Atlantis Highlights in Engineering, volume 6
14th International Renewable Energy Storage Conference 2020 (IRES 2020)

Probability of Correct Decision–Making at Triggering of Load–Shifting, Intended for Low CO_2 Intensity and Low EEX Trading Prices via Simple Grid Frequency Monitoring

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***Abstract*—To provide a simple control signal to operate residential Load–Shifting or Demand–Side–Management, the monitoring of actual grid frequency seems to be an appropriate method. Due to the present inflexibility and the lack of sufficient throttling capabilities of residual lignite and nuclear power plants, a surplus of electricity generation occurs during periods of high wind and solar power generation. While the specific CO_2 emission is decreasing then – due to the increased share of Renewables, the grid frequency is increasing (to a certain limit). Using the grid frequency as an indicator to switch-on and off certain loads (loads that do not require power permanently (e.g. dishwashers, washing machines, dryers, fridges and freezers, heaters) could provide a simple, inexpensive demand–side–management indicator to lower specific CO_2 emissions and costs (if a dynamic consumption tariff is available). To check the truthfulness of that hypothesis, the grid and frequency data of the German grid of the year 2018 have been collected and a the correlation between grid frequency, power surplus, share of renewables vs. CO_2–contents and price at the European energy exchange (EEX) have been calculated. The results show: Correlation between frequency and share of renewables is relatively low (r = 0.155) since primary grid control quickly compensates deviations from the 50 Hz nominal frequency. There is a good anti-correlation (r = -0.687) between the electricity trading prices (EEX) and the share of renewables in the grid. Over the years, correlation between EEX–prices and CO_2 emissions is quite good (r =0.665), within one year (2018) that correlation almost doesn't exist, possibly due to the inflexibility of the bulky lignite power plants that even operate at negative prices.**

Keywords—Correlation, CO_2, Load–Shifting, Demand–Side–Management, grid frequency, EEX, electricity trading prices, renewable share, flexibility, emissions

I. Introduction

Variable Renewables such as wind and solar power are designated to satisfy Germany's electricity demand by large parts. Residual power plants should provide a complementarily supply. Due to the present inflexibility and the lack of sufficient throttling capabilities of the remaining lignite and nuclear power plants in the German energy system, a surplus of electricity generation occurs during periods of high wind and solar power generation. While the adaptability of the generation-side to the residual load curve is at its limits, the demand-side adaptation should offer relief [1]. To perform such demand–side management (DSM), an adequate control signal should be available. To trigger the control signal, online data may be used: Grid load, actual composition of power plant types (e.g., share of wind & solar power), specific CO_2 emissions, and actual trading prices are available online, but are handicapped by a two– to six–hour delay [2,3,4]. Professional systems have direct access to that data but are often too costly for private consumers / prosumers. To provide a simple tool to operate residential Demand–Side–Management systems, the measurement of the actual grid frequency seems to be an appropriate method to trigger load–shifting by switching–on and –off certain loads. This would lead to a higher usage of Renewables, less losses by curtailing, lower CO_2 emissions, and reduced stress in the transmission and distribution system. Despite the relevance of the subject, literature about that method is very scarce, therefore it has been examined in this article.

II. Methodology

Using the grid frequency as an indicator to manage certain loads (loads that do not require a permanent supply (e.g., dishwashers, washing machines, dryers, fridges and freezers, heaters) could provide a simple, inexpensive demand-side management indicator to lower specific CO_2 emissions and costs (if a dynamic consumption tariff is available). To check the truthfulness of that hypothesis, the grid and frequency data of the German grid of the year 2018 have been collected and a the correlation between grid frequency, share of renewables, CO_2–intensity, and actual trading prices at the European Energy Exchange (EEX) have been calculated.

A. Data and Software

Based on available data [2,3,5], the Pearson correlations between the relative shares of renewables, EEX prices, CO_2 emissions and the grid frequency have been calculated, carried out via the software SPSS by IBM.

B. *Correlation indicator*

The Pearson correlation coefficient *r* has been applied, it describes the statistical relationship between two data sets x and y. The formula is:

$$r_{x,y} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \cdot \sum_{i=1}^{n}(y_i - \bar{y})^2}} \qquad (1)$$

x_i and y_i are the specific recorded values (data points), $\bar{y}$ and $\bar{x}$ are the according arithmetic means:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad \text{und} \quad \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \qquad (2)$$

The resulting correlation coefficients *r* can be between -1 and 1. A value -1 is a perfect anti–correlation between the data sets, +1 there is a total correlation. If the correlation coefficient is 0, there is independence between the data sets.

