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CORRELATION OF DAY AHEAD ELECTRIC ENERGY MARKET PRICE WITH RENEWABLE ENERGY SOURCES GENERATION AND LOAD FORECAST

KORELACIJA IZMEĐU CIJENE ELEKTRIČNE ENERGIJE NA TRŽIŠTU DAN UNAPRIJED I PROGNOZIRANE PROIZVODNJE OBNOVLJIVIH IZVORA I POTROŠNJE

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Abstract: An increase in the share of renewable energy sources has an impact on generation variability and generation forecast error, which is also reflected in the formation of the day ahead electric energy market price. This paper analyses the impact of variable renewable energy sources and load forecast on the day ahead German electric energy market. A correlation between the market price, renewable energy sources generation and load forecasts was analysed. Results show that there is a significant correlation between the forecast of renewable energy sources generation as well as the load on day ahead electric energy market price. However, a residual load, which represents the difference between the load and the renewable generation, has the biggest impact on the day ahead price.

Keywords: Renewable energy sources, electric load, day-ahead market price, renewables generation forecast, correlation

Sažetak: Porast udjela obnovljivih izvora značajno utiče na varijabilnost proizvodnje električne energije, što se reflektuje na formiranje cijena električne energije na tržištu dan unaprijed. Kroz ovaj rad prezentovan je uticaj prognoze proizvodnje obnovljivih izvora i prognoze potrošnje na cijene električne energije za tržište dan unaprijed u Njemačkoj. Analizirana je korelacija između tržišne cijene, prognoze proizvodnje obnovljivih izvora i prognoze potrošnje. Rezultati pokazuju da postoji značajna korelacija između prognoze proizvodnje obnovljivih izvora, kao i prognoze potrošnje, i cijene na tržištu dan unaprijed. Dominantan uticaj na formiranje cijene na tržištu dan unaprijed ima razlika između prognoze potrošnje i proizvodnje obnovljivih izvora.

Ključne riječi: obnovljivi izvori, potrošnja električne energije, tržište dan unaprijed, prognoza proizvodnje obnovljivih izvora, korelacija

INTRODUCTION

Energy generation based on renewable energy sources (RES) has become a strategic commitment of the world to enable a sustainable society [1]. Integration of RES into power energy system is related to benefits like reduction of energy losses, decentralization of the power system and contribution to a cleaner environment by reduction of amounts of pollutants in the atmosphere [2].

Energy policies around the world stimulate an increase in renewable energy production [3], so the installed capacity of RES increases notably, worldwide. This largest contribution of new RES includes new installations producing electric energy primarily from solar and wind energy. The latter accounted for 84% of all new facilities installed in 2018, finally pushing the overall share of hydropower to just under 50% of the world's renewable installed capacity [4]. Technological development and decrease in production costs are factors that contribute notably to the fast spread of electric energy production from solar and wind energy in addition to the subsidies, which in the first place pushed these technologies forward years ago.

Although, the introduction of RES connected to power distribution system has its benefits, due to the stochastic nature of RES, it also introduces various issues to the power distribution system, such as voltage deviation, system stability, line congestion, reactive power compensation, and other power quality issues [5].

The challenges for today's electric energy market are the variability of generation and prices, the error in the generation forecast, negative prices, etc., which are a result of the growing share of RES [6]. An increase in

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the share of RES affects various aspects of the electric energy market, primarily the economic aspect, as well as the shape of the supply curve [7].

The introduction of RES has an effect on the merit order curve. Typical merit order curve sorts different types of power plants in the ascending order based on their marginal costs. Base and medium load generators are located on the left hand side of the merit order curve with high fixed costs and low variable costs. Peak load generators like gas plants are located on the right hand side of the merit order curve with lower fixed costs and higher variable costs. Therefore, peak load plants receive revenue from electric energy sales only during high demand or scarcity situations. Due to low variable cost, increasing the share of RES shifts the merit order curve to the right hand side, which leads to less utilization of peak power plants. The effect of increasing the share of RES on merit order is graphically presented in Figure 1 [8]. Due to determining market price as the intersection of supply and demand, the average market electric energy price will be lower, which causes less revenue for peak power plants. This effect is discouraging for future investments in peak power plants and thermal power plants with high variable costs (coal, gas, oil, carbon emission coupons, etc.).

