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DEVELOPMENT OF THE RAILWAY POINT ELECTRIC HEATING INTELLECTUAL CONTROL ALGORITHM

Summary. The article reviews and describes the problems of the railway point heating conventional control system considering its structure, simple design, disadvantages and nonconformity. As a solution to the described problem, an innovative and advanced point heating control algorithm is proposed based on Matlab's Fuzzy Logic Designer module, which will allow control of heating more effectively and intellectually. The tasks for the advanced and intellectual point heating control system were set. The interdependency of different input variables and their weights of the proposed algorithm are shown and described. Conclusions show that the approach of introducing a control algorithm based on Fuzzy Logic will allow to control point heating in a more advanced and efficient way - switching on and off based on the interdependency of different weather conditions and weather forecast; the input data control system will decide automatically when to switch the heating on and off.

1. INTRODUCTION

Currently, railway stations are equipped with a point heating system; it is controlled by the switch on/off principle [1, 10, 14]. The heating is switched on when the weather worsens and is turned off when the weather noticeably improves. In this case, heating is not regulated in any way. This leads to unnecessary consumption of electricity and it is an inefficient method.

Thus, at the moment when point heating is turned on, the snow falling on the point is melted and melts. The heating works for the time period "t", and this time "t" is regulated in the manual mode. When necessary, the point heating is switched on manually, but in this way the minimum power consumption and thus the minimum costs are not achieved. On the other hand, heating of points itself is necessary due to possibility of falling snow to turn into ice and block the point from switching [3, 7]. This can lead to different situations that threaten safety on the railway [13].

The electrical energy W consumed for the current work of point heating is calculated as follows:

$$W = U * I * t , \quad (1)$$

where "W" is the work of electrical energy, "U" is the electric voltage, "I" is the electric current and "t" is time. The heating power is constant if the supplied voltage is constant. The active power of the point heating is calculated using the following formula:

$$P = U * I * \cos\varphi , \quad (2)$$

where "P" is the electric power, "U" is the electric voltage, "I" is the electric current and " $\cos\varphi$ " is the power factor.

This means that point heating can be adjusted by changing the time for which the heating is switched on. The second option is to adjust the voltage that is supplied for heating. If reduced, then the active heating power is reduced accordingly.

$$P = \begin{cases} \text{max, if } U = \text{max. and } t^\circ < 0 \\ \text{nom, if } U = \text{nom. and } t^\circ = 0 \\ 0, U = 0, \text{ if } t^\circ \geq 0 \end{cases} \quad (3)$$

$$t = \begin{cases} \text{wind speed} \\ \text{outside temperature} \\ \text{atmospheric precipitation} \\ \text{atmospheric pressure} \\ \text{rail temperature} \\ \text{point heating current} \end{cases} \quad (4)$$

If the voltage adjustment method is chosen, then, power losses will eventually be present and there is no way to avoid these. Therefore, the author chooses to flexibly adjust the time for which the heating must be switched on.

2. DEVELOPMENT OF THE INTELLECTUAL POINT HEATING CONTROL ALGORITHM

In the fuzzy logic model, the Mamdani algorithm has been applied [2,4] and it consists of the following steps. In the first step, factors or variables are selected that are presented as fuzzy values. The next step is the fuzzification step, i.e. construction of the characteristic function or the membership function of input variables (parameters) and the output variable. Possible ranges of their changes also have to be specified [15].

In the third step, on the basis of existing ideas about the nature of influencing factors, the output variable should be formulated and described by rules that associate input and output variables [5,6,8]. In the final step, a fuzzy logic model is constructed.

2.1. Tasks of the control algorithm

Before starting the development of a new control algorithm, it is necessary to list the tasks that the proposed algorithm must fulfill. These tasks are as follows:

1. insulation resistance measurement of point heating elements;
2. measurement of voltage that is applied to point heating elements;
3. measurement of current that flows through point heating elements;
4. measurement of heated rail temperature;
5. measurement of ambient air temperature;
6. checking of the presence of precipitation; and
7. checking of weather forecast in different Internet resources.

2.2. Fuzzy logic controller

For the intellectual control algorithm, Matlab's fuzzy logic designer will be used. First of all, 4 input variables are set: temperature, snow, rain and wind speed. The overall structure of the fuzzy logic controller control system is shown in Fig. 1.

