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RIGA TECHNICAL UNIVERSITY

Ruslans Muhitovs

PRINCIPLES OF DEVELOPMENT OF MULTI-SENSOR CONTROL SYSTEMS FOR THE THERMAL STATE OF RAILWAY POINT AND THEIR RESEARCH

Summary of the Doctoral Thesis

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RIGA TECHNICAL UNIVERSITY
Faculty of Electrical and Environmental Engineering
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This research is dedicated to my wife Jevgenija Patenko and to my scientific supervisors.

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DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR THE PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF SCIENCE

To be granted the scientific degree of Doctor of Science (Ph. D.), the present Doctoral Thesis has been submitted for the defence at the open meeting of RTU Promotion Council on November 1st, 2022, at 13:00 at the Faculty of Environmental and Electrical Engineering of Riga Technical University, 12/1 Āzenes Street, Room 212.

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DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for the review to Riga Technical University for the promotion to the scientific degree of Doctor of Science (Ph. D.) is my own. I confirm that this Doctoral Thesis had not been submitted to any other university for the promotion to a scientific degree.

Ruslans Muhitovs ……………………………. (signature)
Date: ………………………

The Doctoral Thesis has been written in Latvian. It consists of an Introduction, 5 chapters, Conclusion, 56 figures, 15 tables, 2 appendices; the total number of pages is 103, including appendices. The Bibliography contains 77 titles.

CONTENTS

INTRODUCTION

Inefficient heating of the world's railway points is one of the most topical problems of the industry, which directly affects the consumption of electricity, non-renewable resources, CO_2 emissions and ecology in general [1]. Considering the trends in the development of world transport, especially in railways, and with the increase in freight transportation, the construction of new railway stations and sections [2], [3] and effective heating of points is one of the priorities and the precondition for ensuring safe train movement in the railway sphere not only in Latvia, but also in other Baltic countries [4], [5].

Currently, the point heating systems operated by Latvian Railway (LDz) are one of the most serious problems of the concern [6]. Considering the company's ongoing optimization, review of technological processes and reduction of costs, a situation arises when the existing heating systems are not turned on in winter conditions because they consume a large amount of electricity [6]. Thus, electricity consumption is reduced and financial resources are saved, while the clearing of snow from the points is done with the help of manpower. Such an approach can lead to a situation threatening the safety of train traffic when, as a result of heavy snowfall, a large number of turnouts are covered with snow and there may not be enough human resources to clear the turnouts [7].

Considering the national economic development program, which envisages the increase of port cargo turnover, the increase of railway cargo and transportation and the business model of LDz, one of the priority challenges for ensuring stable and safe train movement in Latvia is also regarding the heating and cleaning of points taking into account the limited human and financial resources and efficient use of funds [8].

Nowadays, geothermal, gas, induction and other heating systems are used to improve the heating of railway turnouts. In this work, the possibility of improving the control system with integration of multi-sensors and fuzzy logic is offered.

It is the study of the control system of the electric heating of points with the integration of multi-sensors that is of great importance in improving the efficiency of the point heating. The point electric heating control system (PEHCS) presented in the Thesis has multiple advantages: the ability to handle non-strict and variable input parameters (wind, precipitation, etc.), possibility to be integrated into a semi-automatic or automatic control system, and compatibility with modern programmable logic controllers.

The aim of the Thesis

The aim of the Thesis is determination, research and application of the principles of creation of an innovative multi-sensor control system of the thermal state of the railway point for the development of an experimental algorithm.

Objectives

1. To describe and analyse the research object – the railway point and the factors affecting its operation.
2. To perform analysis of the disadvantages and inefficiency of existing heating systems.
3. To investigate regression equations and the possibility of their use for normalizing impact factors and solving the problem of heating capacity regulation.

4. To perform an analysis of the applicability of the fuzzy logic theory and to transfer it to improve the efficiency of the heating control system.
5. To develop a multi-sensor control algorithm for point heating and implement it in a programmable logic controller.
6. To integrate the theory of fuzzy logic into the previously developed algorithm.
7. To compare the consumption of electrical energy of the experimental system with the consumption of a similar system and to define the results and conclusions of the Thesis.

Research tools

- MATLAB Fuzzy Logic Designer.
- Weidmueller u–create WEB interface.
- Siemens Totally Integrated Automation (TIA) portal.
- Microsoft Office.
- Powersim (PSIM).

Standards used

- IEC 61508 (Functional safety of electrical/electronic/programmable electronic safety related systems).
- IEC 61511 (Safety instrumented systems for the process industry sector).
- EN 50128 (Railway applications – software for railway control and protection).
- EN 50129 (Railway applications – safety related electronic systems for signalling).

Theoretical methods

- Mathematical modelling.
- Fuzzy Logic.
- Regression equations.
- Statistical, comparative and correlation analysis.

Experimental methods

- Point heating control with an experimental prototype together with a fuzzy logic algorithm.
- Processing and analysis of the data obtained during the experiment.

Research objects

- Railway point.
- The prototype device and algorithm consisting of two programmable controllers, a weather station and secondary devices.
- Executive elements of an existing point heating system – transformers, heating elements.

Scientific novelty of the Thesis

- The possibility to decrease the electricity consumption of the point heating was determined.
- The rail heating and cooling curve was determined, researched and analysed.

- The efficiency of the proposed point heating control system algorithm was scientifically justified.
- An innovative point heating control system algorithm with the integration of fuzzy logic, considering the surrounding environment, process and object data was created.
- A point heating control device was developed based on programmable controllers with an integrated fuzzy logic algorithm.

Theses to be Defended

- Fuzzy logic algorithm as railway point heating system intellectual control algorithm with multi-non-strict parameter processing in algorithm synthesis.
- Precise control of the point heating system with fuzzy logic commands allows to reduce the consumption of electricity.
- The proposed point heating control algorithm with multi-sensor processing can be effectively applied to point heating and improve energy efficiency.

Practical significance of the Thesis

The results of the Doctoral Thesis have a wide practical application in railway companies that operate and service the infrastructure. The innovative electrical heating control system of railway points has been developed, and it is possible to use it in Latvian Railways, the Rail Baltica high-speed railway line, as well as in other railways.

The application of the fuzzy logic algorithm in other control systems in the railway infrastructure opens wide opportunities for process improvement and digitization.

Dissemination of research results

1. International Conference on Recent Advances in Engineering and Technology (ICRAET), August 1–2, 2022. (Muhitovs, R., Mezītis, M., Iriškovs, V., Spunitis, A. Research and Modelling of Point Electric Heating Regulation Method Based on Regression Equation of Impact Factors).
2. LISBON 18th International Conference on "Innovations in Science, Engineering & Technology" (LCISET-22), April 13–15, 2022. (Muhitovs, R., Mezītis, M., Iriškovs, V., Spunitis, A. Analysis of Different Regulation Methods with Aim to Determine Most Efficient One for Point Electric Heating).
3. 2021 International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME), October 7–8, 2021. (Muhitovs, R., Mezītis, M., Baranovskis, A., Spunitis, A. Modelling point electric heating algorithm using Fuzzy Logic).
4. 8th IEEE Workshop on Advances in Information, Electronic and Electrical Engineering (AIEEE'2020), April 22–24, 2021. (Muhitovs, R., Mezītis, M., Spunitis, A., Iriskovs, V. Analysis of Experimental Railway Point Electric Heating System).
5. Fifth Georgian-Polish International Scientific-Technical Conference "Transport Bridge Europe-Asia", October 15–17, 2019. (Mezītis, M., Muhitovs, R. Advanced and Multidisciplinary Railway Network Operators' Training in Management of Emergency Train Situation).

6. IEEE 60th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), October 7–9, 2019. Riga, Latvia (Muhitovs, R., Mezītis, M., Freimane, J. Intelligent Railway Point Electric Heating Control System).
7. XI International Scientific Conference "Transport Problems 2019", June 26–28, 2019, Katowice, Poland (Muhitovs, R., Mezītis, M., Korago, I. Development of Railway Point Electric Heating Intellectual Control Algorithm).

The objectives of the Doctoral Thesis and the results obtained in the laboratory were reported at the management meetings of SJSC "*Latvijas Dzelzceļš*" (Latvian Railway (LDz)), as a result of which a positive conclusion was received and permission to conduct a practical experiment in the existing point heating system.

List of publications

1. **Muhitovs, R.,** Mezītis, M., Baranovskis, A., Spunitis, A. Modelling point electric heating algorithm using Fuzzy Logic, 2021 International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME), DOI: 10.1109/ICECCME52200.2021.9590940. Indexed in SCOPUS.
2. **Muhitovs, R.,** Mezītis, M., Spunitis, A., Iriskovs, V. Analysis of Experimental Railway Point Electric Heating System, 2020 IEEE 8th Workshop on Advances in Information, Electronic and Electrical Engineering (AIEEE), DOI: 10.1109/AIEEE51419.2021.9435805. Indexed in SCOPUS.
3. **Muhitovs, R.,** Mezītis, M., Korago, I. Development of Railway Point Electric Heating Intellectual Control Algorithm. International Scientific Journal "Transport Problems", vol. 15, 2020. ISSN 1896–0596. Online edition: ISSN 2300–861X. DOI: 10.21307/tp-2020-007. Indexed in SCOPUS.
4. Mezitis, M., Strautmanis, G., Baranovskis, A., **Muhitovs, R.** Environment Safety Improving Due to Railway Noise Management Decreasing of RMR Method Adaptation, Lecture Notes in Networks and Systems, vol. 124: 505–563, 2020, ISSN: 23673370, DOI: 10.1007/978-3-030-42323-0_9. Indexed in SCOPUS.
5. **Muhitovs, R.,** Mezitis, M., Freimane, J. Intelligent Railway Point Electric Heating Control System, IEEE 60th Annual International Scientific Conference on Power and Electrical Engineering of Riga Technical University, RTUCON 2019, ISBN: 978-172813942-5, DOI: 10.1109/RTUCON48111.2019.8982345. Indexed in SCOPUS.
6. **Muhitovs, R.,** Mezītis, M., Freimane, J., Korago, I. Development of the Decision–Making Algorithm for Railway Maneuverer Park Equipment with Independent Controllers. Procedia Computer Science. vol. 149, 2019, 2018 ICTE in Transportation and Logistics, ICTE 2018; Code 146441, DOI: 10.1016/j.procs.2019.01.124, ISSN: 18770509. Indexed in SCOPUS.
7. Dolgopolov, P., Konstantinov, D., Rybalchenko, L., **Muhitovs, R.** Optimization of Train Routes Based on Neuro–Fuzzy Modelling and Genetic Algorithms. Procedia Computer Science. vol. 149, 2019, 2018 ICTE in Transportation and Logistics, ICTE 2018; Code 146441, DOI: 10.1016/j.procs.2019.01.124, ISSN: 18770509. Indexed in SCOPUS.