III. Results

A. *Correlation between share of renewable energies and EEX price*

Fig. 1 shows the clearly negative correlation between the share of renewables and electricity prices, i.e. If consumers are specifically switched on during times with a high proportion of renewables (and presumably reduced CO_2 emissions), the electricity price on the electricity exchange is low. Large consumers with direct access to the EEX exchange electricity prices should be able to operate ecologically and economically advantageous load management.

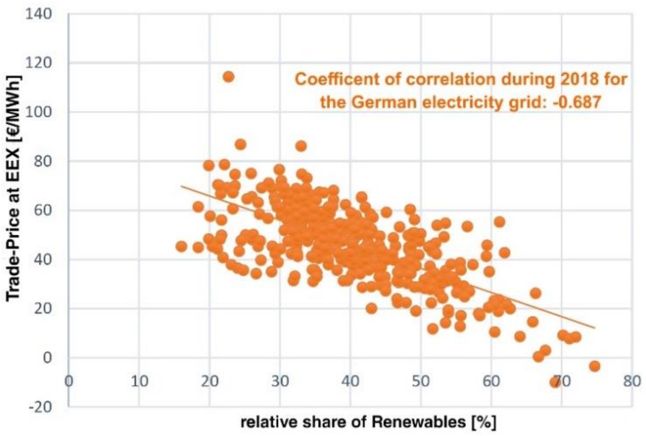

Fig. 1. Correlation between the relative share of renewables and the electricity price on the Leipzig Electricity Exchange (EEX) in 2018 [6].

B. *Correlation between the share of renewable energies in the grid and grid frequency*

The basic idea was to use the grid frequency increase as a trigger signal for load management, e.g. increase the load at grid frequencies above 50 Hz. The grid frequency is available everywhere, is easy to measure, and is free of charge.

Unfortunately, only a weak correlation of *r* = 0.155 (as shown in Fig. 2) occurs between the grid frequency and the share of renewables. Therefore, direct access (e.g., via the Internet) to the actual electricity trading prices (or the current share of renewables) should be provided in order to apply accurate an economically and ecologically advantageous Demand–Side–Management (DSM).

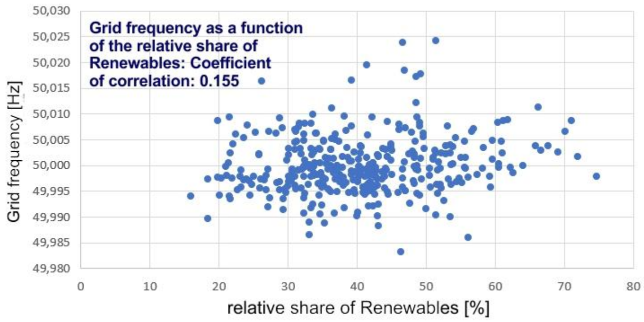

Fig. 2. Relationship between grid frequency and the relative share of renewables in Germany's electricity mix in 2018 [6].

C. *Correlation between the share of renewable energies and EEX trading prices*

The actual trading prices are published online for free on trading platforms (e.g. EEX), but typically with a time delay of 2 to 3 hours. Usually, only paid services offer an immediate access. Instead of the grid frequency, these prices could be used to trigger demand–side–management processes. The idea is that electricity prices will fall when there is a lot of electricity from renewable sources in the grid. This hypothesis was confirmed for the years 2006–2018: Fig. 3 shows a good correlation (*r* = 0.665) between electricity prices and annual CO_2 emissions.

Fig. 3. Correlation between electricity trading prices (EEX) and absolute CO_2 emissions over the years 2006 to 2018 [6].

However, within a year (using the example of 2018) the correlation between the EEX prices and CO_2 emissions was very weak ($r < \pm 0.1$). Therefore, the EEX price signal cannot be regarded as a reliable indicator of actual emissions.

