Influence of Temperature and Transmitted Power on Losses in Particular Transmission System

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Abstract: - Innovations and trends has been significantly increased during modern theory and practical realizations in the field of energetic. In the Czech Republic, the research of predictions of technical losses on the transmission system can be considered as novel and important topic. Using software possibilities can be appropriately utilized in the frame of estimations of the technical losses. While they cannot be eliminated, they may be minimized. Losses can be measured or calculated using transmission-line parameters. This causality is considered in the form of the presented and proposed mathematical equations including real measured data of the atmospheric temperatures achieved on the substations selected in the Moravian-Silesian region. In this contribution, results of proposed calculations of technical losses based only on line parameters considering the ambient temperature are being compared in relation to a particular transmission system using prediction software. Particularly, technical losses caused by a configuration change of a selected part of a transmission system are considered related to the operation of Dlouhe Strane pumped storage hydro power plant. As can be conclude, after the resulted comparisons using by the proposed mathematical models in software and the obtained real measured data, general minimization of the losses is necessary to create the most accurate models of the states that might occur in the future and to propose required modifications of the given part of the transmission system. Future bounded research can be focused on the sensors situated on the transmission lines instead of the substations.

Key-Words: - Transmission System, Technical Losses, Influences of Temperature, Prediction, Software, Correlation Analysis
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1 Introduction

In the research area of the energetic [1]–[3], the modern approaches and trends has been frequently occurred with proposals of modifications in favor of the minimization of external influences as losses or noises. As near research areas of the solving these occurred problems, also, the technical cybernetics [4]–[6] and mathematical modelling of processes control [7]–[9] has been often considered.

Particularly, in this contribution, the calculation of predictions using by the software utilities with following evaluation of losses [10] that occur in the transmission system located in a certain part of the Czech Republic [11]. In the paper proposals, the authors' own realized software is utilized for purposes of the calculating the predictions.

The calculation has been performed with the program which inputs are the measured values obtained from databases of the transmission grid control system [12]. The results of the calculation can be then suitably compared with values of losses of a second program that calculates the technical losses based only on the line parameters. It is then possible to assess the impact of the losses on the examined transmission system in the area.

The specific area of the transmission system has been selected in view of the interesting states that can occur during its operation, especially greater variations of atmospheric temperatures and fluctuations of the transmitted power. [13]–[15]

It is an area in which provision of an optimal power to the Horni Zivotice substation posed problems in previous periods. The capacity of the area has been reinforced by the construction of a new Kletna substation and by the erection of another V458 transmission line. An important aspect that played a role in selecting the examined area has been the commissioning of a new transmission line between the Horni Zivotice and Krasikov substations. This resulted in the creation of a ring transmission system network boosted by power fed from the Dlouhe Strane pumped storage hydro power plant. In terms of the transmission system operation management the power supplied by this power plant is variable. The paper also mentions the states under which this power plant is utilized with respect to its operation and the atmospheric temperature. [13]–[15]

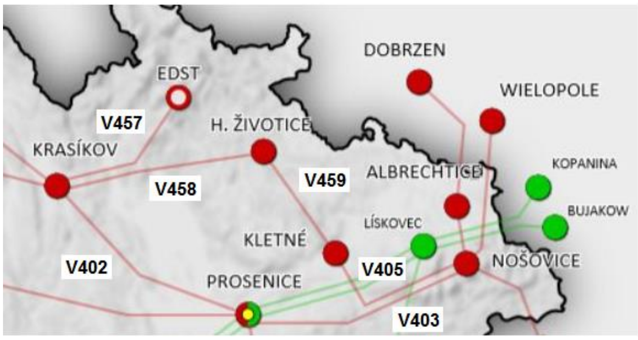

Fig 1: Selected Area of Transmission System Used for Calculations and Analysis [15]