8. Mezītis, M., **Muhitovs, R.,** Arpabekov, M., Sansyzbajeva, Z., Togizbayeva, B., Assiltayev, A. Optimization of Transport Logistical Flows between Railway and Urban Passenger Transportation Systems. Springer Nature book "ICTE in Transportation and Logistics 2019". Lecture Notes in Intelligent Transportation and Infrastructure. Springer. Online ISBN: 978-3-030-39688-6. DOI: https://doi–org.resursi.rtu.lv/10.1007/978-3-030-39688-6_5.
9. Kargin, A., Panchenko, A., Ivaniuk, O., **Muhitovs, R.** Motion Control of Smart Autonomous Mobile System Based on the Perception Model. Springer Nature book "ICTE in Transportation and Logistics 2019". Lecture Notes in Intelligent Transportation and Infrastructure. Springer. Online ISBN: 978-3-030-39688-6. DOI: https://doi–org.resursi.rtu.lv/10.1007/978-3-030-39688-6_20.
10. Mezītis, M., **Muhitovs, R.** Advanced and Multidisciplinary Railway Network Operators' Training in Management of Emergency Train Situations. Fifth Georgian-Polish International Scientific-Technical Conference "Transport Bridge Europe–Asia": Proceedings, 2019. Kutaisi: Akaki Tsereteli State University, 2019, pp. 71–76. ISBN 978-9941-484-82-7.

1. TASKS OF STABILIZING THE THERMAL STATE OF RAILWAY POINTS

To solve the tasks of stabilizing the thermal state of railway points (switch or turnout), first of all, the parameters of the thermal state of the point must be clarified, which, in turn, characterize the point as an object of the regulation and automation system [9]. The main parameters are the values characterizing the power state of the object: heat energy consumption in different situations, in addition, considering the parameters created by both the object itself and the influence of the surrounding environment.

Recently, a constant increase in the use of point electric heating (PEH) has been noted in Europe and the world [1]. PEH is a relatively inexpensive equipment designed for cleaning points from snow and ice [8], [10]. PEH offers the world's widely recognized way to safe, timely and guaranteed completion of point cleaning in winter climatic conditions. PEH systems are used to guarantee cleaning of the turnout in winter conditions and to ensure the safety of train movement. PEH systems are used the most in solving certain tasks (Table 1.1).

Table 1.1

Comparison of Point Cleaning Systems

Class	Cleaning method	Amount of capital investment	Operational expenses	Operational efficiency	Effective operating temp. mode
Pneumatic blowing	Pneumatic	Medium	Medium	Medium	–45 °C up to +5 °C
Heating	Electric heating	Little	Medium	Large	–45 °C up to +5 °C
Heating	Geothermal heating	Large	Little	Large	–15 °C up to +5 °C
Heating	Gas heating	Large	Large	Large	–45 °C up to +5 °C

After the comparison of point cleaning systems, it was found that PEH is the most suitable for the performance of point cleaning tasks in Latvian conditions. It was this system that was chosen for SWOT analysis and further research (Table 1.2).

Table 1.2

SWOT Analysis of Point Electric Heating System

Strengths	*Opportunities*
• Effective cleaning of snow and ice • In the case of LDz and other Baltic railways, it is not necessary to rebuild the existing point heating systems • Relatively low maintenance costs	• Possible regulation with different control systems • The application of the weather station can provide the necessary input data for improving the control system

Table 1.2 continued

Weaknesses	*Threats*
• High CO_2 emissions compared to the geothermal heating system • There is a high power consumption in non-regulated PEH systems	• The absence of monitoring equipment can lead to an emergency, for example, failure to detect cable insulation failure

From the SWOT analysis, it can be seen that the PEAS is the most optimal turnout cleaning system in the winter season, based on the set of strengths and weaknesses. PEH provides the possibility of guaranteed cleaning of the turnout from light or wet snow and ice. Considering the requirements set by the railways of different countries for the cleanliness of the point in winter conditions [6], [11], [12], the PEH type system has a number of advantages compared to other types of cleaning.

When solving the tasks of cleaning point from snow and ice, PEH has significant advantages compared to other cleaning systems:

- guaranteed clearing of snow and ice in the point area;
- possibility to create fully automated systems;
- manual, local and remote control of the system;
- relatively convenient power supply connection (electrical and control cables are required);
- reduced requirements for training and number of service personnel;
- providing constant 24/7 monitoring and sending alarms to the control panel in case of remote control mode;
- system performance in the external environment temperature ranges from –45 °C to +5 °C.

After the analysis of studies [13]–[15], it was concluded that the main point heating impact factors or input values/parameters are:

- ambient temperature – θ_{amb};
- snow and snowfall intensity – N;
- wind speed – V.

The influence of all three factors on the required heating power can be estimated with the following regression expression:

$$P = P_0 + a_1\theta^*_{\mathrm{amb}} + a_2N^* + a_3V^*, \qquad (1.1.)$$

where P_0 is the required power at the average values of all 3 impact factors (zero on the linear scale). If only the extreme values of the linearized scales –1 and +1 are used, then it is necessary to initially create a table of the required powers with $2^3 = 8$ possible factor situations. It is best to make such a table experimentally, but then it is necessary to find the possibility to change all 3 factors in a wide range. Therefore, the expert method is usually used with an approximate calculation of power – an expert's assessment by the size of the effect.

By setting the minimum value (–1) and the maximum value (+1), a power table with the following values was created (Table 1.3).

Table 1.3

Power Table with All Possible Impact Factor Situations

No./impact factor	θ^*_{amb}	*N**	*V**	*Power* *P*, kW
1	–1	–1	–1	$P_1 = 8$
2	–1	–1	+1	$P_2 = 13$
3	–1	+1	–1	$P_3 = 12$
4	–1	+1	+1	$P_4 = 8$
5	+1	–1	–1	$P_5 = 8$
6	+1	–1	+1	$P_6 = 2$
7	+1	+1	–1	$P_7 = 1.5$
8	+1	+1	+1	$P_8 = 2$

* In case the power exceeds the maximum power of the heating element, this parameter indicates an increase in the heating time.

The average power value is determined simply by summing up all 8 power measurements and dividing the sum by 8 (3 factors):

$$P_0 = \frac{\sum_{i=1}^{8} P_i}{8} = \frac{8 + 13 + 12 + 8 + 8 + 2 + 1.5 + 2}{8} = 6.81 \text{ kW}.$$

The ambient air temperature impact factor is determined by summing up the product of each measurement result with the relative value of the factor in the measurement:

$$a_1 = \frac{\sum_{i=1}^{8} P_i \cdot a_{i1}}{8} = \frac{-8 - 13 - 12 - 8 + 8 + 2 + 1.5 + 2}{8} = -3.44.$$

Similarly, the precipitation impact factor is determined:

$$a_2 = \frac{-8 - 13 + 12 + 8 - 8 - 2 + 1.5 + 2}{8} = -0.94$$

and the wind effect factor:

$$a_3 = \frac{-8 + 13 - 12 + 8 - 8 + 2 - 1.5 + 2}{8} = -0.56.$$

Overall:

$$P = 6.81 - 3.44\theta^*_{\text{amb}} - 0.94N^* - 0.56V^* \text{ (kW)} \quad (1.2)$$

Maximum power will be required at low outside air temperature, heavy precipitation (heavy snowfall) and strong wind:

$$P_{max} = 11.8 \text{ kW}.$$

The minimum required power in the evaluation area will be at $\theta_{\text{amb}} = +5$ °C, on bare tracks and no wind:

$$P_{min} \geq 0 = 1.88 \text{ kW}.$$

2. DETERMINATION OF PROJECTED POWER AND DECISION ON CONTROL SYSTEM

Power regulation based on the data of the regression equation with the task of stabilizing the temperature (with feedback) was analysed in the Thesis. The regression equation or normalization block, upon receiving information from the impact factor sensors, transforms the parameters into normalized ones, and thus the reference power depends on the impact factors.

During the development of the Powersim (PSIM) model, the normalization schemes of all influence factors were inserted into it, each multiplication was counted according to Formula (1.1) and, as a result, an equation was obtained, according to which the total power was calculated. This power determines the power consumed by the heating element with the influence of various external factors. For example, it is well known that at a negative ambient temperature and switched-on heating, there will be an initial power P_0, which will be consumed in any case during the heating operation. Next to this power comes additional power, which is meant to compensate for excessively low temperatures, precipitation in the form of snow and wind. Depending on the combination of influencing factors, the resulting power also changes.

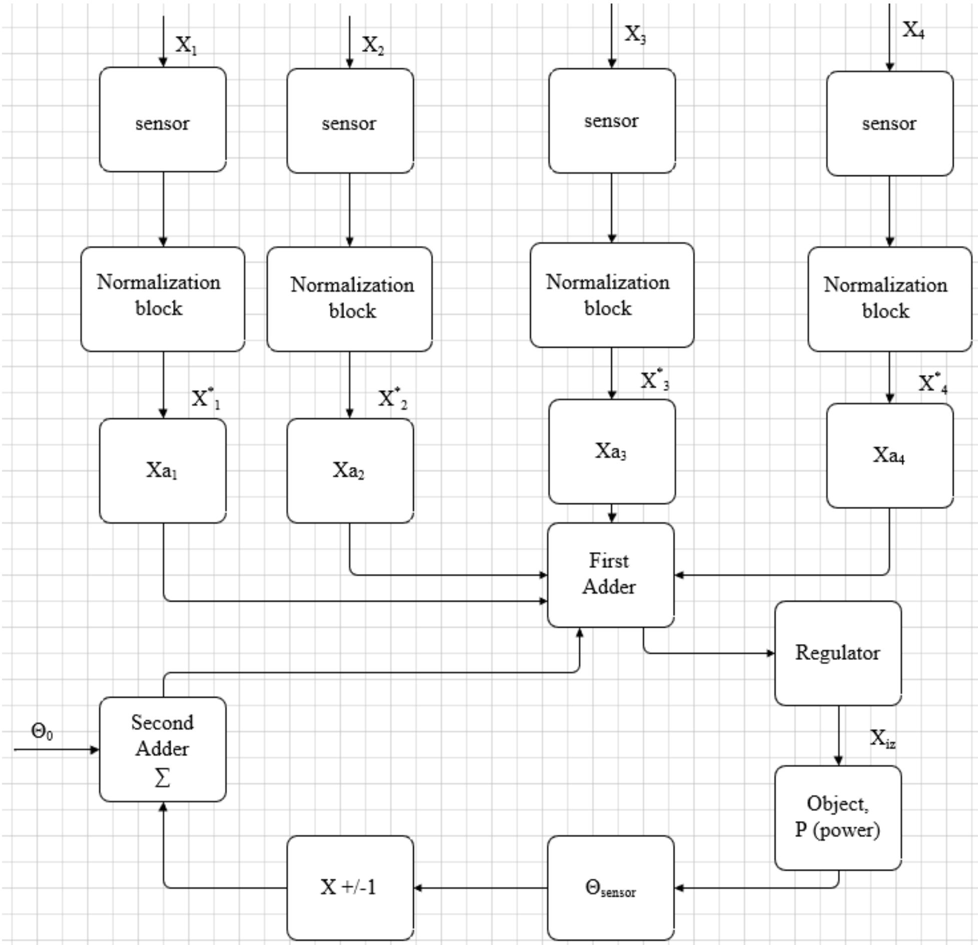

Fig. 2.1. Block diagram of the regulation scheme according to the results of the regression equations.

