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Operational forecasting of railway station electrical energy consumption based on the analysis of consumption data of nearby stations

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Abstract

This paper deals with the problem of operational forecasting of railway station electrical energy consumption. The relevance of the task lies in the fact that for the effective integration of renewable energy sources into the power supply system of railway stations, it is necessary to use energy storage systems and understand at what moments energy needs to be stored and when to spend. To control the energy storage system, it is essential to predict the processes of both generation and consumption. The complex aperiodic schedule of railway station energy consumption makes it difficult to use forecasting methods that are successfully used for other objects in the power industry, such as autoregressive models. At the same time, each station is an element of a whole system of railway stations connected by the train traffic. Therefore, the study tested the hypothesis that the station's electrical energy consumption forecasting can be obtained by analysing the consumption of other stations one hour before the forecast. The obtained results of building a regression model on real-life data collected from 36 stations are shown. Forecast error (mean absolute percentage error) is 19%, which, given the flexibility that the energy storage system brings to the station's power system, is an acceptable result.

Keywords: railway electrification, forecasting, data analysis, energy consumption.

1 Introduction

Recognition of the importance of Environmental, Social, and Governance (ESG) principles leads to industrial and transport enterprises striving to reduce their carbon footprint. One of the ways is using renewable energy sources (RES), which reduces electricity consumption from traditional sources. Railway systems are one of the largest consumers of electricity in many countries of the world, so RES in railway transport can have a significant impact on its environmental friendliness [1]. Railway stations and platforms can use wind or solar energy, but the stochastic nature of generation is a problem for RES integration. The possible solution is energy storage systems (ESS), including hydrogen systems [1-3]. Such systems make it possible to solve the problem of discrepancy between the schedules of generation from wind turbines or solar panels and the schedule of electricity consumption of a railway station, since, with an excess of electricity, it can be stored using hydrogen production. With a shortage, electricity can be generated using hydrogen fuel cells. But for the effective use of ESS, it is necessary to develop predictive control algorithms [4, 5]. These algorithms must determine when necessary to generate energy and when necessary to produce hydrogen (store energy). Moreover, unlike most other prosumers, the complexity of predicting the electrical energy consumption schedule is very high for railway stations since it depends on the train traffic [6,7].

The work aims to analyze the energy consumption data of the system of railway stations for the operational forecasting of their consumption. Consumption data of a number of railway stations were collected, an exploratory analysis of the data was carried out, and a regression model was built to one hour ahead forecast the electrical energy consumption of the station. In the next steps, the forecast of electricity consumption can be used to improve the efficiency of the use of ESS.

2 Methods

The authors collected hourly electricity consumption values for 1.5 months from 36 railway stations located on the section of the Russian railway from Novosibirsk to Omsk; the length of this railway part is about 600 km. The dataset consists of 1104 rows (46 days of 24 hours) and 36 columns. Fragments of energy consumption of three stations are shown in Figure 1. Wavelet analysis is applied to highlight periodic components in the energy consumption graph. Wavelet analysis allows us to select periodic components and determine their frequency and time intervals on which they exist. Thus, it is possible to identify cycles, based on which it is further possible to build an autoregressive model.

Then a correlation analysis was used, which showed a high level of correlation in the consumption between closely spaced stations. Since the problem of forecasting power consumption one hour ahead is considered, the correlation analysis was performed both for the values of consumption coinciding in time and for values with an hourly delay. Then, for one of the stations, two linear regression models were built, the first for the data without taking into account the shift by 1 hour, the second with this shift taken into account. Thus, the second model can actually be used for shortterm forecasting since it determines the station's energy consumption for 1 hour ahead. In addition, the first model helps for additional analysis of how interconnected the energy consumption of stations located along the same railway line is.

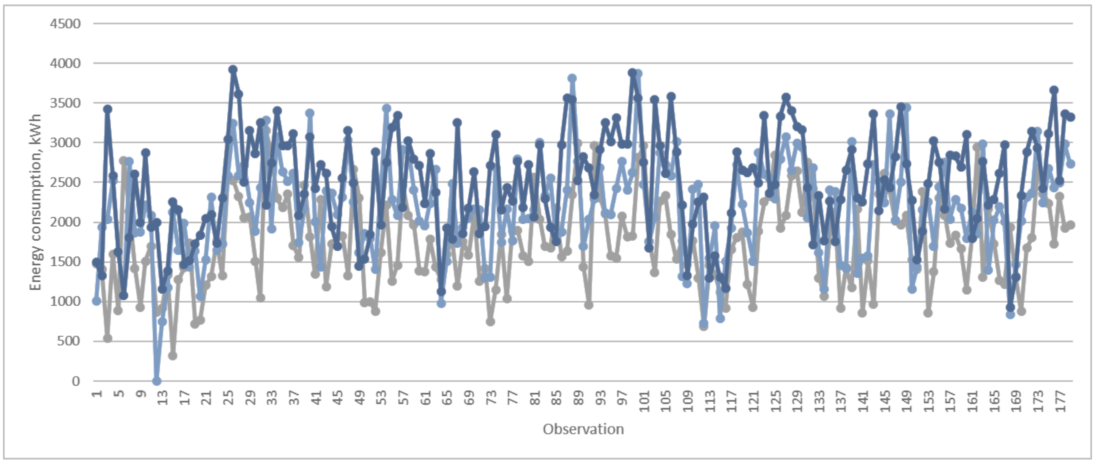

Figure 1. Fragments of stations' energy consumption.