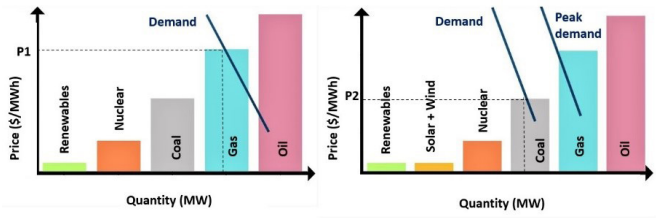

Figure 1: Impact of RES on merit order curve [8]

On the other hand, generation from renewables is intermittent and not reliable enough. Then, the market will be faced with a resource adequacy problem, which means the generation adequacy in the market will not be high enough to meet the peak demand. A well-functioning energy market should be able to provide cost recovery for all types of generators to ensure an adequate level of resource adequacy [9].

In previous years electric energy market has been facing an increase in the share of RES in the generation portfolio and this trend is expected to continue in the future with the highest growth estimated for wind and solar PV technologies [10]. In this paper, the term “renewable energy source” refers to the wind (onshore and offshore) and photovoltaics (PV) RES.

RES variability is a challenge for the power system operators, as it requires additional actions to balance the power system. Power system with a large share of variable RES needs sufficient flexibility to ensure that generation and demand are adjusted.

Intermittent and uncertain characteristic of RES generation implies difficult planning of generation from RES. Precise RES generation forecast provides the basis for optimized power system operation under market conditions, so minimum difference between forecast and realized RES generation is required. Taking multiple market integration into account improves forecast precision [11]. Greater accuracy in the forecast of RES generation is one of the preconditions for a further increase in the share of RES.

The decision-making in the power market highly relies on the electricity prices, making the price forecast model a crucial component for the orderly and efficient operation of the electricity market. Accurate prediction of the electricity price enables the balance between power supply and demand, and facilitates the stable operation of the power market. Various models for day-ahead market price forecast are developed [12]-[18].

In order to determine a price at a day-ahead market auction, it is essential to provide a day-ahead renewable generation forecast. System operators provide a forecast of renewable generation for the next day with an hour or eventually 15 minute resolution. The difference between real and forecasted generation is traded in the intra-day market. Day ahead forecast of RES generation and load are important for the day ahead market, because trading in the day ahead market is based on day ahead forecast values of generation and load.

Germany is one of the most progressive countries in RES installed capacity. In addition, Germany has a liquid electric energy market, so it is convenient to use its example to analyse the impact of RES on various market parameters.

For the purpose of this paper, the following data is used:
- Day ahead PV and wind (onshore and offshore) generation forecast [19],
- Actual PV and wind generation [19],
- Day ahead load forecast [19],
- Actual load [19],
- Day ahead market electric energy price[19],
- Day-ahead transfer capacities [19].

The analysis is performed on data from the ENTSO-E database for the period from 1.1.2019 to 31.10.2021, with hourly resolution. This paper does not propose a forecast method for day-ahead values of RES generation, load and market electric energy price. Forecast values are obtained from the ENTSO-E database.

The objective of this paper is to consider the impact of day ahead forecast values of RES generation and load on day-ahead electric energy market price. Section 2 presents the analysis of variability and forecast error of RES. The third section presents correlation analysis of day-ahead RES generation and load forecast on day ahead electric energy market price and a discussion of the obtained results. The last section presents the conclusion of this work.

1. RES VARIABILITY AND FORECAST ERROR

1.1. RES generation variability

Large variations in RES generation in markets with a large share of RES can cause several issues in power system operation and planning [20]. The installed capacity of wind and PV generation in Germany in 2020 amounted to 62.184 GW and 53.783 GW, respectively. Taking into account the capacity factor of 23% for wind generation and 13% for PV generation [21], the average hourly generation from variable RES would equal 21.294 GWh.

The mean value of hourly RES (wind and PV) generation in Germany for the considered period is 19.223 GWh with a standard deviation of 11.602 GWh. A histogram of hourly RES generation is presented in Figure 2. Maximum, minimum, mean and standard deviation values of hourly PV and wind generation, as well as load, are given in Table I.