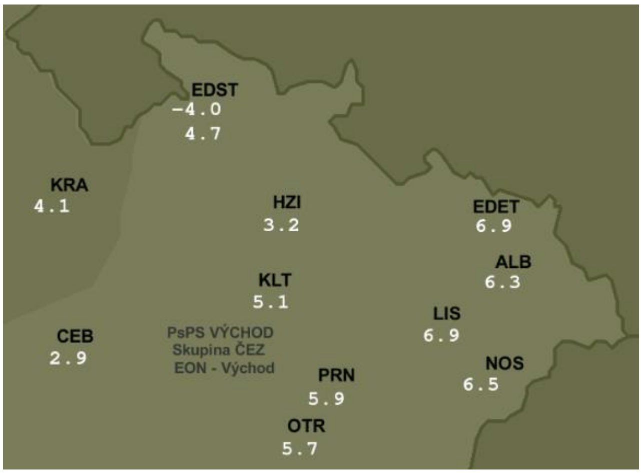

Fig 2: Sample of Measured Atmospheric Temperature Data in Area Under Investigation [15]

Losses can be measured or calculated using transmission-line parameters. This causality is considered in the form of the presented and proposed mathematical equations including real measured data of the atmospheric temperatures achieved on the substations selected in the Moravian-Silesian region. In this contribution, results of proposed calculations of technical losses based only on line parameters taking into account the ambient temperature are being compared in relation to a particular transmission system using prediction software. Particularly, technical losses caused by a configuration change of a selected part of a transmission system are considered related to the operation of Dlouhe Strane pumped storage hydro power plant. [13]–[15]

2 Particular Transmission Network

The calculations are based on real data and calculations using a program developed in previous years [13], [14]. The selected area of the transmission system is shown in Figure 1 and the atmospheric temperature data in Figure 2.

2.1 Description of the Selected Network

The selected area of the transmission system comprises six nodes, five of which are substations and the sixth the controlled power hydroelectric power plant. The area network forms a ring, which consists of six overhead lines, see Table 1 showing their length. The selected network is also connected by seven lines to a neighboring transmission system of Czechia, Slovakia and Poland. The default values used for the calculations are data measured in the power dispatching control system (Table 2) and include node voltages, information on the transmitted power, reactive power, line current and temperatures. An important input is the power contributed into the selected area by the pumped storage hydro power plant. An emphasis is placed on selected seasons and atmospheric temperature changes in the region, which are measured directly at power utilities. A database has been compiled based on all parameters of the lines and the measured data that are used to perform the calculations with the aid of the program. The program was developed by the staff of two Ostrava universities and has been published [13], [14]. The calculations have been performed due to the need to verify the accuracy of software calculations and to clarify changes in the magnitude of losses with respect to atmospheric temperature movements and the line transmitted power in the area where network configuration changes have been made. The changes included commissioning of a new V458 line, construction of a new 400 kV Kletne substation and creation of a V405 line because of splitting the V459 into two V405 and V459 lines terminated in the new Kletna substation. The results and evaluations are set out further in the article.

Table 1: Lengths of Selected Network Lines

400 kV line	Substation 1	Substation 2	Line length

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V457	Dlouhe Strane	Krasikov	59.8 km
V458	Krasikov	Horni Zivotice	107 km
V459	Horni Zivotice	Kletne	42.1 km
V402	Krasikov	Prosenice	87.6 km
V403	Prosenice	Nošovice	79.6 km
V405	Nošovice	Kletne	53.5 km

2.2. Measured Values Database Analysis

The measured value database contains the values of transmitted active and reactive power (*P*; *Q*), technical losses for the given line (*P_ztr*), voltage (*U*), current (*I*) and temperatures from the power utilities (*T_venk*). All values, apart from technical losses, were measured at the start and end of the lines of the respective substation. Database data between August 2017 and February 2018 were used for processing. The measurement databases also include seasonal differences according to a given month and are divided into the summer season - L and the winter season - Z. The measured values are then divided into columns, where the respective measured quantity for the given line is shown in a separate column. The header of each column contains an abbreviation for the substation outlet, the code designation of the line and finally the symbol of the measured quantity. Take for example the designation C: KRA4: V402: P, where KRA4 stands for the measurement taken at Krasikov station. From the line designation of V402 it can be inferred that it is a 400 kV line, as this designation starts with the number 4. For the 220 kV line the designation then starts with the number 2. The last part consists of a letter. For example, P means active power values. The sample of the database section is shown in Table 2.