The scheme consists of stages, the main of which are adder $\sum$, object "Object, P" and block "X +/–1", which implements the feedback function. Each stage has its own algebraic transfer function, which makes it possible to describe the whole system with a common algebraic transfer function.

In the example shown in Fig. 2.1, in Adder $\sum$, the input signal Θ_0 and the feedback output signal are summed $-x_{out}(s) \cdot W_{fb}(s)$. The regulator is an amplifier whose input has a reduced control signal. In this example, the signal from the temperature sensor enters the adder and the resulting difference between the set reference temperature and the measured temperature is the basis for the control system's action on the control object, which is a heating element (active power *P*).

The given control scheme, which uses the results of the regression equations, is a closed control system with a rail temperature sensor S_{rail}, whose output signal corresponds to the rail temperature Θ_{sensor} (Fig. 2.1). This signal is reduced through the feedback unit to value $(-\Theta_{\text{rail}})$ and compared with the set temperature signal Θ_0 in the adder, and the difference signal $(\Theta_0 - \Theta_{\text{rail}})$ impacts the primary adder, which in turn acts on a regulator at its output that regulates the power in the control object.

As the next task, the regression expression with the effect of different parameters on power was calculated in the PSIM software. To do this, the results obtained from the PSIM simulation were put in formula

$$P = P_0 + a_1\Theta^*_{amb} + a_2N^* + a_3V^* \qquad (2.1)$$

and summarized in Table 2.1.

Table 2.1

Table of Powers of Input Parameters and Their Normalized Values

Input parameters			*Normalized input parameters*			
Ambient temperature, θ_{amb} (°C)	*Precipitation intensity, N (mm/h)*	*Wind speed, V (m/s)*	θ^*_{amb}	N^*	V^*	*Power P,* kW*
–45	0	0	−1	−1	−1	11.75
–43	1.5	1.5	−0.92	−0.9	−0.9	11.33
–40	3	3	−0.8	−0.8	−0.8	10.76
–37	4.5	4.5	−0.68	−0.7	−0.7	10.2
–34.5	6	6	−0.58	−0.6	−0.6	9.71
–31.8	7.5	7.5	−0.472	−0.5	−0.5	9.19
–29.1	9	9	−0.364	−0.4	−0.4	8.66
–26.4	10.5	10.5	−0.256	−0.3	−0.3	8.14
–23.7	12	12	−0.148	−0.2	−0.2	7.62
–21	13.5	13.5	−0.04	−0.1	−0.1	7.1
–18.3	15	15	0.068	0	0	6.58
–15.6	16.5	16.5	0.176	0.1	0.1	6.06
–12.9	18	18	0.284	0.2	0.2	5.54
–10.2	19.5	19.5	0.392	0.3	0.3	5.01
–7.5	21	21	0.5	0.4	0.4	4.49

Table 2.1 continued

–4.8	22.5	22.5	0.608	0.5	0.5	3.97
–2.1	24	24	0.716	0.6	0.6	3.45
0.6	25.5	25.5	0.824	0.7	0.7	2.93
3.3	27	27	0.932	0.8	0.8	2.41
6	28.5	28.5	1.04	0.9	0.9	1.88
	30	30		1	1	1.36

* In case the heating power exceeds the maximum power of the heating element, this parameter indicates an increase in the heating time.

From the data in the table, it was concluded that under the most unfavourable conditions, the heating power will be 11.75 kW, which exceeds the maximum power of the heating element and indicates an increase in the duration of heating. On the other hand, when the outdoor temperature is +6 °C, the heating should be switched on with a power of 1.88 kW, but in reality, the control algorithm should provide a system shutdown circuit that would switch off the heating at an ambient temperature > +5 °C because, obviously, that there is no need to heat the point at such outside air temperature.

The graph of the dependence of the heating capacity on the ambient temperature, precipitation and wind strength was examined and analysed (Fig. 2.2). After constructing the graph, the curves have similar characteristics – they are almost linear but with some details. From the starting points of no precipitation and no wind, and as the intensity of precipitation increases, it can be seen that more power is required to heat the turnout. On the other hand, wind has a smaller effect on the amount of power, by about 30 %. Such a trend persists until the normalized influence parameter values do not reach the value of 0.2, and further their influence on the heating capacity is almost the same.

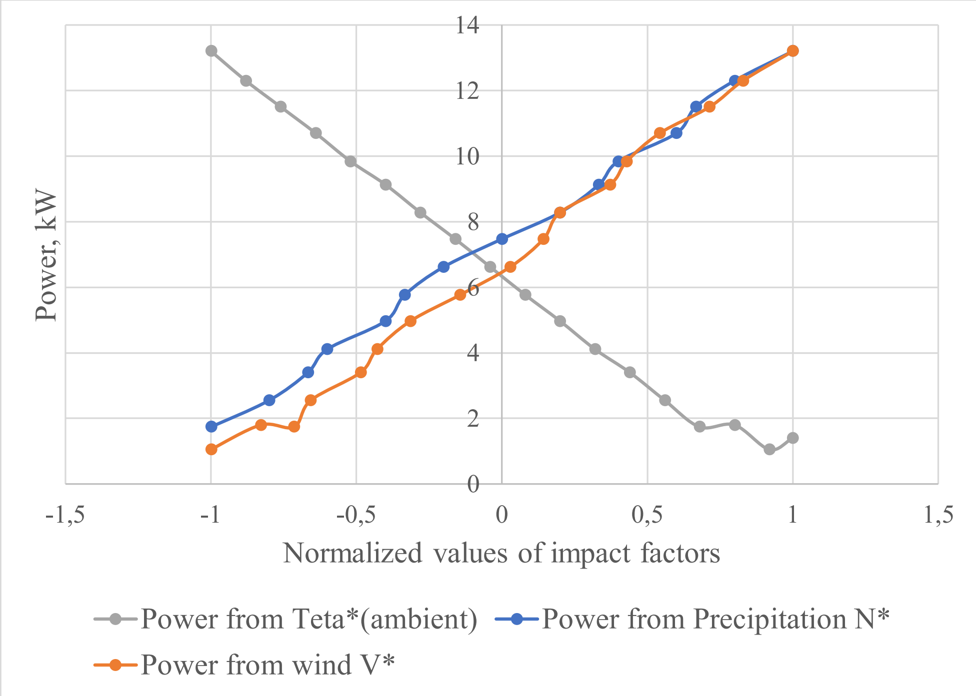

Fig. 2.2. Graph of dependence of heating capacity on snowfall and wind strength.

This can be explained by the fact that a large amount of power is required for heating during heavy snowfall and almost the same amount of heating power is also required during strong winds, as the wind cools the point, but the algorithm is based on maintaining the rail temperature within a certain range. In addition, during strong wind and precipitation, or during strong wind (after heavy precipitation), the snow mass is moved and the turnout part between the frame rail and the open blade can be dusted with snow, which, in turn, is unacceptable from the point of view of train movement safety.

Next, the complex heating regulation model (Fig. 2.3) was created in the PSIM software with the aim of improving the schemes discussed in the previous paragraphs. The model is based on Formula (1.1) described in Chapter 1, but with calculated impact coefficients:

$$P = 6.81 - 3.44\theta^{*}_{\text{amb}} - 0.94N^{*} - 0.56V^{*} \text{ (kW)}. \qquad (2.2)$$

In the diagram (Fig. 2.3), the source of the temperature of the external environment is the source of the triangular-shaped signal, which best corresponds to the nature of the temperature variance. Next, this outdoor temperature source was linearized according to Expression (1.2). The precipitation source was also modelled as a triangular signal source, which, like the temperature source, was linearized according to Expression (1.2). The wind was also modelled with a triangular signal source, which was linearized according to Expression (1.2). Next, according to Expression (2.2), the summation took place to arrive at the resulting power required for heating under all adverse external factors (outdoor temperature, wind, precipitation).

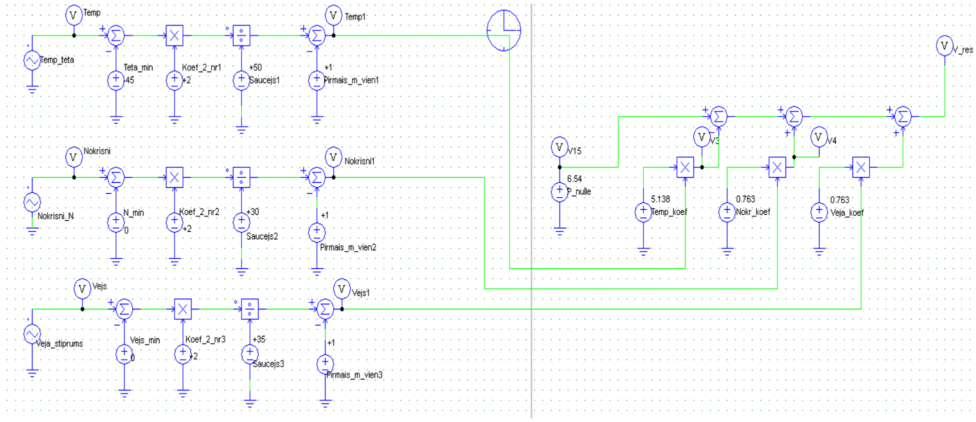

Fig. 2.3. The complex model of the influence of ambient temperature, precipitation and wind.

Next, the model parameters were simulated and studied in PSIM software, and the overall signal graph is shown in Fig. 2.4. The graph shows the changes of all impact factors (air temperature, precipitation, wind strength) over time.