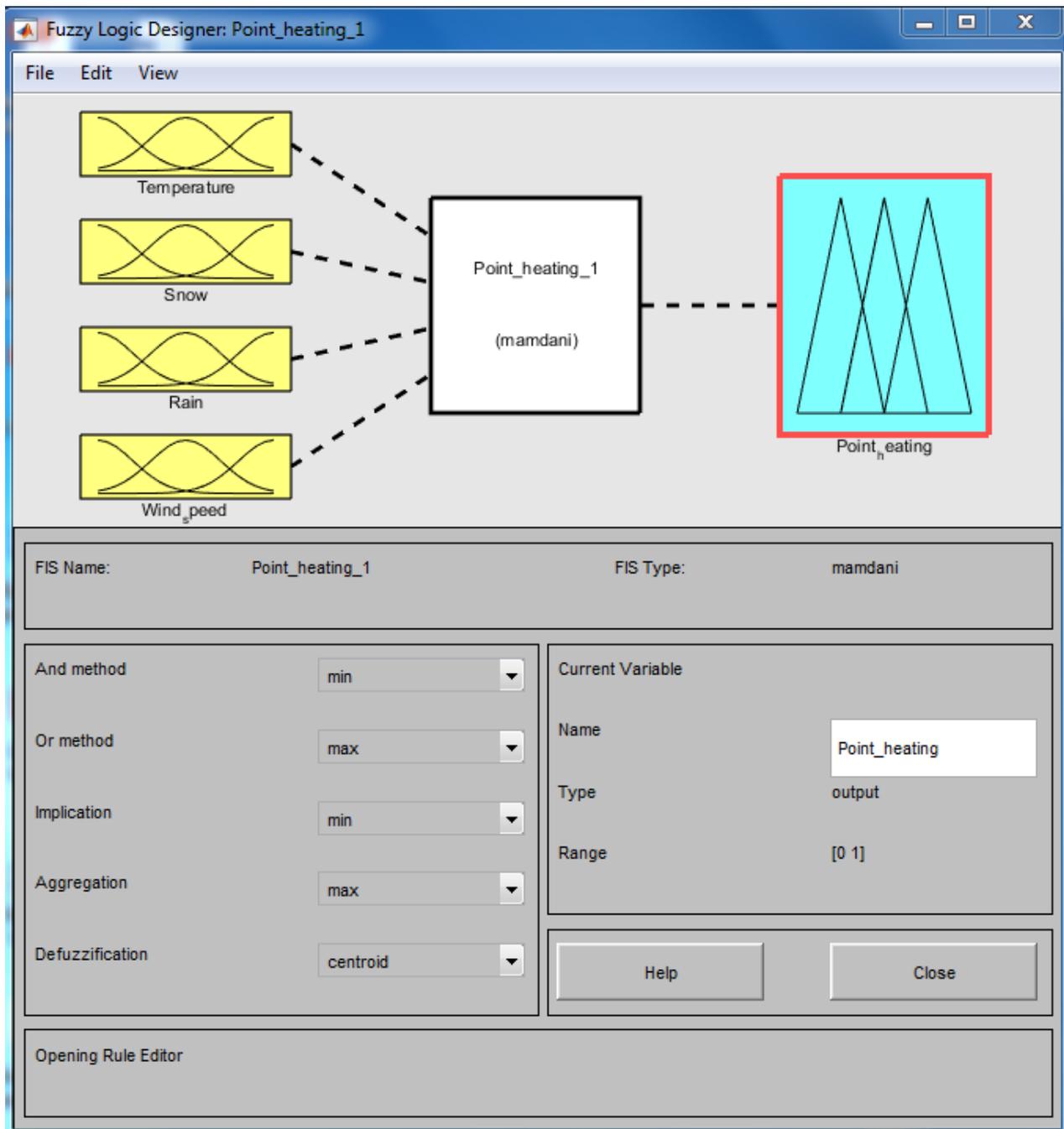


Fig. 1. Overall structure of the fuzzy logic controller control system

The next stage is to select or specify a characteristic function (membership functions) for input and output parameters [9]. The membership function may be triangular, trapezoidal, in the form of a Gaussian function, sigmoid and others [11, 12].

Membership functions of each input factor form the trapezoidal representation of fuzzy values: temperature - low temperature, snow - light, medium and strong 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. 2, 3.