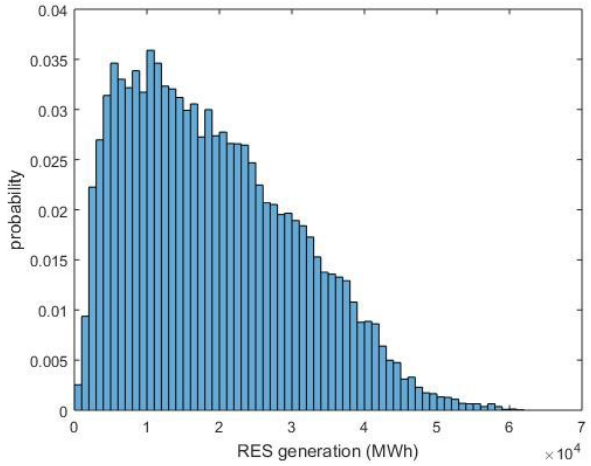

Figure 2: Histogram of hourly RES generation

Table I. Descriptive statistics of hourly values of RES and load

Parameter	Max (GW)	Min (GW)	Mean (GW)	St.dev. (GW)
PV	36.4	0.0	5.3	7.9
Wind	46.9	0.1	13.9	10.2
PV+wind	61.5	0.3	19.2	11.6
Load	80.0	29.6	56.7	9.9

Hourly variability of each parameter presents hourly gradients of that parameter. The maximum and minimum hourly RES generation gradients are +11.34/-10.05 GW. The ratio of the maximum and minimum RES generation gradient to the average hourly RES generation is +58.99% and -52.28%, respectively. The average hourly gradient of RES generation is approximately 1.77 GW and the ratio of the average RES generation gradient to the average hourly RES generation is 9.21%.

Figure 3 and Figure 4 show histogram of RES generation hourly gradient for the considered period in MWh and as a percentage of RES generation for a specific hour. The ratio of RES generation hourly gradient and RES generation for a specific hour have a mean value of 11.66%.

These findings prove that the variability of RES generation in the German electric energy market is high. By increasing the share of variable RES, the market will consequently face a higher level of variability of the generation profile.

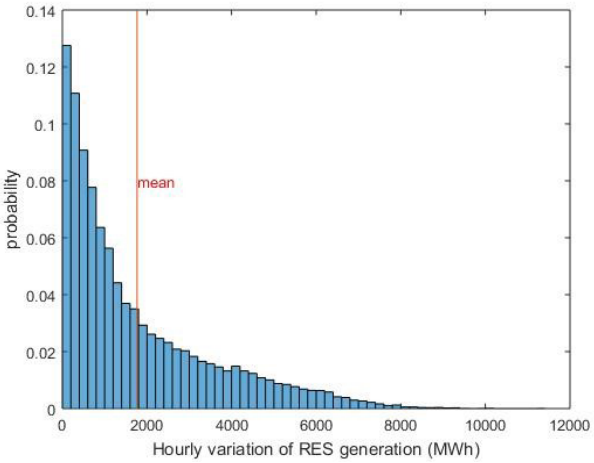

Figure 3: Histogram of RES generation hourly gradient

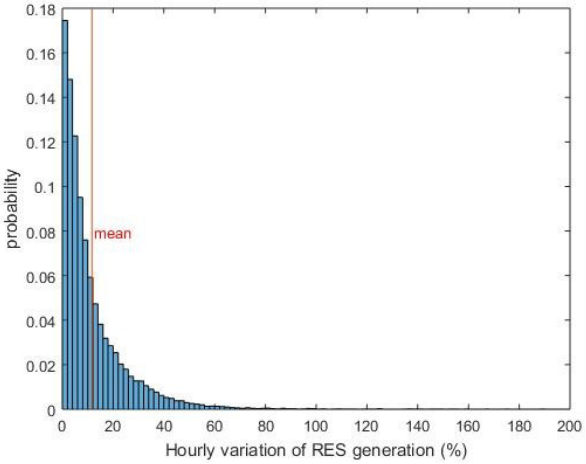

Figure 4: Histogram of RES generation hourly gradient (%)

1.2. RES generation forecast error

There are several ways of calculating the forecast error. In this analysis, the forecast error is calculated by subtracting realized RES generation from day ahead forecast values for each hour of considered period. Forecast values are obtained from the ENTSO-E database for the period from 01 January 2019 to 31 October 2021 with hourly resolution.