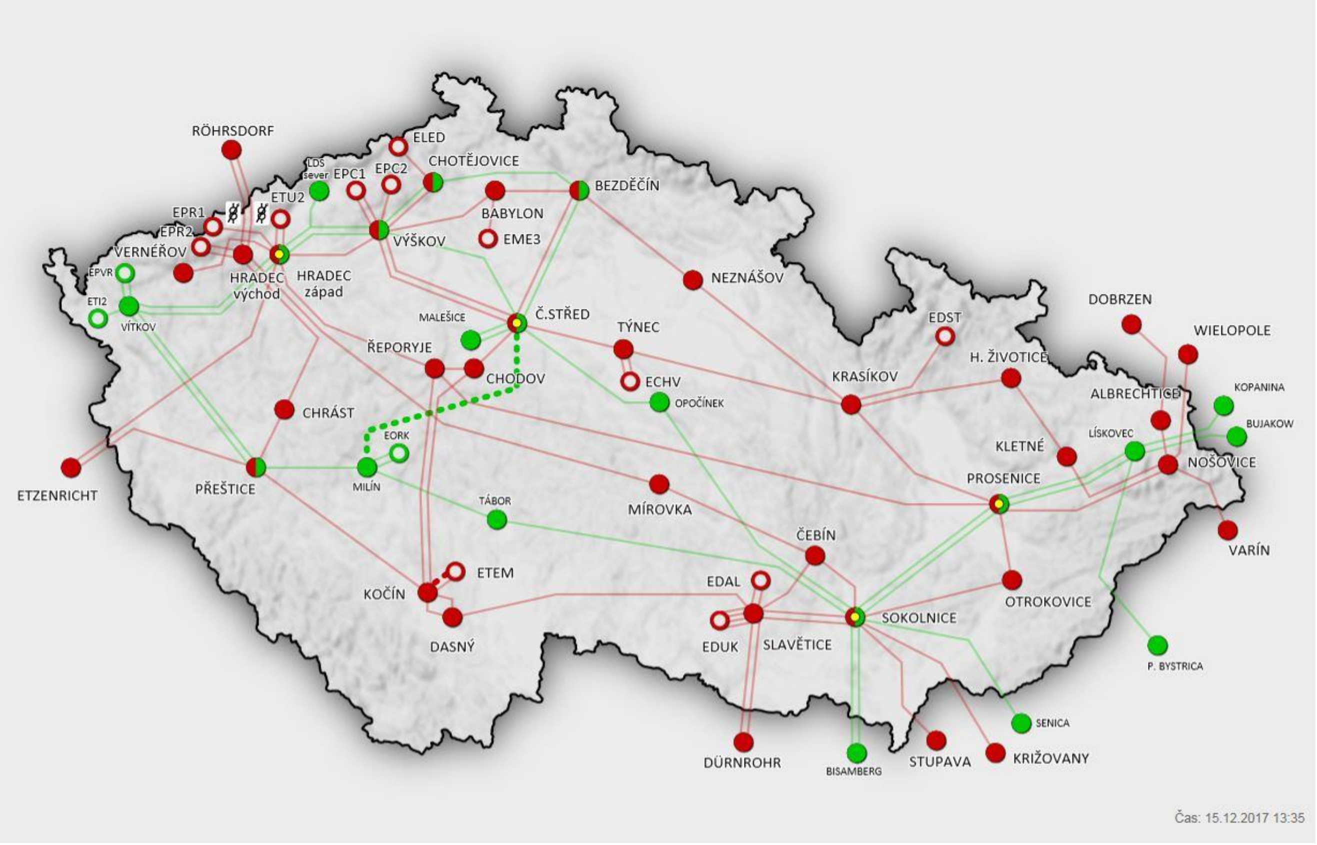

Fig 3: Transmission Power Network Interactive Map ČEPS [15]

Table 2: Part of Database of Measured Values for v402 Line

Time	**C: KRA: 4: V402:** *P*	**C: KRA: 4: V402:** *Q*	**C: KRA: 4: V402:** *U*	**C: KRA: 4: V402:** *I*	**C: KRA:** *T*_venk
10.12.2017 24:00:00 Z	-150.36	27.61	418.52	211.16	0
11.12.2017 00:15:00 Z	57.13	19.76	417.29	94.23	0.59
11.12.2017 00:30:00 Z	68.49	20.93	417.38	102.8	0.77
11.12.2017 00:45:00 Z	56.7	20.2	417.16	84.69	0.83

11.12.2017 01:00:00 Z	94.02	22.11	417.71	143.78	1.09
11.12.2017 01:15:00 Z	99.39	16.79	417.06	151.97	1.14

2.3. Analysis of Calculated Losses of Selected Transmission System Network

The calculations of the selected network are based on the real values measured by the sensors that are part of the energy dispatch control system in the given power utility. An example of the location of the sensors in the selected region is shown in Figure 2-3. The values have been selected from certain periods since 2017. These values serve as a basis for calculations and analysis of the selected area.