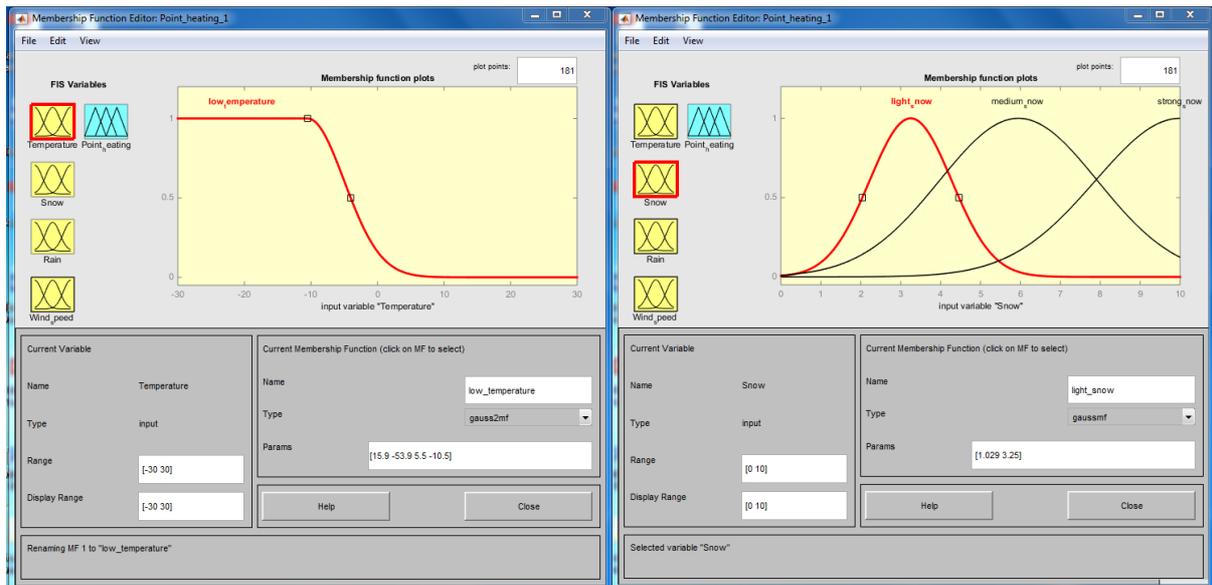


Fig. 2. Membership functions of input variables

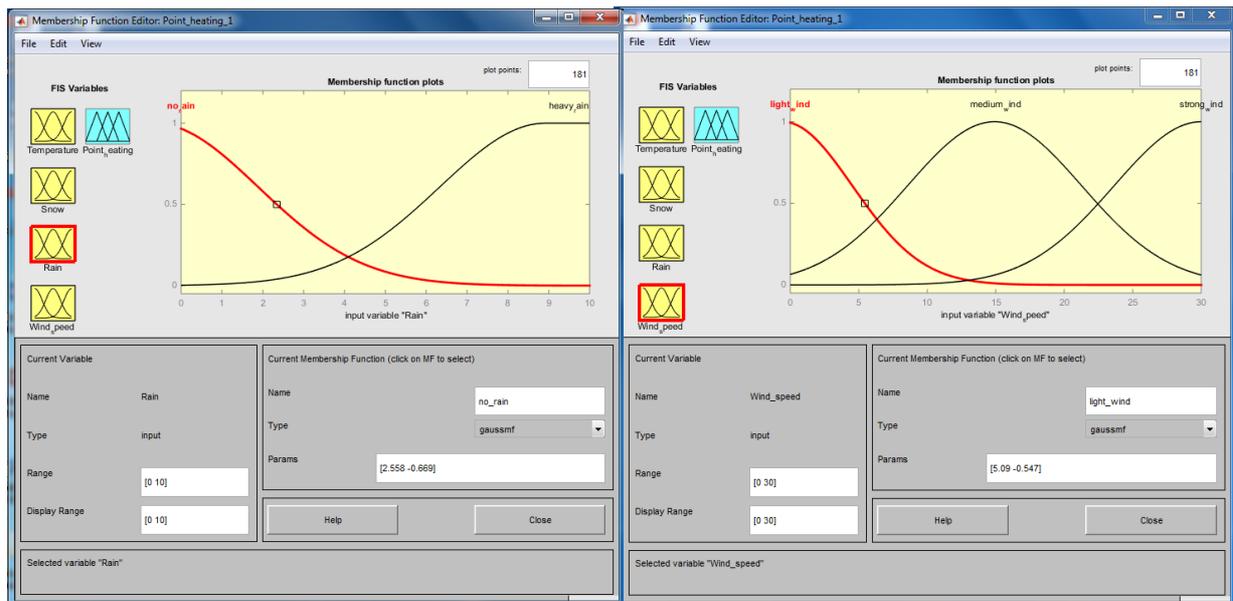


Fig. 3. Membership functions of input variables

Next, to start a simulation, it is necessary to create a rule base (Fig. 4.) that will be used as a basis for the algorithm.