The histogram of RES day ahead generation forecast error is shown in Figure 5. RES generation forecast error for the considered period was in the range of -11.79 GWh to 11.26 GWh with a mean absolute percentage error of 9.19%.

Figure 6 presents a renewable generation forecast error as a percentage of the hourly load, which has a normal

distribution with a mean value of 0.12% and a standard deviation of 3.13%. Renewable generation forecast error as a percentage of hourly load is in the range of -24.38% to 20.82 %.

Renewable generation forecast error as a percentage of the hourly load for the German electric energy day ahead market for years 2012 and 2013 had a mean value of 0.3% [20]. Compared to results for the German electric energy day ahead market for years 2012 and 2013 [20], a mean value of renewable generation forecast error has a smaller value for 60%. This can be explained by a larger share of renewables, so the forecast generation error of individual generation units is compensated by other units. As expected, range of forecast error is larger than in years 2012 and 2013 because RES installed capacity and thus RES generation has significantly increased.

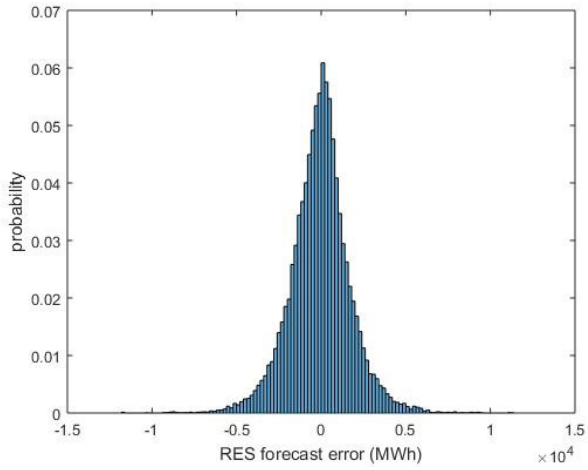

Figure 5: Day ahead RES generation forecast error

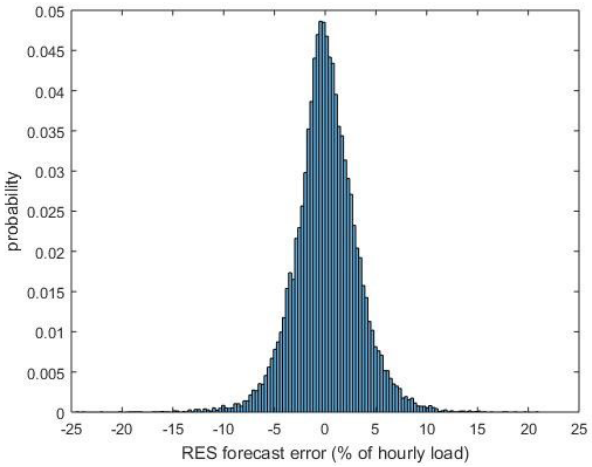

Figure 6: Day ahead RES generation forecast error (%)

2. RES IMPACT ON THE DAY-AHEAD MARKET PRICE

In this section impact of RES on day ahead market price is analysed based on hourly day ahead forecast values of RES generation, load and market price data.

In Germany, day-ahead electric energy price for the considered period was in the range from -90.01 €/MWh to 442.90 €/MWh, with the mean value of 45.02 €/MWh and standard deviation of 34.54 €/MWh. The histogram of the hourly day ahead price for the considered period is shown in Figure 7.

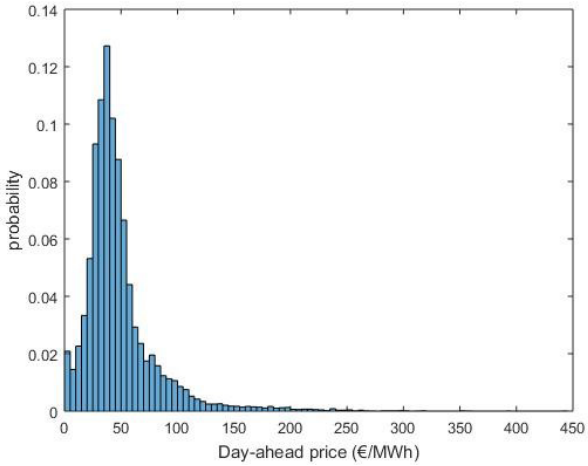

Figure 7: Histogram of day ahead price

In order to examine the impact of RES on the day ahead market price, it is necessary to analyse the correlation between hourly values of day-ahead RES generation forecast and hourly day-ahead market price. A scatter plot of hourly day ahead RES generation forecast versus hourly day ahead market price is shown in Figure 8. Results show that by increasing renewables infeed to the market the day ahead price decreases.