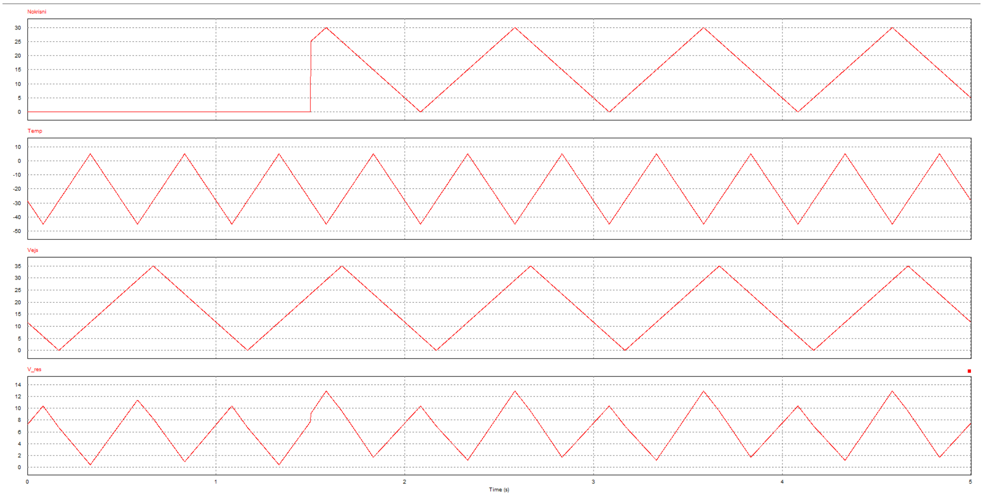

Fig. 2.4. Complex graph of outdoor temperature, precipitation and wind impact model signals.

Figure 2.4. shows the dependence of the heating power on the outdoor temperature in the complex with wind strength and precipitation. The graph shows that in the worst conditions, when the outdoor temperature is the lowest, the precipitation intensity is the highest and the wind strength is the highest, then the heating power is also the highest and can reach ~12 kW. Of course, in real life conditions, there is a small probability that all the mentioned adverse conditions can coincide at one moment. It should be mentioned that the graph shows that wind and precipitation have a great influence on the heating power level, and a strong wind can dissipate the thermal energy supplied to the rail so much that to reach the set temperature, the power must be increased more than 1.5 times – from 8.84 kW at –45 °C and wind speed of 4 m/s up to 12 kW at –45 °C and wind speed of 34 m/s.

3. REGULATION OF THE THERMAL STATE OF RAILWAY POINTS USING FUZZY LOGIC

Fuzzy logic systems are best applied where traditional solutions do not produce the desired result. Fuzzy logic systems can also be applied in other fields of activity where it is possible to apply fuzzy sets and logic, for example, fuzzy logic-based systems that apply if-then conditions, fuzzy logic software development, where uncertainty is in the composition of programs and data, in databases that store and display such information [16].

MATLAB Fuzzy Logic Designer software was used for the proposed intelligent control algorithm. Four input variables were set: temperature, snow, rain, and wind speed.

The membership functions of each input factor formed a trapezoidal, triangular and Gauss representation of the non-strict values [17]–[20]: temperature – low temperature; snow – light, medium and heavy snow; rain – no rain and heavy rain; and wind speed – light, medium and strong wind. The range of membership functions varies as shown in Figs. 3.1 and 3.2.

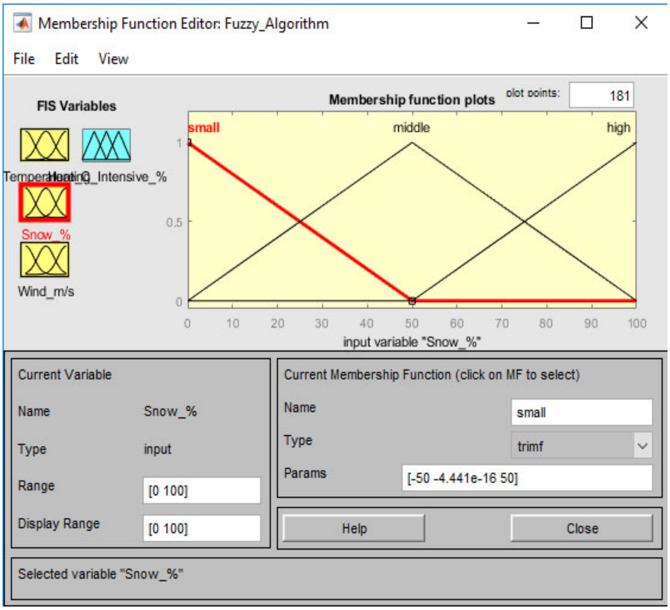

Fig. 3.1. Defining the membership functions of the input parameters of the fuzzy logic model 1(2).

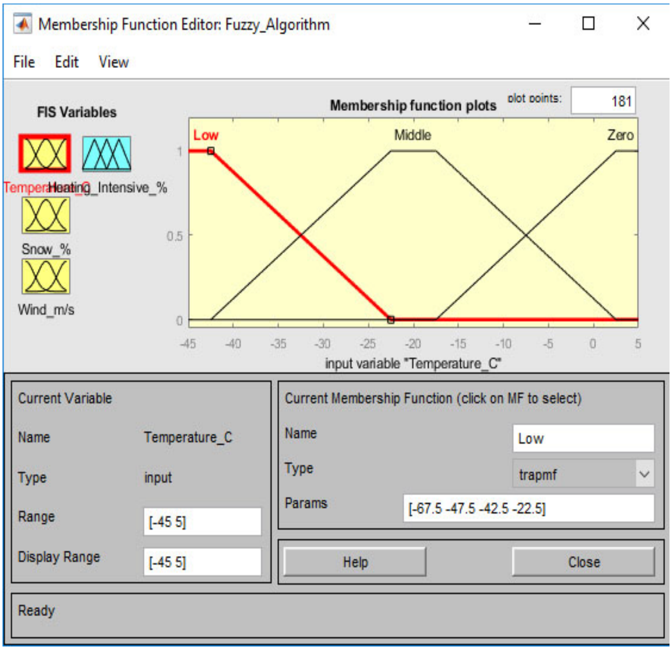

Fig. 3.2. Defining the membership functions of the input parameters of the fuzzy logic model 2(2).

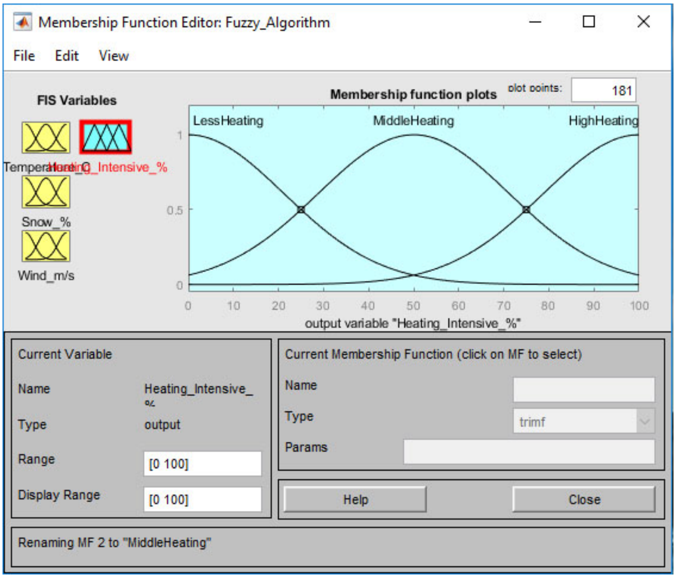

Fig. 3.3. Defining the membership functions of the output parameter of the fuzzy logic model.

Next, to run the simulation, it was necessary to create a rule base (Fig. 3.4), which was used as a basis for the algorithm.

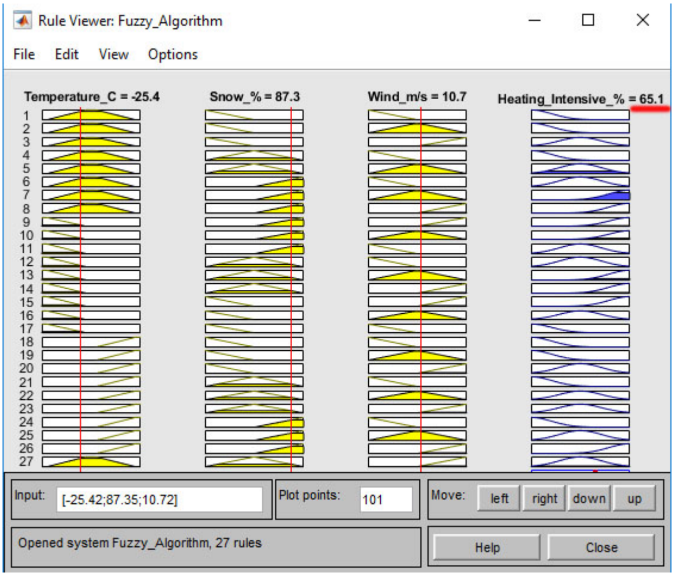

Fig. 3.4. Rule base of the fuzzy logic model.

The created rules allowed to formulate the principles of behaviour of the resulting diagram, thus clearly showing that one or two input variables are not enough to achieve the optimal result. In addition, a certain number of rules had to be applied to show acceptable results in the rule base.

As a final step after simulation, the resulting graph was created in *Fuzzy Logic Designer*.All described and implemented rules are shown in 3D surface diagrams Graph Surface Views (see Figs. 3.5, 3.6). The first surface view (Fig. 3.5) is the result of a simulation dependent on two input parameters with the following input variables – snow intensity and ambient temperature.

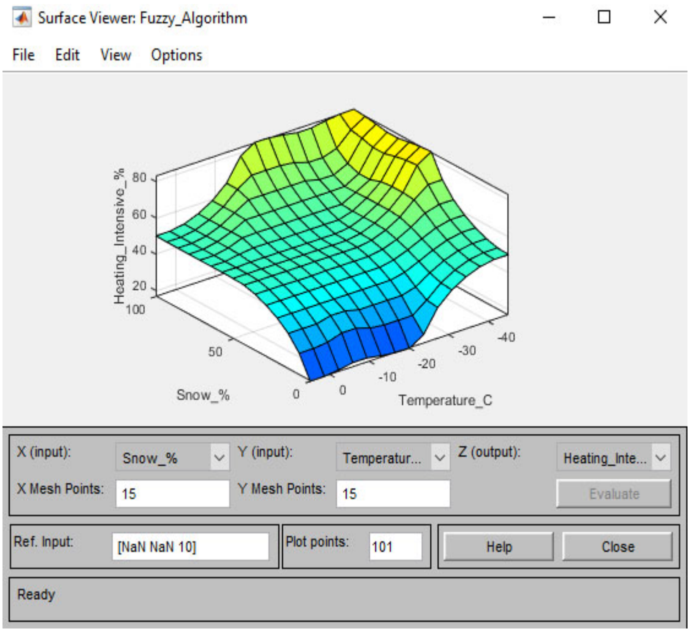

Fig. 3.5. Resulting graph surface views of the fuzzy logic model 1(2).

The second surface view (Fig. 3.6) is also the result of the simulation of two input parameters – snow intensity and wind speed.