1. if $t < 0\text{ }^{\circ}\text{C}$, do not switch on point heating;
2. if $t < 0\text{ }^{\circ}\text{C}$ and there is little snow, switch point heating on with minimum power;
3. if $t < 0\text{ }^{\circ}\text{C}$, there is little snow and light wind, switch point heating on with minimum power;
4. if $t < 0\text{ }^{\circ}\text{C}$, there is little snow and medium wind, switch point heating on with minimum power;
5. if $t < 0\text{ }^{\circ}\text{C}$, there is little snow and strong wind, switch point heating on with medium power;
6. if $t < 0\text{ }^{\circ}\text{C}$, there is medium snow and light wind, switch point heating on with medium power;

7. if $t < 0$ °C, there is medium snow and medium wind, switch point heating on with medium power;
8. if $t < 0$ °C, there is medium snow and strong wind, switch point heating on with maximum power;
9. if $t < 0$ °C, there is heavy snow and light wind, switch point heating on with medium power;
10. if $t < 0$ °C, there is heavy snow and medium wind, switch point heating on with medium power;
11. if $t < 0$ °C, there is heavy snow and strong wind, switch point heating on with maximum power;
12. if $t < 0$ °C, there is strong rain and light wind, switch point heating on with minimum power;
13. if $t < 0$ °C, there is strong rain and medium wind, switch point heating on with minimum power; and
14. if $t < 0$ °C, there is strong rain and strong wind, switch point heating on with medium power.