3 Model Statuses for Calculating Losses of Selected Transmission System Lines

The program for calculating Joule's losses works on the following principle: it takes the long-term measurements and uses it to assemble the predictive polynomial to calculate the losses in the selected temperature interval for the specified transmitted power [13]. The boundary temperatures of the temperature interval are chosen so that the one polynomial represents losses at the low temperatures and the second one loss at the higher temperatures. The transmitted power values are selected between 0 MW and 100 MW up to the maximum transmitted power [13], [15]–[18]. The V402 line Joule losses e.g., at a transmitted power of 500 MW taken from the line parameters and an assumed power factor of $\cos\phi$ = 0.95 are calculated from the values given in Table 2 as follows - first we calculate the current then use it to arrive at the reactive power:

$$I = \frac{P}{\sqrt{3} U \cdot \cos\phi} = \frac{500 \cdot 10^6}{\sqrt{3} \cdot 400 \cdot 10^3 \cdot 0.95} = 760\,\text{A} \tag{1}$$

$$\begin{aligned} Q &= \sqrt{3} \cdot U \cdot I \cdot \sin\phi = \\ &= \sqrt{3} \cdot 400 \cdot 10^3 \cdot \sin(\arccos(0.95)) = 164\,\text{Mvar} \end{aligned} \tag{2}$$

The Joule's loses are then:

$$\begin{aligned} \Delta P &= R \cdot \frac{P^2 + \left(Q + \frac{V^2 \cdot B}{2} \cdot 10^{-6}\right)^2}{V^2} = \\ &= 2.57 \cdot \frac{500^2 + \left(164 + \frac{400^2 \cdot 354}{2} \cdot 10^{-6}\right)^2}{400^2} = 4.029\,\text{MW} \end{aligned} \tag{3}$$

3.1. Analysis and Calculations for V402 Krasikov – Prosenice Line

To calculate Joule's losses using the program, we select two temperature intervals, one for the winter and the other for the summer period

ΔT_1 between -14°C and 0°C and
ΔT_2 between 10°C and 35°C.

Then the resulting prediction polynomials for the selected temperature ranges are:

$$\Delta P_{T1} = 0.01203 + 0.00019 \cdot P + 1.4 \cdot 10^{-5} \cdot P^2 \tag{4}$$

$$\Delta P_{T2} = 0.014095 + 0.00011 \cdot P + 1.5 \cdot 10^{-5} \cdot P^2 \tag{5}$$

In Table 3 By program calculated Joule's loss results and the losses from the line parameters are then compared.

Table shows that the program-predicted losses in dependence on temperature are lower than the losses calculated by the program without considering the ambient temperature. These values are more realistic because they include the influence of the ambient temperature and the program is based on a comprehensive database of measured values, contrary to the losses calculated only from the line parameters that do not comprise the influence of the temperature [13], [14], [18]–[21].

Table 3: Resulting Joule's Losses of v402 Line of Selected Part Transmission System Network.

Software calculated losses			**Losses from the line parameters**		
P	ΔP_{T1}	ΔP_{T2}	I	Q	ΔP
(MW)	(MW)	(MW)	(A)	(Mvar)	(MW)
0	0.012	0.015	0	0	0.013
100	0.176	0.173	152	33	0.174
200	0.629	0.626	304	66	0.655
300	1.371	1.373	456	99	1.459
400	2.402	2.414	608	131	2.583
500	3.722	3.751	760	164	4.029
600	5.331	5.381	912	197	5.795
700	7.229	7.307	1064	230	7.884
800	9.416	9.527	1215	263	10.293
900	11.893	12.041	1367	296	13.024
1000	14.658	14.85	1519	329	16.075
1100	17.713	17.954	1671	362	19.449
1200	21.056	21.352	1823	394	23.143