This was probably due to the fact that even in times of low demand and low market prices, certain conventional power plants (e.g., lignite) could not be throttled and thus sometimes led to a low trading price with high CO_2 emissions. With the introduction of elevated CO_2–pricing and more flexible power plants (e.g., gas turbines instead of lignite power plants) this situation may change considerably.

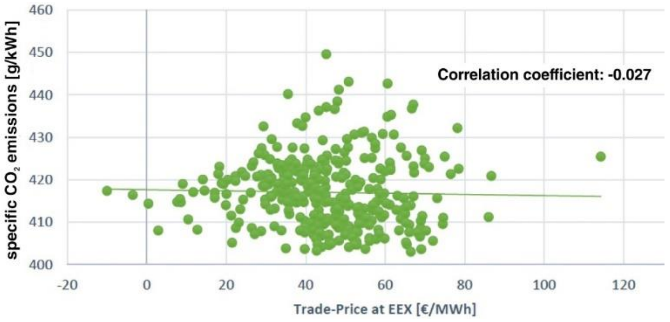

Fig. 4. Very weak correlation between electricity trading prices (EEX) and specific CO_2 emissions within 2018 [6].

D. *Correlation between the share of renewable energies and CO_2 emissions*

Although it seems obvious, the expected negative correlation between the relative share of renewable energies and the specific CO_2 emissions has been checked. The results are shown in Fig. 5. As expected, the long–term development from 2006 to 2018 shows a clear negative correlation (r = -0.803).

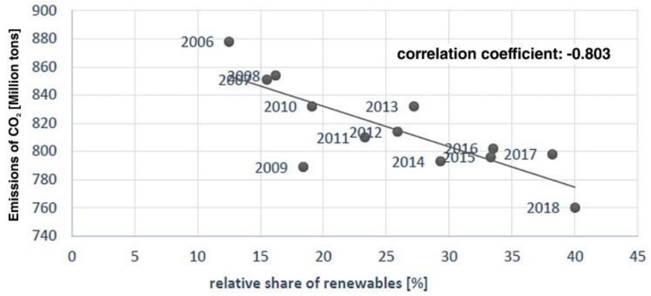

Fig. 5. Absolute CO_2 emissions from generated electricity in Germany as a function of the relative share of renewable energies for the years 2006 to 2018 [6].

When examining a single year (2018), the anti-correlation was relatively weak (r = -0.227, see Figure 6) – contrarily to the expectations. This is probably due to the fact that conventional back-up power plants were always running, even at low efficiency and accordingly high specific CO_2 emissions during periods when most of the power is provided by renewables.

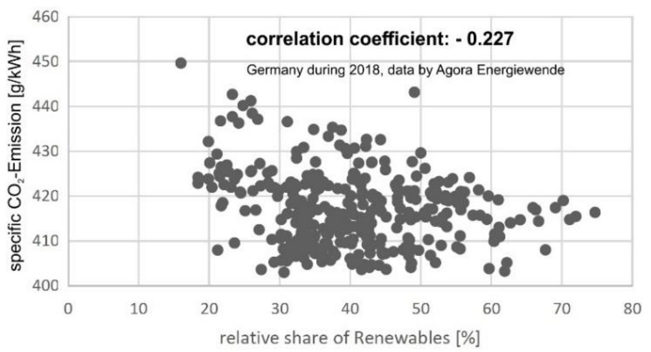

Fig. 6. Specific CO_2 emissions from generated electricity as a function of the relative share of renewable energies in Germany during the year 2018 [6].

III. DISCUSSION

The grid frequency cannot be regarded as a reliable indicator for the actual emissions and therefore cannot be used for efficient Demand–Side–Management. The use of actual EEX trading prices better serves that purpose, but it does not show a profound correlation to the share of renewables nor the CO_2 emissions. Even if it is more expensive, direct data revealing the share of renewables in the electricity mix or – even better – the actual emissions should be used for control. The situation will improve because controllability and flexibility of residual / backup power plants will increase due to upgrades, or these plants even will be replaced by fast–acting storage devices. Besides the advantage in EEX trading prices, rising CO_2–prices will additionally boost investments in controllability and flexibility.

ACKNOWLEDGMENTS

The authors would like to thank Agora–Energiewende, Energy–Charts and Gridradar for kindly providing the data of CO_2 emissions, the share of power plants in the electricity output, EEX trading prices, and grid frequencies.

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