potential, which can be made available on daily basis, is to be approximated by taking into consideration standardized load profiles of the consumers mentioned in the tables 1 to 3. The reference load profiles describing appliances of domestic sector were developed by Stadler [12]. Other load profiles can be found in [4]. Results representing the profile of the total amount of available shifting load are shown in Figure 4. It has to be mentioned that the presented values represent the maximum available amount of load shifting potentials. These are only once available during a day. If potentials have already been called up, these will no longer be available for a certain period of time and are to be subtracted from the given maximum amount. By comparing the values related to the maximum expected positive or negative forecast error, 210 MW and - 239 MW, respectively, and the maximum amount of load shifting power that could be provided by regional consumers, it can be easily recognized that the technical available load shifting potential can compensate expected errors in most of the cases. The maximum negative forecast error, with an expected magnitude equal to - 239 MW exceed the technical potential available during the night. However, forecast errors of similar magnitudes are rather unusual and are mostly to be attributed to very particular events, such as accidents or storms that put entire wind parks out of service. Furthermore, forecast errors due to overestimation lie in over 90 % of the cases within a band of 0 and 25 MW. Over 85 % of the underestimation errors do not exceed 25 MW. Taking into consideration the presented profile in Figure 4, a forecast error of this extent could be easily compensated by making use of regional load shifting potentials. Even if forecast errors up to 25 MW occurred simultaneously or repeatedly, there would be a reasonable chance that the required share of load shifting potential was available. Due to the fact that great forecast errors are more likely to occur during the late evening hours, the chance to compensate them by means of load shifting, increases.

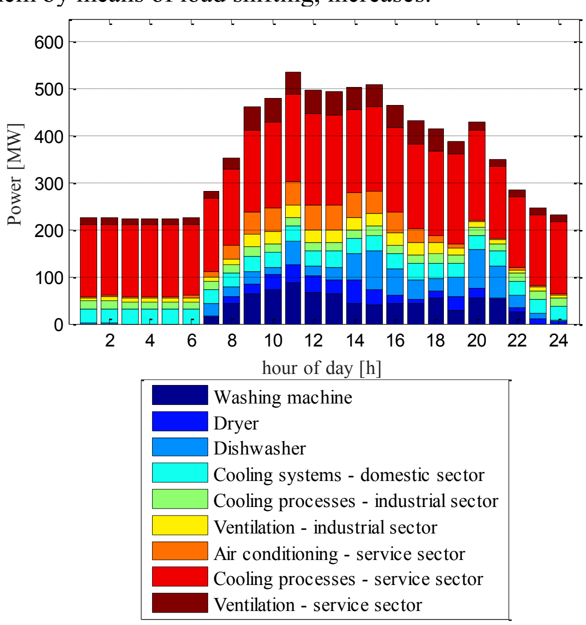

Figure 4. Profile of Available Load Shifting Power

VI. CONCLUSION AND FUTURE WORK

Based on a survey, an investigation of the technical potential of a German federal state was performed. The results are in accordance with already published results regarding Germany. These showed that every sector can be part of a DSM concept and contribute to it. A total technical potential equal to 533.3 MW was calculated. This technical potential could be activated only once during a day, assuming that all participants are able to shift load. During the night, over 200 MW technical potential for load shifting can be made available.

Most reasonable participants to a DSM concept turned out to be the cross-section technologies in the service and industrial sector, as these can be activated at least once a day. A further option is represented by appliances of the food industry and the food retail like cooling houses or supermarkets with high surface areas. These have a high power consumption and a forecast error could be compensated by including only a small number of participants. Technical potential for load shifting connected to industrial production processes is only represented by the steel industry. To a limited extent, a load reduction can be achieved. However, there is a huge need of modernization in this sector so that processes can be deployed for this purpose.

The domestic sector also shows a high technical potential for load shifting. A direct load control could be applied to cooling systems. Still, it has to be highlighted that the duration of this process shouldn't exceed one hour. Further appliances in the domestic sector to contribute to a DSM concept are washing machines or dishwashers, which might be connected to comfort limitations of the inhabitants. It also has to be mentioned that including diverse appliances related to the domestic sector in a DSM concept is associated to an elaborate control concept and vast communication network.

A reduction of the ICT infrastructure development and though a relief of the transition to a smart grid can be achieved, if every wind park had a few regional partners, which are willing to deploy their technical potential of load shifting, if required by the wind park or grid operators. Nevertheless, deploying available technical potential in order to compensate forecast errors is only possible if all involved participants are likely to profit from it. The economic benefits of their participation should definitely exceed the resulting effort or the comfort limitations.

Future research should consider the effects of other forecast methods on the resulting forecast error magnitudes in more detail. In addition, the development of an algorithm that identifies and quantifies load shifting potential, as well as the magnitude of the forecast error to be expected in a given electric grid is desirable in order to prove that there is a high probability of successful elimination of unbalances in diverse grids.

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