ISBN-978-989-9121-01-0
LISBON 18th International Conference on "Innovations in Science, Engineering & Technology" (LCISET-22)
Lisbon (Portugal) April 13-15, 2022

Analysis of Different Regulation Methods with Aim to Determine Most Efficient One for Point Electric Heating

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***Abstract*:** *Current article reviews and analyses different optimal regulation seeking methods with focus on choosing the most appropriate for railway point electric heating control system. Problems of applicability of different regulation methods for point electric heating control systems are described. Different regulation methods, their properties are described and researched. The possibilities of use of each analysed regulation method for point electric heating control is discussed. Next, after choosing the most appropriate regulation method, a simulation is performed in simulation software in order to assess its effectiveness. As a result of simulation, graph of input and output voltage is created that shows effectiveness of chosen regulation method. Future research and modelling of advanced systems of point electric heating control with possible inclusion of fuzzy logic and neural network are discussed in conclusion section.*

Keywords: *railway, point electric heating, intelligent regulation scheme*

1. Introduction

Railways is an infrastructure that never stops and must be able to operate in different climatic conditions – heat, cold, rain, snow, etc [3], [5], [10]. The challenge in Latvian climatic conditions is weather in winter, and the fact that weather constantly changes during winter. It can be snowy and cold during first part of the winter but most of the time it is snowy with light cold temperature and then positive temperature can set in. After some days it is again little cold and snowstorm. Such changing conditions put additional requirements on point cleaning systems used in railways in Latvia.

In Latvia railway stations are usually equipped with point pneumatic cleaning systems or point electric heating (PEH) systems [6], [8]. Focus of the article will be on one of the most effective method of point cleaning – point heating with electric heating elements. In such weather conditions as described above, point pneumatic cleaning systems often cannot clean the wet and heavy snow from the area between point's blade and stock rail, but PEH is able to melt the snow and ice and can perform in different temperature ranges and also from light snow to wet and heavy snow.

The downside of the PEH is quite high consumption of electrical energy. As stated in [12] costs of electrical energy consumed by PEH in Latvian Railway can exceed 2 million Euro.

2. Comparison of different regulation methods

2.1. Direct regulation with no feedback

In old railway stations in Latvia where PEH is installed, it is operated by simple switch on/off method (see Fig.1) [6]. Power is turned on when railway station operator has switched the PEH on using special control panel [5]. Once switched on, PEH is working with full power and there is no possibility of regulation nor in automatic, nor in manual mode. The object is a heating element - a heating element that is attached to the point frame rail, which can be replaced in a reduced way in the diagrams and calculations with active resistance.

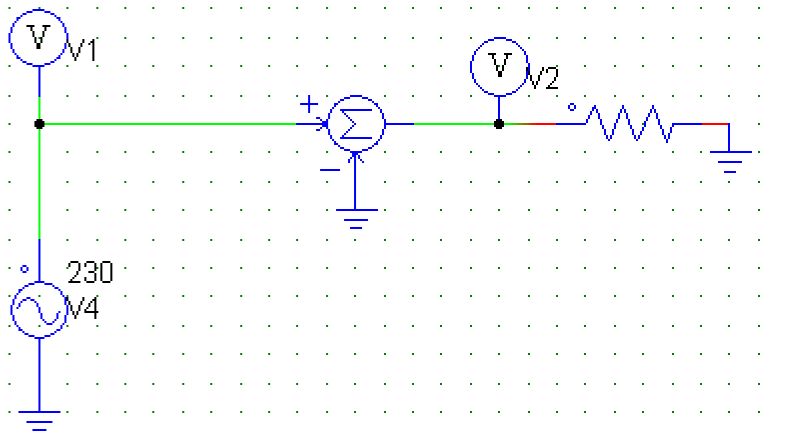

Fig. 1: Electric scheme of direct regulation method with no feedback

Above method represents simple direct regulation method when voltage is fed to the heating element. PEH is switched on manually when ambient temperature is below 0 °C and there is precipitation in the form of snow. As there is no feedback loop, it is impossible to automatically regulate the voltage thus the heating intensity based on weather conditions. It is necessary for operator to manually check and assess weather conditions and switch off the PEH when weather conditions have improved.