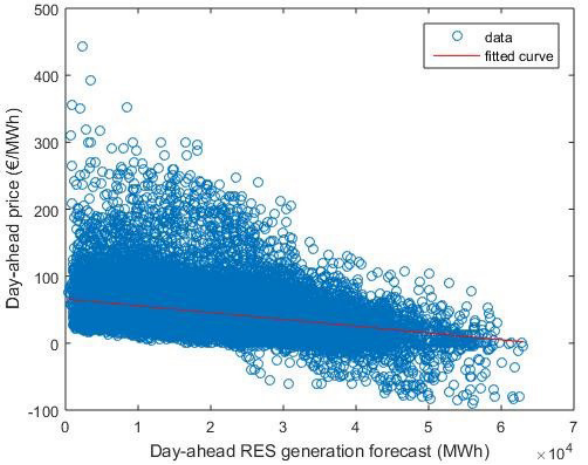

Figure 8: RES generation and day ahead market price

Negative day ahead electric energy price is recorded for 2.58% of hours during the considered period. Previously, negative electric energy price has usually been related to the holiday season because of low consumption. But with the increase share of RES, due to their nature, periods of higher generation than consumption are happening more often, so negative price is distributed through the year.

The period of peak price was 07 October 2021, when load had significantly higher values than average for

the considered period and renewable generation was extremely low.

A scatter plot of hourly day ahead load forecast versus hourly day ahead market price is shown in Figure 9. As presented in Figure 9, an increase in consumption predominantly implies an increase in price, because in periods of high demand peak power plants with high variable costs are engaged.

Figure 8 indicates that an increase in generation from RES has the effect of reducing electric energy prices, while Figure 9 suggests that higher consumption has the effect of increasing prices. However, it is interesting to observe the impact of the difference between the hourly day ahead forecast of load and RES generation, i.e. residual load. The residual load is supplied from non renewable sources, which are characterized by higher variable cost than RES. Figure 10 presents a scatter plot of hourly day-ahead residual load forecast versus hourly day ahead market price. As it can be seen, there is a clear correlation between residual load and day ahead price.

Table II provides an overview of the correlation coefficients between hourly day ahead price and hourly day ahead forecast of RES generation, load and residual load.

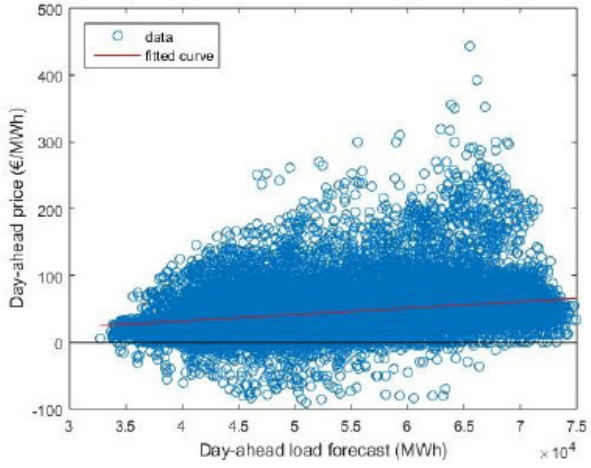

Figure 9: Load forecast and day ahead market price

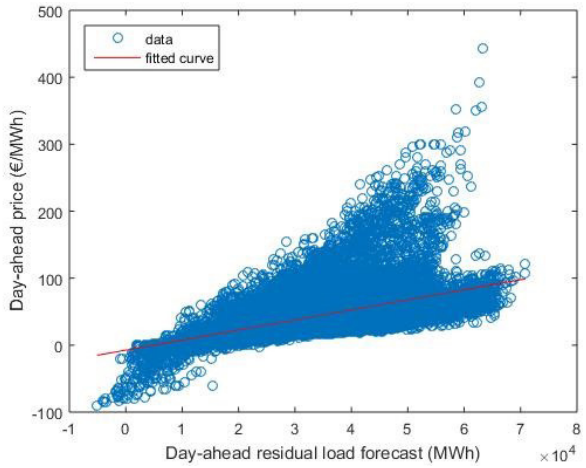

Figure 10: Residual load and day ahead market price

Table II. Correlation coefficients

Corr. coef.	RES generation forecast	Load forecast	Residual load forecast
Price	-0.3413	0.2638	0.5298

The correlation coefficient between a day ahead forecasted load and a day ahead price shows that a larger load significantly affects an increase in day ahead price.