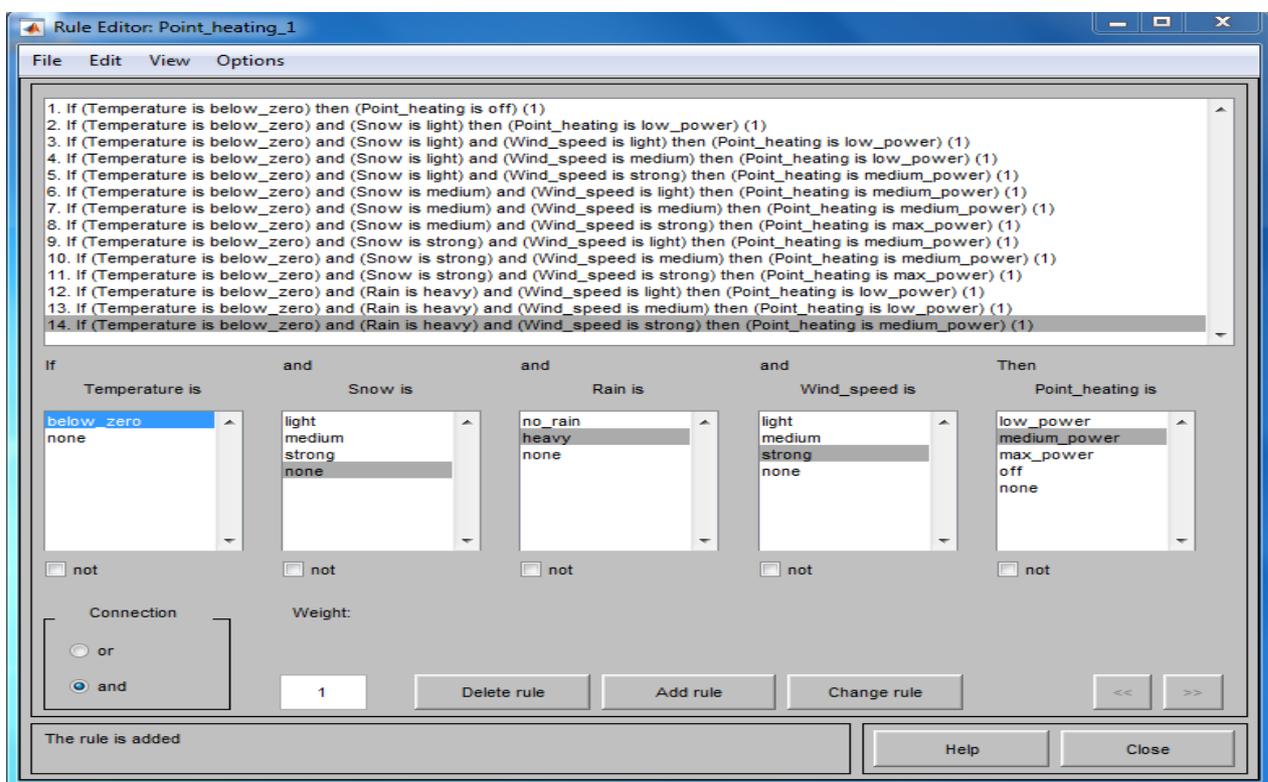


Fig. 4. Fuzzy logic controller rule base

2.3. Fuzzy logic controller simulation results

Simulation results (Fig. 5.) clearly show that using the proposed algorithm, it is possible to manage point heating efficiently and flexibly. The results show considerable dependence on the intensity of snowfall, wind speed and rainfall. The highest peak of point heating membership is in the center of the graph. This is where membership functions of input factors (especially snow and temperature) are most true and input of this forms the output result – the value of membership function of the point heating system is close to 1. Based on the situation prevailing at the time of the simulation, it is possible to confer more importance to the corresponding category input factors, thus leading to an overall output result of the simulation.

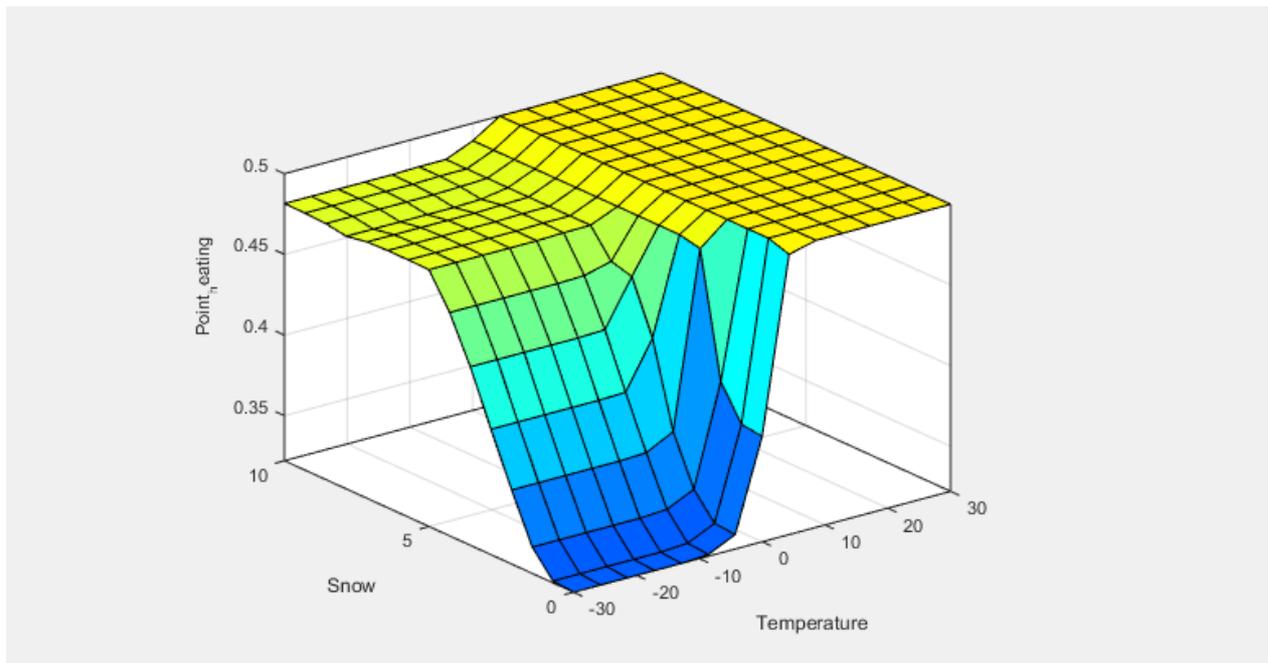


Fig. 5. Simulation results

2.4. System structure, description and scheme of electric connections

To gain a better idea of the structure of the completed system and the interaction of different devices in it, it is necessary to develop a system architecture block diagram (Fig. 6). The heating element is mounted on the frame rail of each blade. It can either be an electric heating element or a heating induction plate. Each frame rail is fitted with a temperature sensor that measures the rail temperature and real-time data transfer to the heating control controller. The current to the heating element is fed through a force contactor and this contactor is activated by a relay controlled by the controller. The temperature sensor is also connected and constantly sends information about the frame rail temperature to the controller. An insulation resistance-measuring device is installed to measure the insulation resistance of the heating element. In case the resistance of the insulation is below the minimum value ($R < 7.3 \text{ k}\Omega$), the measuring device sends an alarm to the controller.

Voltage-, current- and active power-measuring devices are installed to control these parameters and send a signal if their values are beyond the minimum and maximum limits.