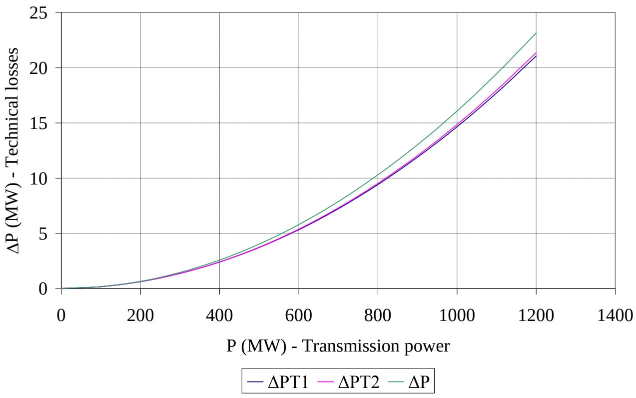

Figure 3: Technical Loses of V402 Line

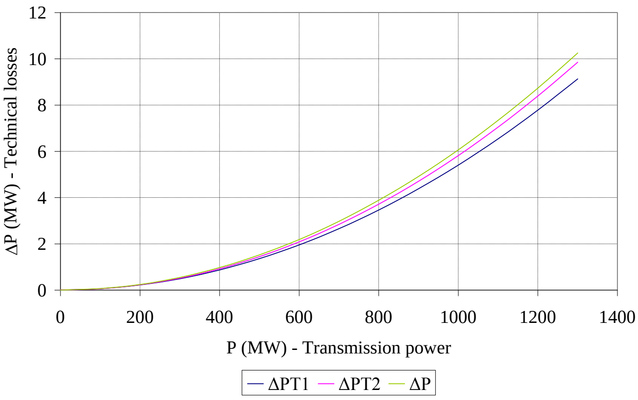

Figure 4. Technical Loses of V459 Line

The biggest losses in the year were recorded in September, when the peak transmitted power was 800 MW, and the lowest one in February with the transmitted power of up to 600 MW. The graphical comparison of all three values of losses is shown in Figure 3 graph.

3.2. Horni Zivotice – Kletne V459 Line

For all subsequent lines, calculations are performed at the same temperature intervals as for the V402 line.

$$\Delta P_{T1} = 0.000312 + 10^{-5} \cdot P + 5.4 \cdot 10^{-6} \cdot P^2 \quad (6)$$

$$\Delta P_{T2} = 0.00454 - 6 \cdot 10^{-5} \cdot P + 5.9 \cdot 10^{-6} \cdot P^2 \quad (7)$$

The difference in predicted losses, considering the temperature and loss calculated only with respect to the transmitted power (ΔP - ΔPT_1 and ΔP - ΔPT_2) is increasing. At the transmitted power of 1300 MW, the difference is 1.12 MW at low temperatures and 0.4 MW at high temperatures.

3.3 Dlouhe Strane – Krasikov V457 Line

This line is connected to the Dlouhe Strane pumped storage hydro power plant with the installed capacity of 600 MW.

$$\Delta P_{T1} = 0.00762 + 5.6 \cdot 10^{-5} \cdot P + 8.9 \cdot 10^{-6} \cdot P^2 \quad (8)$$

$$\Delta P_{T2} = 0.01599 - 4.7 \cdot 10^{-4} \cdot P + 7.3 \cdot 10^{-6} \cdot P^2 \quad (9)$$

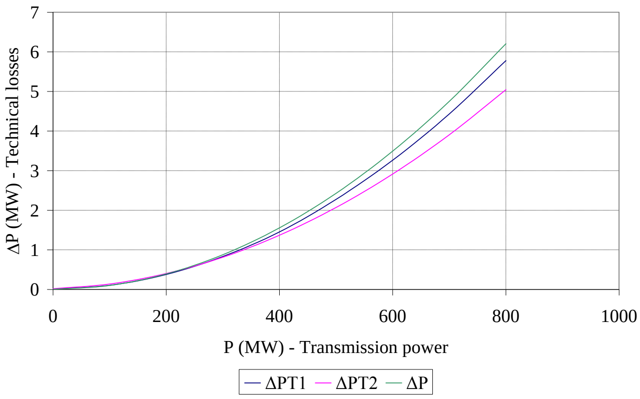

Figure 5: Technical Losses of V457 Line

The V459, together with the V405 line formed the so-called radial network until the V458 line was connected. The Dlouhe Strane power plant transmitted power at higher temperatures ranged around 300 MW; the maximum of 600 MW was rarely achieved. Its transmitted power was influenced by the needs of the transmission system. Therefore, the higher temperature prediction is more accurate only up to the transmission power of 300 MW, for higher transmitted power it is distorted because of the small data rate in the default database of measured values. At low temperatures, the prediction is accurate because the peak power values were much more frequent during this period, and therefore there were enough data lines to calculate losses for the transmitted power above 300 MW.