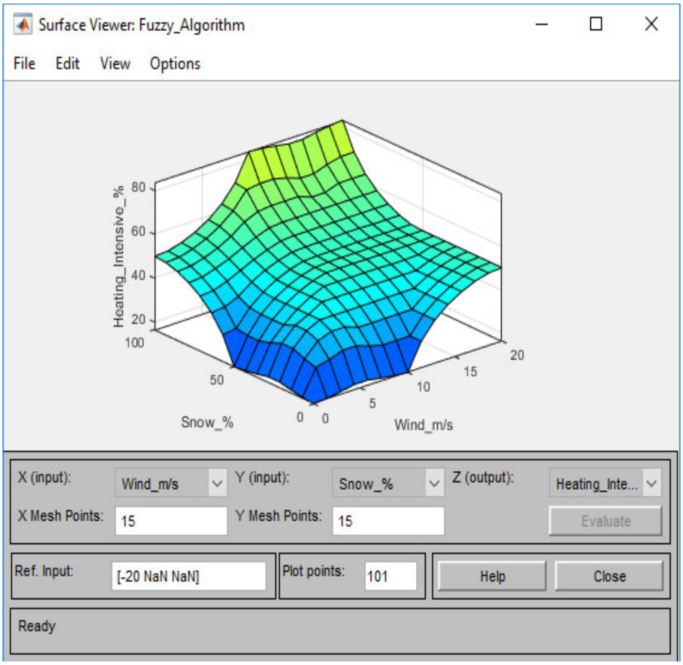

Fig. 3.6. Resulting graph surface views of the fuzzy logic model 2(2).

After that, the obtained results were verified with *SIEMENS Fuzzy Logic “FuzzyControl++”* software, and the obtained results are shown in Figs. 3.7 and 3.8.

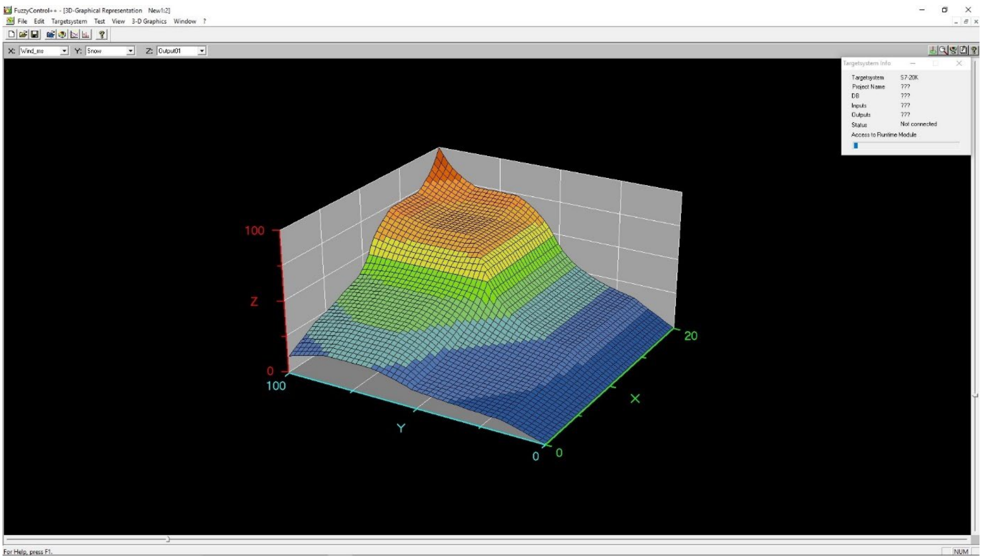

Fig. 3.7. Verified resulting graph surface views of the fuzzy logic model 1(2).

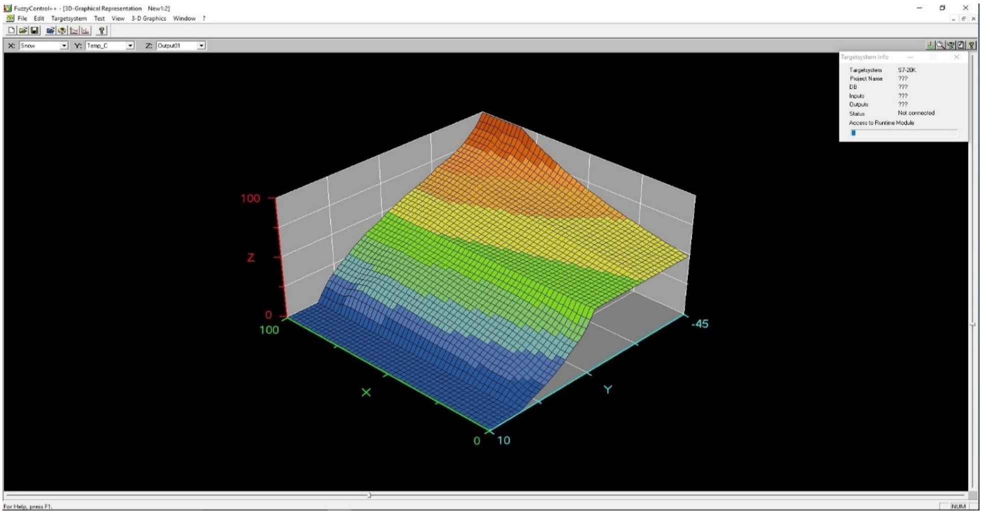

Fig. 3.8. Verified resulting graph surface views of the fuzzy logic model 2(2).

The resulting surfaces are not smooth, and it is not possible to obtain smooth surfaces because the generated rules are equations of several non-linear input variables. The calculated results show a significant dependence on the snowfall intensity. The highest PEH membership point is where the value of the input parameter “Snow” reaches its highest value.

After simulation, it was concluded that the fuzzy logic model can be further used for the development of neural network or more advanced expert system. Since railway stations are located in different regions of Latvia, it is reasonable to install the developed model in different PEH control systems and connect such systems to a neural network to train the network in different climatic zones. This will allow the network to be trained under different climatic conditions in these areas and thus the model can be significantly improved and made more robust and efficient.

4. IMPLEMENTATION OF THE POINT ELECTRIC CONTROL SYSTEM FOR CLEARING POINTS FROM SNOW AND ICE

When choosing PEHCS, it is necessary to check whether the control system is able to perform the following tasks:

1) measurement of insulation resistance of heating elements and measurement of the voltage applied to the heating element;
2) measurement of the current flowing in the heating elements;
3) temperature measurement of heated rails;
4) measurement of ambient air temperature;
5) checking the presence of precipitation and measuring its intensity;
6) possibility to modernize/upgrade the configuration and program code.

When developing the requirements for the PEAS, the following main parameters, which are necessary for clearing the point from snow and ice in railway stations, were considered.

1. Feasibility of PEH performance over a wide range of ambient temperatures. In order to ensure the clearing of snow and ice, the PEH must work at outdoor temperatures in the range of –45 °C to +5 °C.

2. Ability to monitor the system regardless of weather and environmental conditions. Wind speed, low ambient temperature or snowfall should not significantly affect the operation of the PEHCS. PEH must be able to perform snow melting with wind speed up to 30 m/s, snowfall and rain. The PEH must have equipment that is resistant to the effects of an aggressive environment, which is the oil, grease, dust and abrasive particles from the railway rolling stock.

3. The possibility to transfer monitoring information about operational results in real-time (online) mode. The communication system must provide the ability to read the parameters of the PEHCS sensors in real time mode. In addition, for the reliable operation of data transmission channels, it is necessary to build them with resistance to the effects of various interferences. The analysis of different PEHCSs showed that they have shortcomings and there is a need to develop a PEHCS with multi-sensor control principles.

According to [6], [14], an effective PEHCS must fulfil the following conditions:

$$P = \begin{cases} max, f(k_0) \ = 1 \ if \ t < -25\ °\mathrm{C} \\ f(k_0) = variable, if - 25°C \le t < +5\ °\mathrm{C}. \\ 0, \quad f(k_0) \ = 0 \ if \ t \ge +5\ °\mathrm{C} \end{cases} \tag{4.1}$$

Argument k_0 consists of the set of variable parameters shown in (4.2). The result of function $f(k_0)$ is the correlation of the different parameter values included in the set.

$$k_0 = \begin{cases} wind\ speed \\ outside\ temperature \\ atmospheric\ precipitation \\ atmospheric\ pressure \\ rail\ temperature \end{cases} \tag{4.2}$$

Formula (4.1) can also be transformed into the following state:

$$\lim_{n \to \min} f(k_0) = 0 \ if \ t \ge 0 \tag{4.3}$$

When developing PEHCS with multi-sensor control, the following requirements were formulated:

• the possibility of using several sensors and an external weather station to have maximum information about surrounding factors;

• continuous monitoring of the system, sensors and external parameters;

• the possibility of smooth adjustment of the heating power.

During the research, the PEHCS method and prototype equipment were developed. The turnout heating method for clearing snow, ice and other precipitation from the turnout surface includes timely heating based on data from the weather station, regulation of heating power depending on the interaction of precipitation intensity and ambient temperature, and continuous monitoring of rail temperature. To optimize the use of PEHCS during the monitoring of different types of precipitation, an external weather station was used, which was integrated into the overall PEHCS.

Analysing the choice of the algorithm for the PEH control system and with the aim of determining the most suitable one, a SWOT analysis was performed for the genetic algorithm and the fuzzy logic algorithm.

Table 4.1

SWOT Analysis of the Genetic Algorithm of the PEH Control System

Strengths	**Opportunities**
• Innovative algorithm • It is possible to precisely adjust the heating, its power and duration	• The more iterations, the more accurate the control algorithm • Controller resource redundancy – can be used for other purposes
Weaknesses	**Threats**
• To make a decision, an excessively large number of iterations is required, which affects the decision-making time (any change in external parameters requires 100 and 1000 iterations to find a new control signal value) • Requires a powerful controller to execute the many iterations • The more powerful the controller, the more expensive it is in terms of price • The load on the controller will be uneven and therefore the controller will be idle for most of the operating time. • Highly qualified personnel are required for algorithm administration and implementation of changes	• In case of controller failure, there will be high replacement costs • In case of failure of the controller, there are possible difficulties with the purchase of an equally powerful analogue • In case of sensor failure, the system remains inoperable, or the final decision will be extremely wrong

Table 4.2

SWOT Analysis of the PEH Control System Fuzzy Logic Algorithm

Strengths	**Opportunities**
• It is possible to precisely adjust the heating, its power and duration • Able to handle multi-impact factors – temperature, snow, wind, etc. • Algorithm can be implemented with almost any modern controller without strict requirement for excessive performance • The use of standard controllers significantly reduces the cost of system construction • It is possible to create the code of the fuzzy logic algorithm with an understandable graphical interface and easily transform it into the controller's programming language • Algorithm administration can be done by a person having railway engineer's qualification	• Possibility to integrate the control controller into a neural network • The algorithm can control several systems simultaneously
Weaknesses	**Threats**
• A less accurate algorithm compared to the genetic algorithm, which in the given case is not critical in the performance of system tasks • A small range of controllers that directly support fuzzy logic	• In case of sensor failure, the system will work with reduced efficiency

After the SWOT analysis, it was concluded that the fulfilment of the requirements for the efficient point heating and cleaning from snow and ice, and the monitoring system is possible using the PEHCS with an external weather station and fuzzy logic algorithm in the control system. This solution is complex and allows measurement of snow and ice-forming weather conditions and processing of measurement results with the aim of validating the results.