To control and monitor weather changes, a weather station has been designed and it includes precipitation, temperature and humidity sensors, wind speed and atmosphere pressure sensors, and all data are sent to the weather station controller. The local weather station enables monitoring of the environment and by sending up-to-date data about the weather conditions to the controller, the controller can control point heating very precisely and efficiently. The weather controller is connected to a switch that is located in the station building, and this switch also connects all point heating controllers into one network and is connected to the station point heating server.

The point heating server also receives the weather forecast from the Internet information on upcoming weather changes. This is needed to keep switch point heating on, for example, during the strong wind, rain and in case of temperature dropping below zero. In such weather conditions, ice can develop on the rails and it is prudent to turn the point heating on with low power in advance to prevent such a situation.

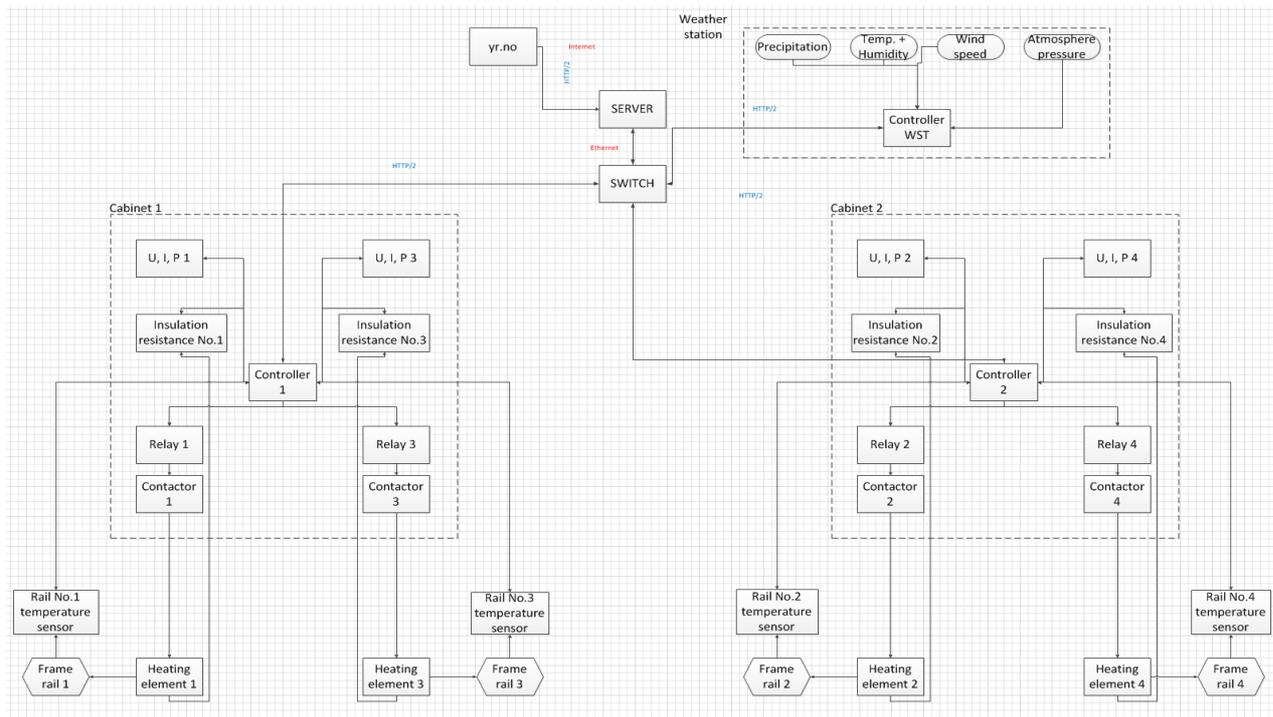


Fig. 6. Proposed point heating system architecture block diagram

When the block diagram of system architecture is ready, it is necessary to show the circuit diagram of all system elements (Fig. 7). Three-phase power is fed through current transformers T1 and T2 to two voltage-, current- and power-measurement devices. One phase and neutral are connected to a 5V power supply unit, which provides 5V DC to the controller. In parallel with the controller, an Ethernet controller is installed to provide network connectivity. To switch the power to point heating elements, the controller provides power to two relays K1 and K2, which close NO-type contacts to place coils of the contactors KM1 and KM2 under current. When the contactor coils are under current, they switch on their contacts KM1.1 and KM2.1, and thus all power is fed to heating elements through isolating transformers. On each frame rail, temperature sensors are installed; these are connected directly to the controller to provide input data. Isolation resistance-measurement devices are installed and connected to heating elements to constantly control the resistance value and send alarms to the controller when the value drops below the minimum limit.