3.4 Krasikov – Horni Zivotice V458 Line

This is a new line erected in connection with the construction of a new 400 kV:

$$\Delta P_{T1} = 0.01769 - 4\cdot 10^{-5}\cdot P + 1.4\cdot 10^{-5}\cdot P^2 \tag{10}$$

$$\Delta P_{T2} = 0.19254 - 9\cdot 10^{-4}\cdot P + 1.6\cdot 10^{-5}\cdot P^2 \tag{11}$$

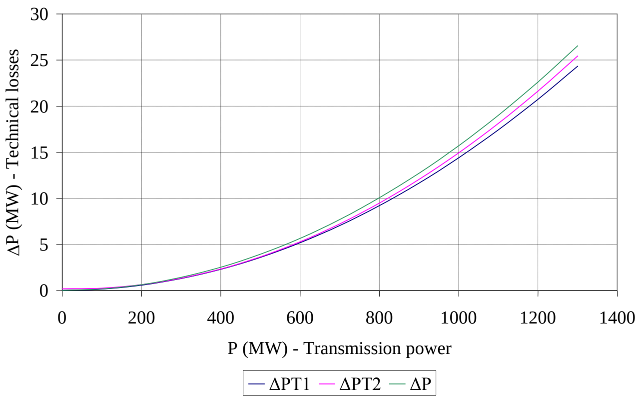

Figure 6: Technical Losses of V458 Line

The difference in predicted losses, considering the temperature and loss calculated only for the transmitted power (ΔP - ΔPT_1 and ΔP - ΔPT_2), is again rising. At the transmitted power of 1300 MW the difference is 1.2 MW at low temperatures and 1.1 MW at high temperatures.

4. Influences on the Dlouhe Strane Power Plant Operation by Connecting the New V458 Line

In terms of the transmitted power over the respective lines, in relation to the technical losses and the atmospheric temperature the situation changed in the selected area of the transmission system after terminating the new V458 line connecting the Krasikov substation to the Horni Zivotice substation. Prior to the line termination the substation formed the end of a radial network that comprised Nošovice - Kletne - Horni Zivotice substations. (V405, V459). The V402 and V403 lines experienced a significant drop in technical losses. The termination of the new V458 line also changed the direction and size of the transmitted power by the V405 and V459 lines from the Horni Zivotice substation to the Nošovice substation. With the increased power transmission in the area, the technical losses also increased. The transmitted power from the Krasikov substation was split into two directions, along the V402 line and along the new V458 line. It can be stated that the technical losses have been divided and their total size has been reduced. The size of the technical loses is also notably influenced by the Dlouhe Strane pumped storage hydro power plant operation. After connecting the new V458 line, the power plant started supplying more power to the selected area [16]–[18].

5. Tightness of Predictive Models Analyzed by Autocorrelation Analysis

According to the principle of the statistical significance guarantee included in frame of paired testing [9], the autocorrelation functions [22] were utilized. For purposes of influences of the low and high temperature losses due to the transmission power, these both types of functions have been analysed in statistical software PAST Statistics 2.17. For sessions 3.1-3.4, the regression models in form of the predictions ΔPT_1 and ΔPT_2 of aimed variables were considered and paired compared.