The PEHCS operation algorithm was created in the work, which is shown in Fig. 4.1. In the event of adverse weather conditions, the system starts performing tests before applying voltage to the heating element. Insulation resistance, voltage, operating mode, and presence of data transmission from the weather station are checked. Next, the weather conditions are checked and if the outside temperature is below 0 °C and there is precipitation, then the heating is switched on with medium power. If the outside temperature is higher than 0 °C but lower than 5 °C, the wind speed >5 m/s and there is precipitation, then the heating is switched on at minimum power. The PLC control algorithm selects the exact heating power.

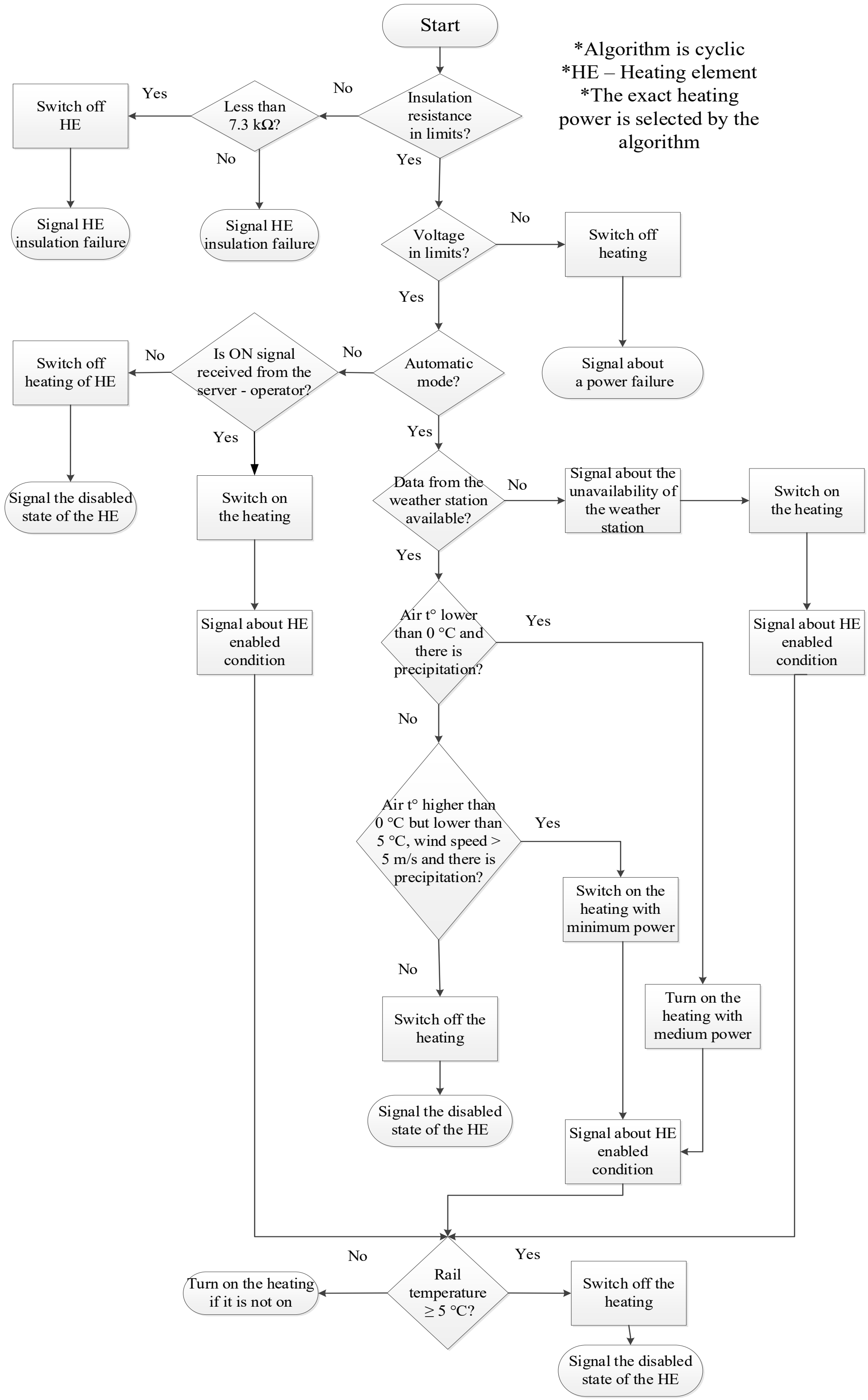

Fig. 4.1. Algorithm of operation of the proposed PEHCS in adverse weather conditions.

5. TESTING OF THE POINT ELECTRIC HEATING CONTROL SYSTEM IN REAL CONDITIONS

In order to verify the theoretical calculations, the performed modelling and the performed calculations, testing of the proposed PEHCS in real railway conditions was carried out. To perform the experiment, a turnout with heating elements, a point heating cabinet in which there is free space for equipment placement were necessary, as well as an optical cable communication line between the point heating cabinet and the station's telecommunication centralized equipment for providing remote access. As a result of discussions, an agreement was reached with LDz on conducting experiments. Station *Zasulauks* and Point 9 with its existing electric heating system were chosen, in which the experimental PEHCS unit was installed in the field cabinet. It should be mentioned that the existing heating elements, cables from the PEH cabinet to the heating elements, isolating transformer 230 V/230 V and circuit breakers were used in the experiment.

The proposed PEHCS, which is installed at the facility, is shown in Fig. 5.1.

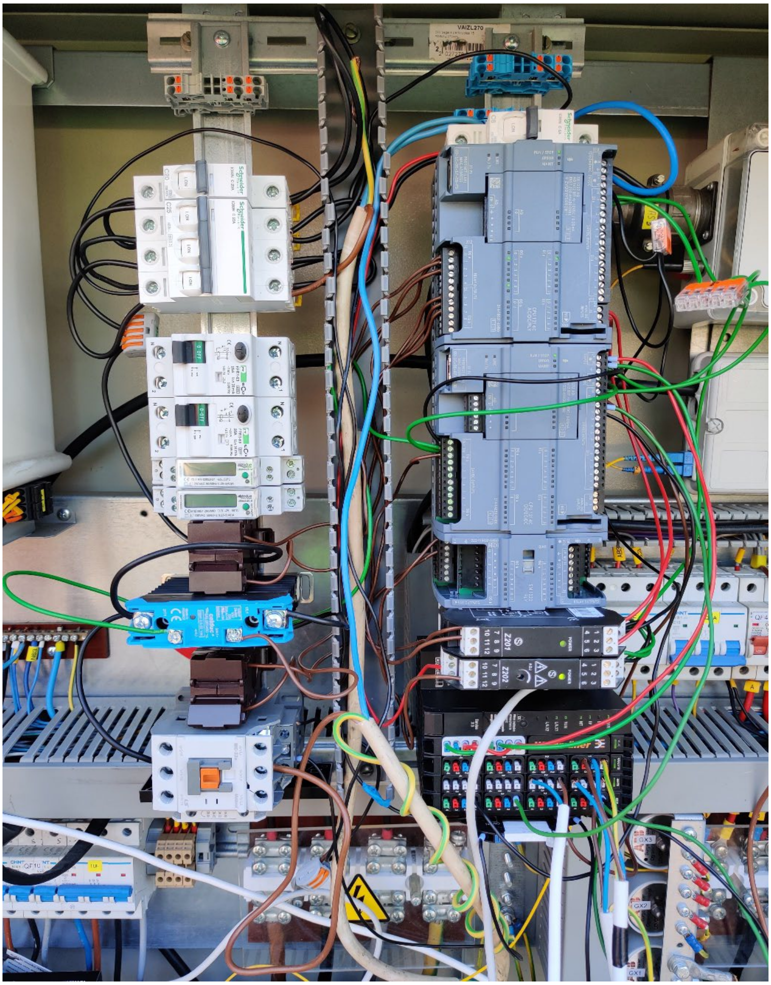

Fig. 5.1. Proposed PEHCS in the point heating cabinet.

The proposed PEHCS is a complex of devices that includes circuit breakers, electrical energy consumption meters, current measuring transformers, magnetic contactor, semiconductor relay, Siemens 1214 controllers (AC/DC/Rly and DC/DC/DC) and expansion unit, devices for measuring voltage, Weidmueller controller (UC20-SL2000-OLC-EC) and expansion units (UR20-4DO-P, UR20-4AI-RTD, UR20-4AI-UI-12) for receiving information from the weather station.

A Lufft WS600–UMB weather station [21] was used throughout the experiments. The main task of the weather station was to send accurate data about weather conditions to the control PLC in real time. Next, the control PLC performed heating power regulation based on data from the weather station, from the interaction of precipitation intensity and ambient temperature, and continuous monitoring of rail temperature. The weather station was installed on a mast at a height of about 4 m from the level of the rail head next to the turnout, which was chosen for the execution of the experiments.

In the course of the experiment, it was planned to perform the following tests:

1. PEHCS operation test. PEHCS turns on when the station operator turns on the heating centrally or when the combination of weather conditions is suitable for switching on the heating, and the control algorithm turns on the PEHCS automatically.
2. Clearing the point from snow and ice, checking compliance.
3. Power consumption control of the experimental PEHCS.
4. Comparison of the power consumption of the experimental PEHCS with a similar system already in operation.
5. Logging of experimental PEHCS data.

In the course of the experiment, it was very important to observe the operation of the system in nature – how the snow melted. Usually, at the beginning of snowfall and when the heating power was moderately intense, the PWM in the range of 30–40 % was applied. While the author was at the facility of the turnout, the operation of the PEHCS was monitored both on site and by monitoring the log files. Every 10 minutes, the temperature of the heating element and the rail was measured and the melting of snow from the area between the turnout's open blade and the frame rail was monitored. Figure 5.2 shows the thermal image taken during heating, which shows the temperature of the heating element (70.5 °C) during the experiment.

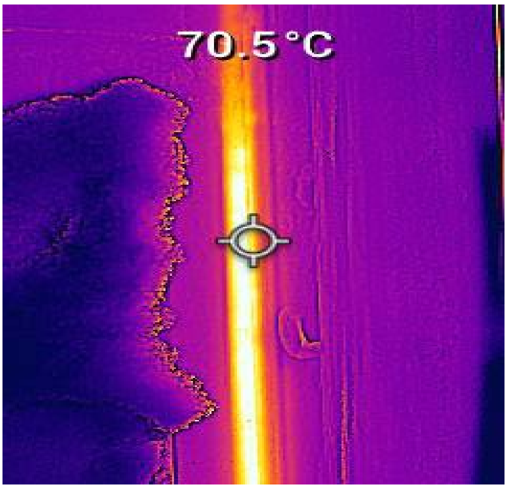

Fig. 5.2. Heating element temperature measurement on Point 9.