The Python Scikit-Learn machine learning library was applied to build the models. The dataset was divided into training and validation in 90% to 10%. The usage of the simplest model, linear regression, is explained by the fact that the dataset contains a relatively small number of samples. However, some more complex machine learning models were also used, but their results did not outperform results obtained by the linear model.

3 Results

The results of applying the wavelet analysis to the energy consumption of one of the stations are shown in Figure 2. It can be seen that there are practically no pronounced periodic components in the consumption profile. Figure 1 above also shows that the consumption profile is aperiodic. Therefore, the use of auto-regression models does not allow obtaining an acceptable forecasting accuracy.

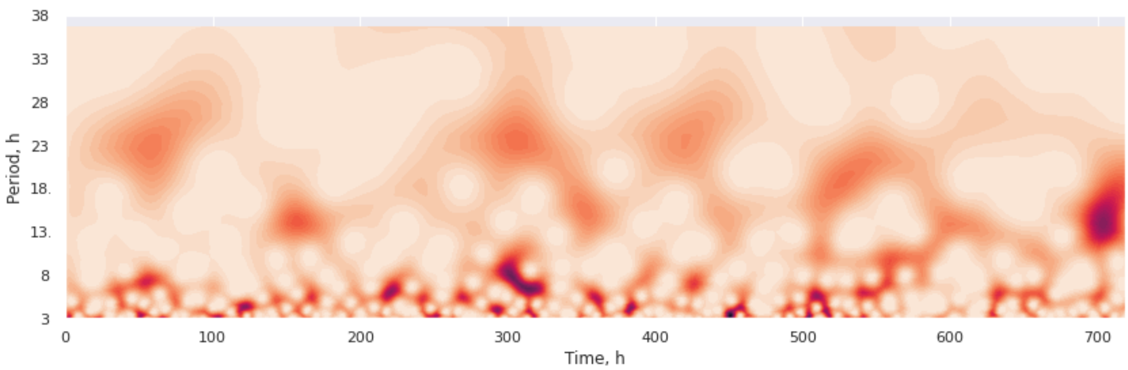

Figure 2. 3D surface obtained by the wavelet analysis.

The results of the correlation analysis showed a high level of Spearman correlation coefficients for closely spaced stations, as shown in Figure 3. The order of the stations corresponds to the location along the railway section under consideration.

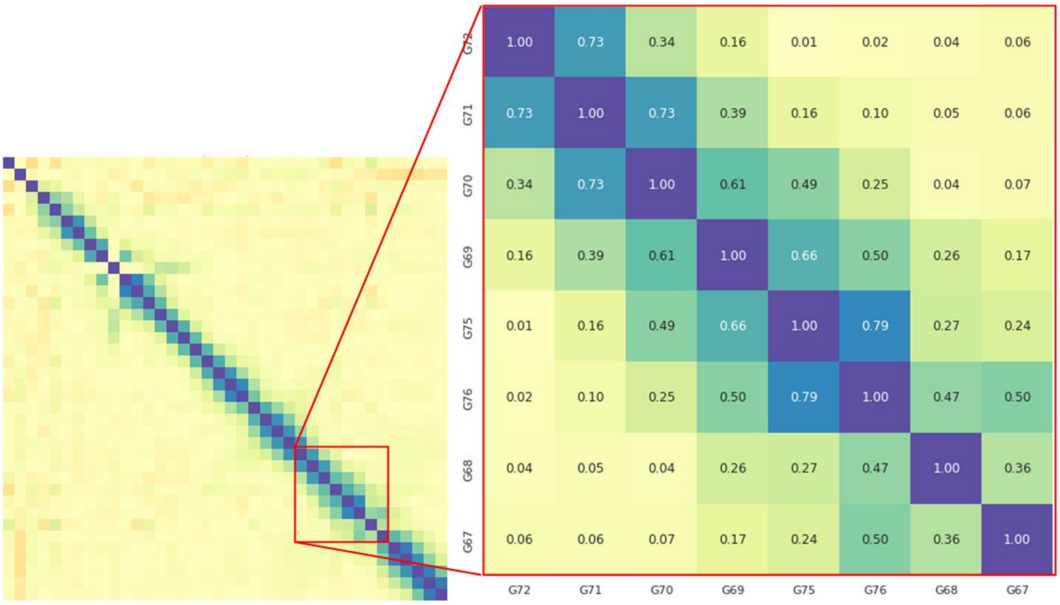

Figure 3. Correlation matrix.