3. CONCLUSIONS

This article defines an equation of states that allows the determination of the dependence of the objective function on various parameters. Such a definition allows the evaluation and adjustment of the parameters of the output function by a combination of many quantities.

The use of a fuzzy logic controller for energy management and saving purposes enables it to be successfully integrated into the point heating control algorithm. In this article, the intellectual control algorithm based on fuzzy logic was developed. Input and output variables were defined; membership function levels were set. As a result of the simulation, it is clear that using the proposed algorithm, it is possible to manage point heating efficiently and flexibly and, using the fuzzy logic makes the process of managing it smart and modern. This algorithm allows to effectively manage the operation of switching point heating on and off. The results show considerable dependence on snowfall intensity, wind speed and rainfall. The study of interdependence of these input variables is an important and useful result of this work.

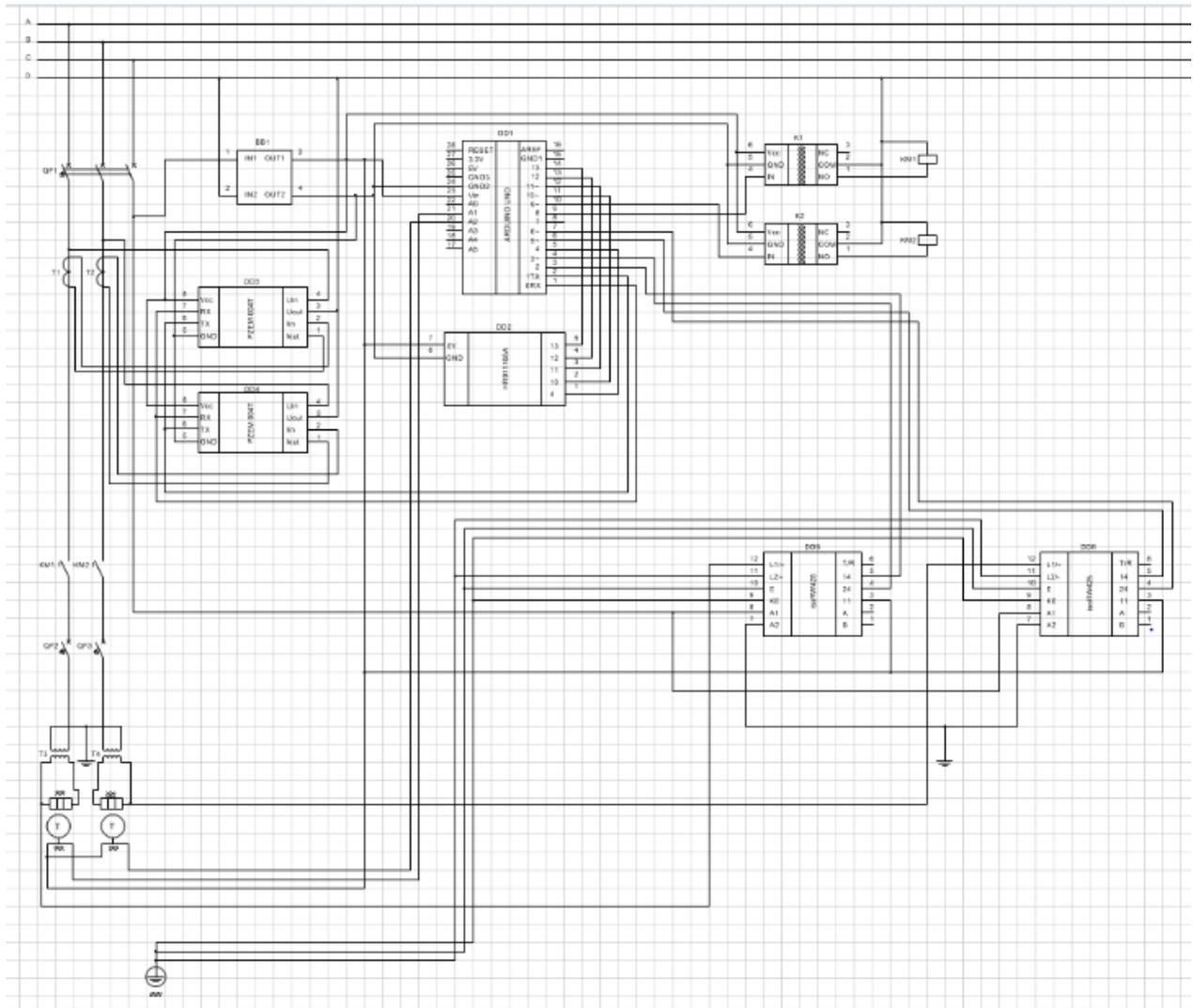


Fig. 7. Proposed point heating system circuit diagram

The results are shown in the form of Graph Surface View (Fig. 5). The output variable (point heating) shows strong dependence on low temperature, wind speed and whether there is precipitation, and the interdependence of these inputs is a significant and useful part of this research.