The autocorrelation functions were computed for each session 3.1-3.4. for both measured approaches as $R_{\Delta PT1}$ and $R_{\Delta PT2}$ (Figures 7-10)

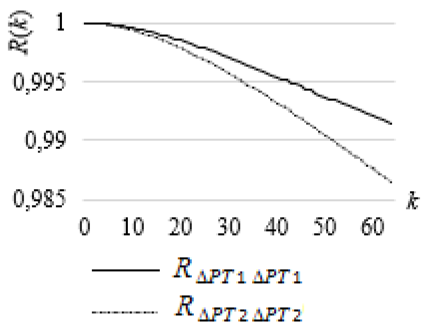

Figure 7: Autocorrelation Functions for Considered Transmission Network in Session 3.1

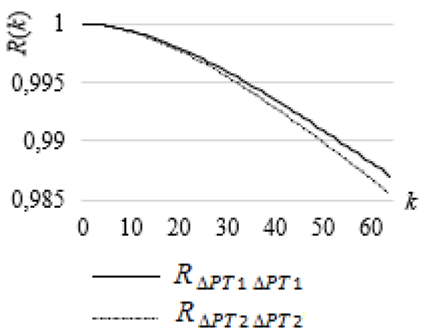

Figure 8: Autocorrelation Functions for Considered Transmission Network in Session 3.2

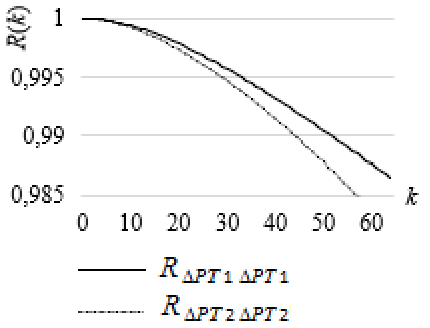

Figure 9: Autocorrelation Functions for Considered Transmission Network in Session 3.3

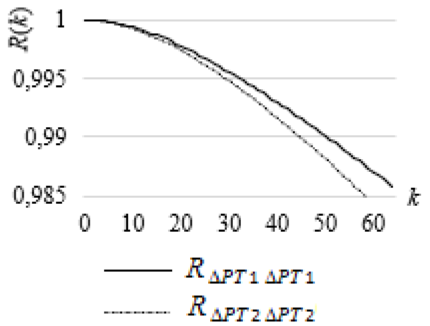

Figure 10: Autocorrelation Functions for Considered Transmission Network in Session 3.4

On the significance level 0.001, the following results of the paired comparisons of mathematical models were obtained using by Wilcoxon test (Table 4):

Table 4: Resulting Paired Comparisons of Autocorrelation functions for Mathematical Models of ΔPT_1 and ΔPT_2

Network	Paired Comp. $R_{\Delta PT1\,\Delta PT1}$ and $R_{\Delta PT2\,\Delta PT2}$
3.1	*z score* = 6.846 p<0.001
3.2	*z score* = 6.791 p<0.001
3.3	*z score* = 6.843 p<0.001
3.4	*z score* = 6.901 p<0.001

6. Conclusion

In conclusion we can state that many factors have changed in the selected area of the transmission system and those factors significantly influenced the size of the technical losses. The most important factors include the new network configuration, temperature influences, the power transmitted over the lines and the Dlouhe Strane pumped storage hydro power plant operation. The technical losses calculated from the line parameters were compared and, in the latter case, calculated using a special program.

The losses calculated by using the program that takes temperature variations into account were lower on all lines. We can say that the results obtained by the program that considers the outdoor temperature are more realistic because they are based on the analysis of long-term measurements performed on the relevant lines and include the temperature influence. The program can be used for further analysis of losses in the transmission system networks and its use will result in correct analyzes and conclusions.

The computational program used could also find its use in practice. The analysis of the transmission system lines' technical losses is an important indicator for the economical evaluation of electricity transmission and also serves to evaluate changes taking place in certain parts of the system after construction of new substations and lines. In order to minimize the losses, it is necessary to create the most accurate models of the states that might occur in the future and to propose required modifications of the given part of the transmission system.

Future bounded research can be focused on the sensors situated on the transmission lines instead of the substations.

In additional analysis, the statistically significant paired differences were being identify across the observed low and high temperature predictive models with regards to their thigness. With statistical guarantee, the tightness of all comparisons proved the difference behavior for all considered part of transmission network – as can be assumed for the various temperature dynamical phenomenon.

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Contribution of individual authors to the creation of a scientific article (ghostwriting policy)

Ladislav Rudolf, Milan Bernat, Lubomir Zacok – authors has been contributed by collecting data, computation of predictions in software tool, sumarizing the theoretical background

Tomas Barot, Marek Kubalcik, Jaromir Svejda - authors has been contributed by guarantee of correctness of proposed mathematical models with addition of correlation approaches.

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