Presented results in Table II suggest that day ahead price is more affected by the day ahead forecast of RES generation than load. The negative sign of the correlation coefficient implies that an increase in RES generation brings to decrease in the day ahead price.

Results show that the day ahead electric energy market price is dominantly correlated to residual load. Residual load presents load that cannot be covered with RES generation, so non renewable sources from the right hand side of the merit order curve must be engaged. Low residual load occurs in periods of low demand, high RES generation, or a combination of both. On the other side, the high residual load occurs in periods of high demand, low RES generation, or a combination of both. Higher residual load implies the need for a larger amount of generation from non renewable sources. The operation cost of non renewable sources is much higher than renewable ones, so electric energy price increases.

Hourly variations of hourly day-ahead RES generation forecast versus hourly variations day ahead price are shown in Figure 11, where it can be seen that in periods of low RES generation variability there is a big spread of price variation. Increase in hourly variation of RES generation leads to an increase in price variation. This is expected due to additional cost for balancing. The correlation coefficient between hourly variations of day ahead RES generation forecast and hourly variations of day ahead price is 0.15. The reason for the low correlation coefficient lies in the fact that price variability depends on several factors such as hourly electric energy load, load variations, available

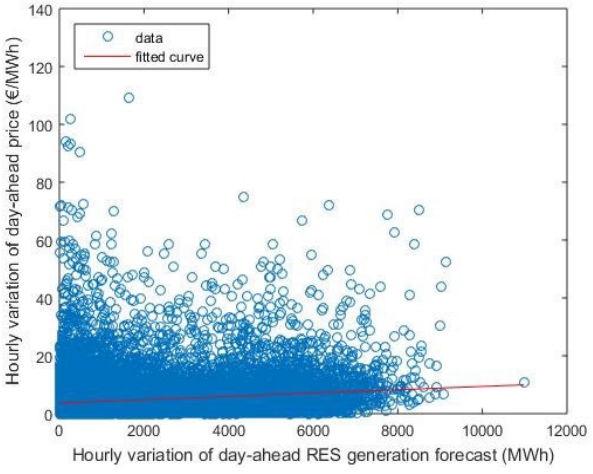

Figure 11: Hourly variation of RES generation and day ahead price

generation from different generators and the share of RES in the generation mix. Therefore, price variability must be analysed by considering all related factors.

3. CONCLUSION

Increasing RES generation brings new challenges to the electric energy market. For the considered period, RES generation was 33.92% of consumption with average hourly RES generation variability of 1.77 GW. Hourly variation of the load is 1.89 GW, which shows that load has higher variation than RES generation. However, that is not a big problem because the load can be very well predicted compared to RES generation.

Increase in share of RES contribute to reduction of RES forecast generation error, because other units compensate the forecast generation error of individual generation unit. Due to low variable costs, RES shifts the merit order curve to right hand side thus reducing the electric energy price. In the periods when RES generation is higher than demand, electric energy market price is negative. With increasing the share of RES, periods with negative price are becoming more frequent and are distributed trough year. Price peaks are recorded in periods of high consumption and extremely low RES generation.

Results show that the correlation between price and residual load is much higher than the correlation between price and RES generation. Increasing the share of RES in generation portfolio contributes to reducing residual load, i.e. less demand is supplied from conventional non renewable sources. Therefore, generation from non renewable sources decreases. However, power system still needs conventional energy sources in order to balance RES generation.

Opposite to expected, an increase in variation of RES generation does not imply an increase in price volatility. The reason for this is that the price does not depend only on RES generation, but also on other factors, such as hourly electric energy load, load variations, available generation from different generators and the share of RES in the generation mix.

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