Next, the temperature measurements of the turnout's frame rail, on which the heating element was attached, were performed. During the experiment, it was found that the frame rail itself does not heat up to the temperature of the heating element (Fig. 5.3), i.e. the heating element does not give all its thermal energy to the rail. This is understandable because the heating element is not a rail and there are losses when heat energy passes from one element to another, also considering melting the snow and weather conditions that contribute to the dissipation of energy. On the other hand, experiments and publications [14], [15] have shown that it is not necessary to maintain a high rail temperature and only a few degrees are enough, because as it was found out during the experiment, it is important to melt the snow and ice in the area between the point blade and the frame rail. It is also important to melt the snow and prevent the formation of ice on the shift feet – the iron platforms on which the blade slides.

As can be ascertained from Fig. 5.3, during the operation of the experimental PEHCS, the zone between the point blade and the frame rail was thawed and at the same time the temperature in the lower part of the rail neck is 3.8 °C, which is the desired result – the frame rail is not excessively heated and the snow has melted.

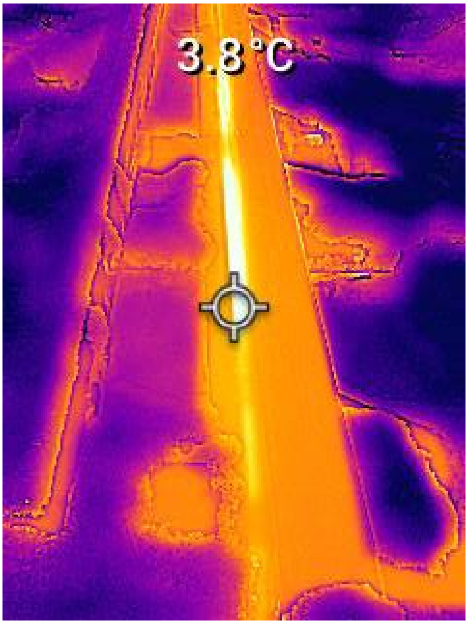

Fig. 5.3. Temperature measurement of the lower part of the frame rail on Point 9.

The confirmation of a positive result of the experiment is the common thermal image from the zone of Point 9 (Fig. 5.4), where the ambient temperature at the point machine (outside the heated zone) is shown. Also, a relatively dark overall thermal image can be observed, which indicates a low temperature at the location of the thermal image.

As can be seen in Fig. 5.4, the average temperature in the Point 9 area (outside the heated area) was –8.6 °C, which roughly corresponds to the outdoor temperature at the time of observation (–9.4 °C).

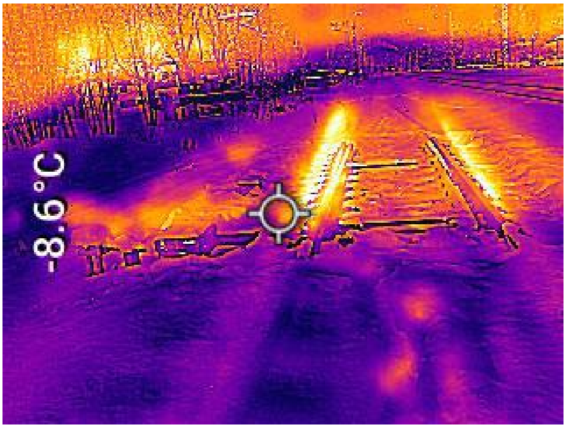

Fig. 5.4. Overall thermal image of the Point 9 area.

In the course of the experiment, Point 7 was a reference point or reference object with which the comparison of the experimental PEAVS was made and whose measurements were taken into account, on which a similar PEH (used by LDz) with its own control system was in operation. Temperature measurements were made in the same way as measurements on Point 9 – every 10 minutes, the temperature of the heating element and the rail were measured and the snow melting from the area between the open blade of the point and the frame rail was monitored. Figure 5.5 is the thermal image taken in the course of heating and shows the temperature of the heating element (89.1 °C) on Point 7.

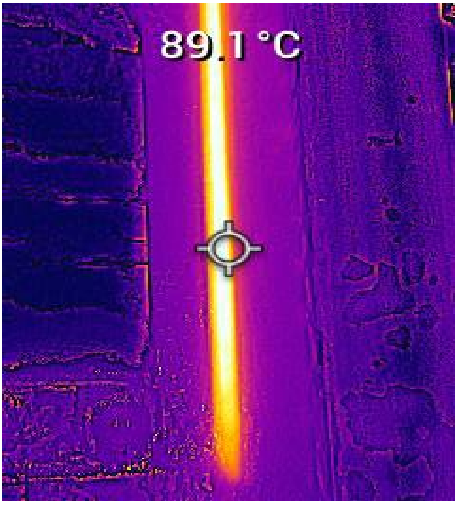

Fig. 5.5. Heating element temperature measurement on Point 7.

Comparing the obtained measurement results, it was observed that the existing PEHCS (operated by LDz) heats up the heating element to a higher temperature than the experimental PEHCS, while maintaining the purity of both turnouts. While this may result in faster snow melting, it also means that much more electricity is used and the existing PEHCS continues to operate even after the snow has already melted.

Also, temperature measurements were performed of the frame rail of Point 7 on which the heating element was attached. In the course of the experiment, it was found that frame rail of

Point 7 heats up to a temperature of 9.8 °C (Fig. 5.6), which is much more than frame rail temperature (3.8 °C) of Point 9. Knowing the heat capacity of the steel and the weather conditions during the experiment, it can be concluded that a lot of excess electricity was used to heat the frame rail to such a high temperature.

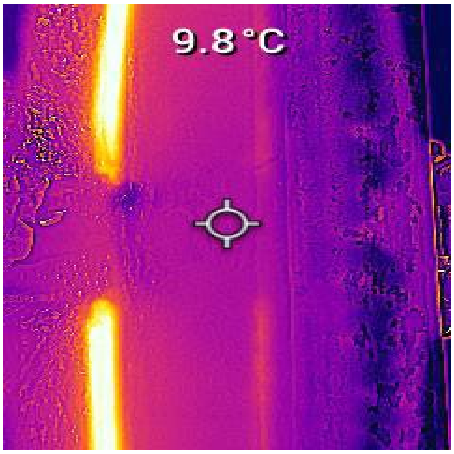

Fig. 5.6. Temperature measurement of the lower part of the frame rail on Point 9.

For the evaluation of the experimental result, a common thermal image was created from the Point 7 zone (Fig. 5.7), where the ambient temperature at the point machine area is shown (outside the heated zone). In Fig. 5.7, a bright overall thermal image can be observed compared to Fig. 5.4, which indicates a high temperature at that location. Temperature measurements also show that in the zone of Point 7 the temperature is –5.5 °C compared to –8.9 °C in the zone of Point 9, which was the main object of the experiment.

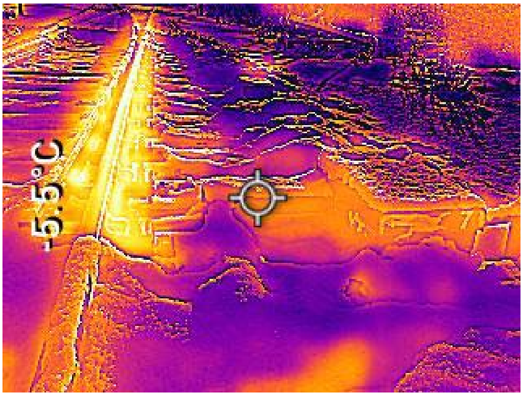

Fig. 5.7. Overall thermal image of the Point 7 area.

During the course of the experiment, it was found that:

- the experimental PEHCS fulfils the assigned function and ensures the melting of snow and ice on Point 9 and performs it with a lower electricity consumption than the existing PEHCS on Point 7;
- the experimental PEHCS maintained the temperature of the rail heating element and the rail in the range when the snow was melted (and the area was clean) and, at the same

time, the temperature of the heating element was much lower than the existing PEHCS on Point 7.

- throughout the day of the experiment, it was observed that in the area of Point 7 (existing PEHCS), the outdoor temperature was quite high compared to the measured temperature in the area of Point 9.

The difference in the temperature of the heating elements, expressed as a percentage, was 26.4 %, which is a significant difference within the heating system cabinet of one point and, even more so, within the entire station. On Point 9, where the experimental PEHCS was installed, the rail temperature was 3.8 °C, but on Point 7 with an existing PEHCS it was 9.8 °C. The difference was 157.9 %. As the author mentioned in the Thesis, the main task of an effective PEHCS is to melt the snow in the area between the point blade and the frame rail, and the second task is to maintain the temperature of the frame rail in a certain positive range.

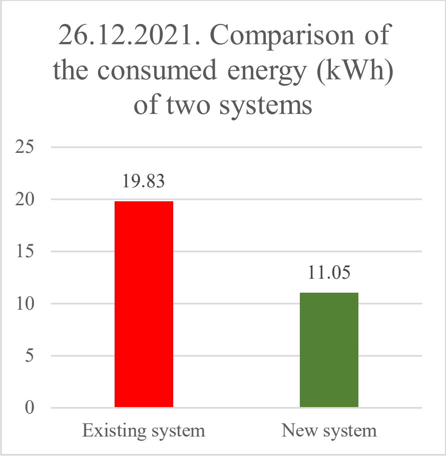

Fig. 5.8. Comparison of electricity consumed by two systems.

A considerable and convincing comparison of the proposed PEHCS and the existing PEH system is shown in Fig 5.8, where both systems were switched on during the experiment on 26.12.2021 (during the whole day). As a result, the proposed PEHCS consumed 11.05 kWh, and the existing PEH system – 19.83 kWh (Fig. 5.8). The electricity saving amounted to 44.28 % (Fig. 5.9). The graphs convincingly show the effectiveness of the proposed PEHCS in real field conditions.