The obtained data allow to confirm the hypothesis of the versatility of the task, thereby indicating that to achieve the optimal result, taking into account only one or two parameters is not enough. Thus, direct regulation of the point heating process will not always be optimal in terms of the output result and more complex, interdependent control algorithms must be applied.

Further research needs to be carried out to study the interdependence of the input variables and to clarify membership functions more precisely. Some more subsections could be designed and, –also, the fuzzy logic algorithm could be fine-tuned (e.g. by adding more input variables), thus making it more complex and, at the same time, much more effective.

References

1. Теег, Г. & Власенко, С. (ред.). *Системы автоматизации и телемеханики на железных дорогах мира*. Москва: Интекст. 2009. 496 p. [In Russian: Teeg, G. & Vlasenko, S. (eds.). *Automation and telematics systems on the world's railways*. Moscow: Intext].
2. Kargin, A. & Panchenko, S. & Vasiljevs, A. & Petrenko, T. Implementation of cognitive perception functions in fuzzy situational control model. *Procedia Computer Science*. 2019. Vol. 149. P. 231-238.
3. Panchenko, S. & Siroklyn, I. & Lapko, A. & Kameniev, A. & Buss, D. Critical failures of turnouts: expert approach. *Procedia Computer Science*. 2019. Vol. 149. P. 422-429.
4. Леоненков, А.В. *Нечеткое моделирование в среде MATLAB и fuzzyTECH*. Санкт-Петербург: БХВ-Петербург. 2005. 736 p. [In Russian: Leonenkov, A.V. *Fuzzy modelling in MATLAB and fuzzyTECH*. Saint-Petersburg: BHV- Petersburg].
5. Dorokhov, O. & Dorokhova, L. Fuzzy model in fuzzyTECH environment for the evaluation of transportation's quality for cargo enterprises in Ukraine. *Transport and Telecommunication*. 2011. Vol. 12. No. 1. P. 25-33.
6. Dorokhov, O. & Chernov, V. The desirability and feasibility of using fuzzy modeling for risk assessment in information systems. *Securitateea informațională. The VII Conf. Intern. Chichineu*. 2010. P. 18-22.
7. Lukasik, Z. & Nowakowski, W. & Ciszewski, T. & Freimane, J. A fault diagnostic methodology for railway automatics systems. *Procedia Computer Science*. 2019. Vol. 149. P. 159-166.
8. Ribickis, L. & Gorobecs, M. & Ļevčēnkovs, A. Neuro-Immune Algorithm for Embedded Real-Time Control System in Transport Safety Tasks. *Frontiers in Artificial Intelligence and Applications*. Las Palmas de Gran Canaria. 2018. P. 251-265.
9. Klir, G.J. & Yuan, B. *Fuzzy Sets and Fuzzy Logic: Theory and Applications*. New Jersey: Prentice Hall. 1995. 592 p.
10. Горелик, А.В. (ред.). *Системы железнодорожной автоматизации, телемеханики и связи*. Москва: Учебно-методический центр по образованию на железнодорожном транспорте. 2012. 205 p. [In Russian: Gorelik, A.V. (ed.). *Systems of railway automation, telemechanics and communication*. Moscow: Training centre for education in railway transport].
11. Munakata, T. *Fundamentals of the New Artificial Intelligence*. London: Springer. 2008. 256 p.
12. Ross, T.J. *Fuzzy logic with engineering applications*. Third Edition. Chichester: John Wiley & Sons. 2010. 585 p.
13. *Latvian Railway - Key Performance Indicators*. Available at: <https://www.ldz.lv/sites/default/files/LDZ-raditaji-2019-LV-web.pdf>.
14. Сапожников, В.В. & Сапожников, В.В. & Шамапов, В.И. *Надежность систем железнодорожной автоматизации, телемеханики и связи*. Москва: Маршрут. 2003. 263 p. [In Russian: Sapozhnikov, V.V. & Sapozhnikov, V.I. & Shamanov, V.I. *Reliability of railway automation, telemechanics and communication systems*. Moscow: Marshrut].
15. Russell, S. & Norvig, P. *Artificial intelligence: a modern approach*. New Jersey: Prentice Hall. 2009. 932 p.