Further, station G67 is considered for forecasting, since its average power consumption is the largest. Regression models of the following type are constructed:

$$Y_i = f_1(E^1{}_i, E^2{}_i, E^3{}_i, \dots E^n{}_i),$$

$$Y_i = f_2(E^1{}_{i\text{-}1}, E^2{}_{i\text{-}1}, E^3{}_{i\text{-}1}, \dots E^n{}_{i\text{-}1}),$$

where Y_i is the predicted unknown electrical energy consumption of the considered station, i is the hour number, $E^k{}_{i\text{-}1}$ is the known consumption of the k^{th} station in the previous hour.

Table 1 shows the results of training and validation of models built using various machine learning algorithms.

Model	Algorithm	MAE, training [kWh]	MAE, validation [kWh]	MAPE, training [%]	MAPE, validation [%]
f_1	linear regression	330	372	15.35	15.43
f_1	support vector regr.	556	545	26.80	24.06
f_1	random forest	169	417	7.45	16.80
f_2	linear regression	559	545	26.98	24.17
f_2	support vector regr.	425	432	20.07	19.16
f_2	random forest	215	506	9.89	21.73

Table 1: Model results.

Figure 4 shows a fragment of the actual and predicted energy consumption of the considered station when forecasting 1 hour ahead.

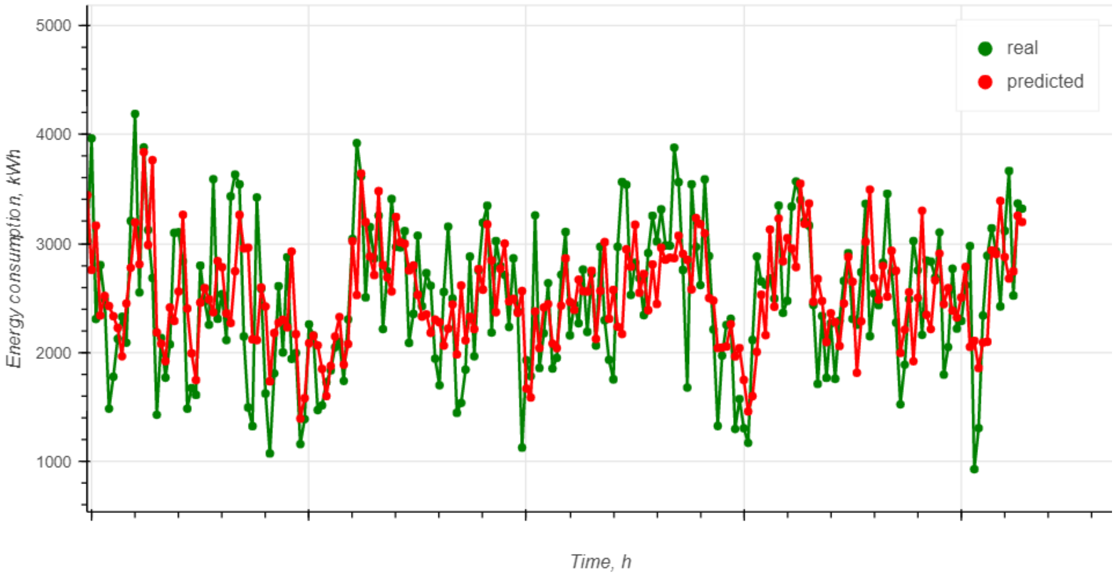

Figure 4. Comparison of the real and predicted energy consumption graphs.

4 Conclusions and Contributions

The paper analyses a real-life dataset of hourly electrical energy consumption for 36 railway stations located along one long section of the railway. A regression model for operational (an hour ahead) forecasting of the electrical energy consumption of one of the stations has been built using a machine learning approach. The developed model uses only the actual energy consumption data of the railway station system. Thus, it does not depend on the train traffic schedule and its errors. The achieved forecasting error is 19% or 0.43 MWh, which is an acceptable result for the developed hybrid power supply system of the railway station, the feature of which is the use of wind or solar energy and hydrogen storage. The high-capacity hydrogen storage makes it possible to solve the problem of the discrepancy between the energy generation and load schedules. The results also show that the error can be reduced to 15-16% with a shorter forecasting horizon.

In addition, the wavelet analysis of the electrical energy consumption was performed in the study. The wavelet analysis confirmed that the periodic components in the load profile of a railway station are relatively weak. Therefore, autoregressive models are not applicable to the problem being solved.

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