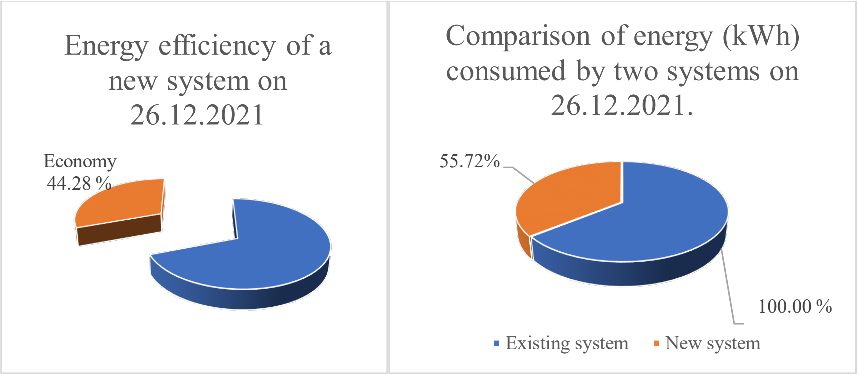

Fig. 5.9. Electricity savings and consumption graph.

CONCLUSIONS AND MAIN RESULTS OF THE RESEARCH

1. The point cleaning systems used in Latvia, Europe and the world were studied. The advantages and disadvantages of the operated systems were described and analysed. It was found that all electric PEH systems have a significant drawback – the rails are heated unnecessarily for a long time and there are very significant heat losses. It is concluded that it is necessary to develop a PEHCS with multi-sensor and fuzzy logic control integration. In the course of practical experiments, the effectiveness of the proposed solution was demonstrated in comparison with PEH system currently operated by LDz.
2. The main external factors influencing the heating of turnouts were identified and verified, and it was studied how and to what extent they affect the point heating. Coefficients of impact factors and normalized values of impact factors were calculated with the help of regression expressions. The dependences of the heating power of turnouts on each influencing factor have been determined. During the formulation of the problem of inefficient point heating, it was determined that currently existing PEH systems are operated by a simple switch on/off principle or by control with one sensor (control by one influence factor); in these systems the heating power is not regulated or is regulated at an insufficient level.
3. A general definition of the control system was carried out, feedbacks and their functions were studied. A comparison of point heating control systems, an analysis of the main tasks and methods was carried out. Modelling of the regulation of the thermal state was carried out with different techniques – direct regulation, regulation with feedback, according to the results of regression equations. The mentioned techniques were modelled in the PSIM environment, the results were collected and analysed. It was concluded that the regression method is relatively good but does not fully satisfy the requirements of efficient heating of the points, therefore, for further work, modelling and practical experiment, the model was further developed. As a result, experimental railway point heating system was developed with an intellectual control algorithm with fuzzy logic algorithm integrated into it.
4. The application of fuzzy logic in the computer control and control system of electrical technologies was described. The construction of the described PEHCS fuzzy logic model is in progress, the construction itself and modelling of the model in the *MATLAB* environment have been completed. Analysis of Fuzzy-PI and Fuzzy-PID controllers and their applicability in PEHCS was performed. It was concluded that the application of fuzzy logic commands in the synthesis of the algorithm gives the most correct result regarding the selection of the basic heating influence parameter and its nomination as the primary parameter in the development of the control algorithm. This conclusion is confirmed by the simulation performed in *MATLAB* and *SIEMENS Fuzzy Logic "FuzzyControl++"* software.
5. The formulation of the requirements for the point heating control system was carried out and the functional options of the PEHCS were determined. Devices and technologies were chosen for efficient heating of points. A comparison of the experimental PEHCS and the main competitors has been performed and an analysis of the shortcomings of different PEHCS control algorithms has been performed. An operational algorithm for efficient point heating and weather monitoring was developed. The methodology was implemented in accordance with the control algorithm, which includes automatic monitoring of weather conditions, automatic switching on of the heating system when the threshold value of adverse weather conditions

occurs. At the end of Chapter 4, the main tasks of the PEHCS to be developed were defined and the development of PEAS devices and technology was carried out.

6. An experimental PEHCS was developed, which is equipped with a weather station capable of detecting all types of weather conditions, ambient air temperature and wind speed and logging operational data or parameters in real time. The developed PEHCS consists of a main PLC that is connected to a secondary PLC that receives information from a weather station and a rail temperature sensor. The experimental PEHCS was described, its operation scheme and a description of the main devices were given. A PEHCS control algorithm with real-time data transmission from the weather station was developed. The algorithm, which integrates fuzzy logic techniques, implements the selection of the heating power, consists of the program code and finds the optimal value to be given at the output. The practical experiment, its progress and the achieved results were described.

7. One of the results of the experiment is the difference of the ambient air temperature in the zone near the point on each of the compared points. The difference was 56.4 %. This comparison shows the unnecessary heating of the ambient air of the point zone in the vicinity of the existing heating system.

8. Practical experiments were carried out at the facility of the LDz operated turnout during several winter seasons, and the experimental PEHCS was tested in various possible weather conditions and operating modes. The results of the experiments were analysed, and it was concluded that the experimental PEHCS fulfils its tasks and does not overheat the frame rail.

9. During the experiment, the temperature difference of the heating elements amounted to 26.4 %, which is a significant value. A significant difference in rail temperatures was also observed during the experiment. On Point 9, where the experimental PEHCS was installed, the rail temperature was 3.8 °C, but on Point 7 with existing PEHCS it was 9.8 °C, which makes 157.9 %. As already described in the work, the main task of an effective PEHCS is to melt the snow in the area between the blade and the frame rail, and the second task is not to overheat the frame rail unnecessarily. As a result, the operation of the experimental PEHCS algorithm heated the rail to a sufficient temperature without overheating the frame rail.

10. A comparison of the results obtained during the experiment was made with a similar point of LDz, which was equipped with an existing PEHCS, and which operated simultaneously with the experimental PEHCS. During the comparison of the results, it was found that the experimental PEHCS has lower heat energy losses, i.e. less power is spent on unnecessary heating of the surrounding environment, while at the same time achieving the same results of snow removal. Also, the economic efficiency of the experimental PEHCS was calculated, which amounted to 44.28 %, or 11.05 kWh consumed, against 19.83 kWh for the existing PEHCS in one day. As can be concluded, during the practical experiments, the experimental PEHCS proved its energy efficiency.

11. Conclusion of the experiment – the currently operated PEHCS on Point 7 is inefficient and wastes electricity by heating the point to an unnecessarily high temperature, dispersing a considerable amount of heat energy throughout the turnout area. In contrast, the experimental PEHCS on Point 9 performed the assigned task as efficiently with lower electricity consumption and with minimal thermal energy losses to the surrounding environment.

BIBLIOGRAPHY

[1] I. C. C. D. J. Pagand, Fostering Rail Through Green Deal, 2020.

[2] P. Dolgopolov, D. Konstantinov, L. Rybalchenko, and R. Muhitovs, Optimization of train routes based on neuro-fuzzy modeling and genetic algorithms, in *Procedia Computer Science*, 2019, vol. 149. doi: 10.1016/j.procs.2019.01.101.

[3] M. Mezitis, R. Muhitovs, M. Arpabekov, Z. Sansyzbajeva, B. Togizbayeva, and A. Assiltayev, Optimization of Transport Logistical Flows Between Railway and Urban Passenger Transportation Systems, 2020, pp. 28–34. doi: 10.1007/978-3-030-39688-6_5.

[4] Ягудин Р.Ш., *Надёжность устройств железнодорожной автоматики и телемеханики*. Москва: Транспорт, 1989.

[5] Сапожников. Вл.В., Шаманов В.И., Сапожников В.В., *Надёжность систем железнодорожной автоматики, телемеханики и связи*. Москва: Транспорт, 2003.

[6] R. Muhitovs, M. Mezitis, and J. Freimane, Intelligent Railway Point Electric Heating Control System, 2019. doi: 10.1109/RTUCON48111.2019.8982345.

[7] Gržibovskis M., *SCB Lauku iekārtu uzbūve un tehniskās apkopes principi. Mācību līdzeklis.* Rīga, 2009.

[8] J. Smirnovs, P. Balckars, D. Sergejevs, T. Altbergs, and V. Greckis, Dzelzceļi. Vispārīgais kurss. 1996.

[9] B. A. Palsson, Optimisation of Railway Switches and Crossings, Chalmers University of Technology, Goteborg, 2014.

[10] O. Podsosonnaja, M. Mezītis, *Vilcienu kustības intervālu regulēšanas sistēmas (releju). Mācību līdzeklis*. Rīga: RTU, 2007.

[11] R. Muhitovs, M. Mezitis, and I. Korago, Development of the railway point electric heating intellectual control algorithm, *Transport Problems*, vol. 15, no. 1, 2020, doi: 10.21307/TP-2020-007.

[12] M. Mezitis, G. Strautmanis, A. Baranovskis, and R. Muhitovs, *Environment Safety Improving Due to Railway Noise Management Decreasing of RMR Method Adaptation*, vol. 124. 2020. doi: 10.1007/978-3-030-42323-0_9.

[13] P. Norrbin, J. Lin, and A. Parida, Energy efficiency optimization for railway switches & crossings: a case study in Sweden, 2016.

[14] R. Muhitovs, M. Mezitis, A. Spunitis, and V. Iriskovs, Analysis of Experimental Railway Point Electric Heating System, 2021. doi: 10.1109/AIEEE51419.2021.9435805.

[15] R. Muhitovs, M. Mezitis, A. Baranovskis, and A. Spunitis, Modelling point electric heating algorithm using Fuzzy Logic, 2021. doi: 10.1109/ICECCME52200.2021.9590940.

[16] Munakata Toshinori, *Fundamentals of the New Artificial Intelligence*. London: Springer London, 2007. doi: 10.1007/978-1-84628-839-5.

[17] E. Ginters, M. Mezitis, and D. Aizstrauta, Sustainability Simulation and Assessment of Bicycle Network Design and Maintenance Environment, in *2018 International Conference on Intelligent and Innovative Computing Applications (ICONIC)*, Dec. 2018, pp. 1–6. doi: 10.1109/ICONIC.2018.8601225.

[18] G. Strautmanis, M. Mezitis, and V. Strautmane, Model of a vertical rotor with a ball-type automatic balancer, *Vibroengineering PROCEDIA*, vol. 8, pp. 57–62, Oct. 2016, Accessed: Sep. 10, 2022. [Online]. Available: https://www.extrica.com/article/17598

[19] M. Mezitis, V. Panchenko, M. Kutsenko, and A. Maslii, Mathematical model for defining rational constructional technological parameters of marshalling equipment used during gravitational target braking of retarders, *Procedia Comput Sci*, vol. 149, pp. 288–296, 2019, doi: 10.1016/j.procs.2019.01.137.

[20] V. Yatsun *et al.*, Searching for the two-frequency motion modes of a three-mass vibratory machine with a vibration exciter in the form of a passive auto-balancer, *Eastern-European Journal of Enterprise Technologies*, vol. 4, no. 7 (106), pp. 103–111, Aug. 2020, doi: 10.15587/1729-4061.2020.209269.

[21] Compact Weather Sensors – WS600-UMB Smart Weather Sensor. https://www.lufft.com/products/compact-weather-sensors-293/ws600-umb-smart-weather-sensor-1832/ (accessed Sep. 10, 2022).

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