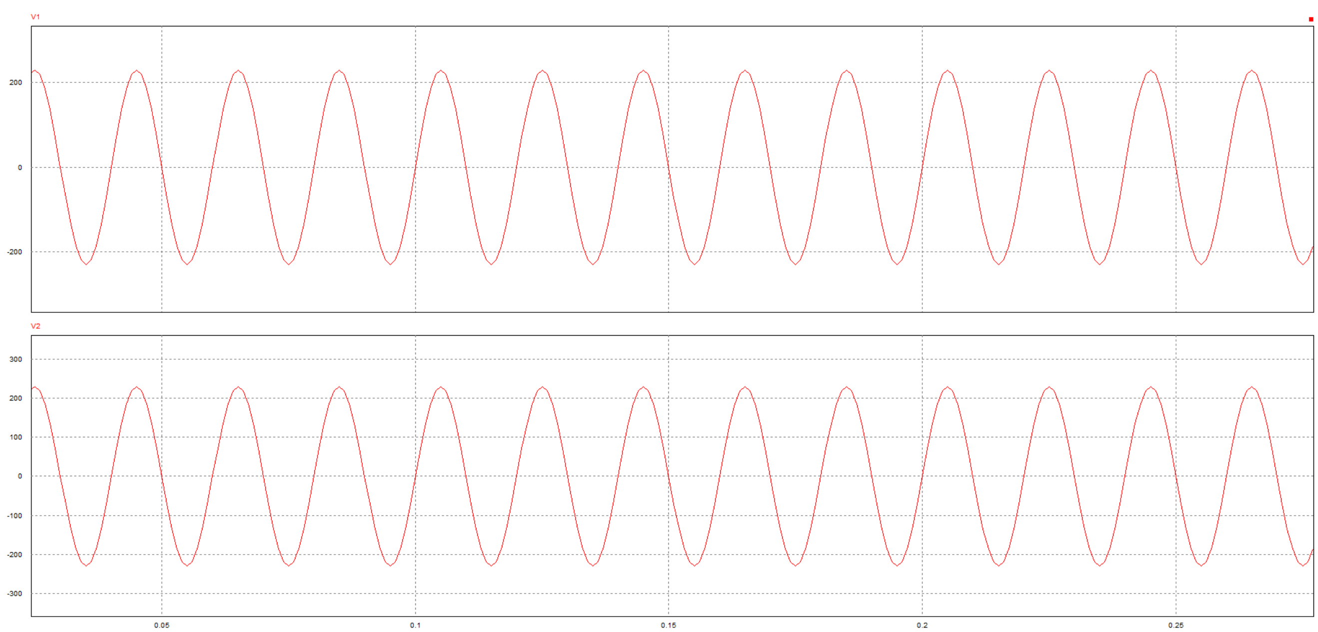

Fig. 2: Voltage diagram of direct regulation method with no feedback

https://doi.org/10.17758/HEAIG9.H0422603

Resulting voltage diagram of direct regulation method with no feedback is presented above. It is obvious that if voltage is supplied to resistance (heating element) and with no feedback link, then there is no possibility of regulation of the voltage or current according to Fig.1. This is the simplest way of heating points, but it is also obsolete and absolutely unacceptable in terms of saving valuable resources and environmental pollution [7].

2.2. Regulation with negative feedback

Next option of supplying voltage to the point heating element is using regulation scheme with negative feedback. In this case it is understood that the control system with feedback forms a closed information transmission circuit, which enables continuous control of the processes taking place in the control object and the formation of appropriate regulatory effects [1], [3], [9]. Therefore, feedback systems are called closed systems, in which the transmission of information from the output of the system to its input takes place via the main feedback [2], [4].

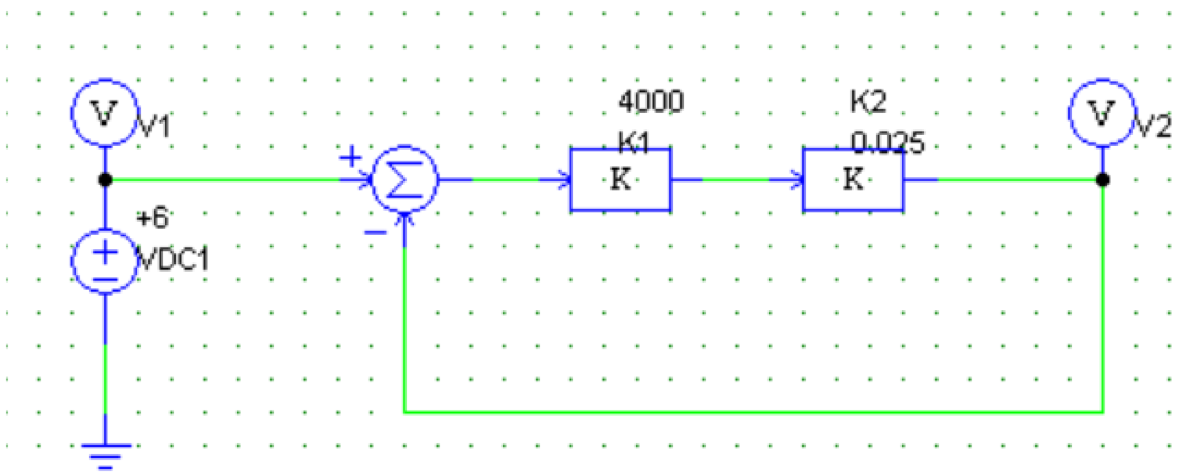

Fig. 3: Scheme of the model of the negative feedback control circuit without influence of external factor

Power is turned on manually by Operator or PEH can automatically be turned on and off based on algorithm, e.g. when temperature of the rail is lower than threshold. For example, when rail temperature is around -5 °C, then heating turns on for a particular time period in order to heat the rail up to set temperature. This is controlled by temperature sensor and then signal is sent to the adder unit using feedback (Fig. 2.). Such approach allows to switch on voltage supply when necessary and to switch it off when not needed – in rail temperature range from around -10 °C until +6 °C. In this temperature range it is possible for PEH to work in switch on/off mode because ΔΘ (difference between set temperature and measured temperature) is considerably less than if the rail temperature was -40 °C.

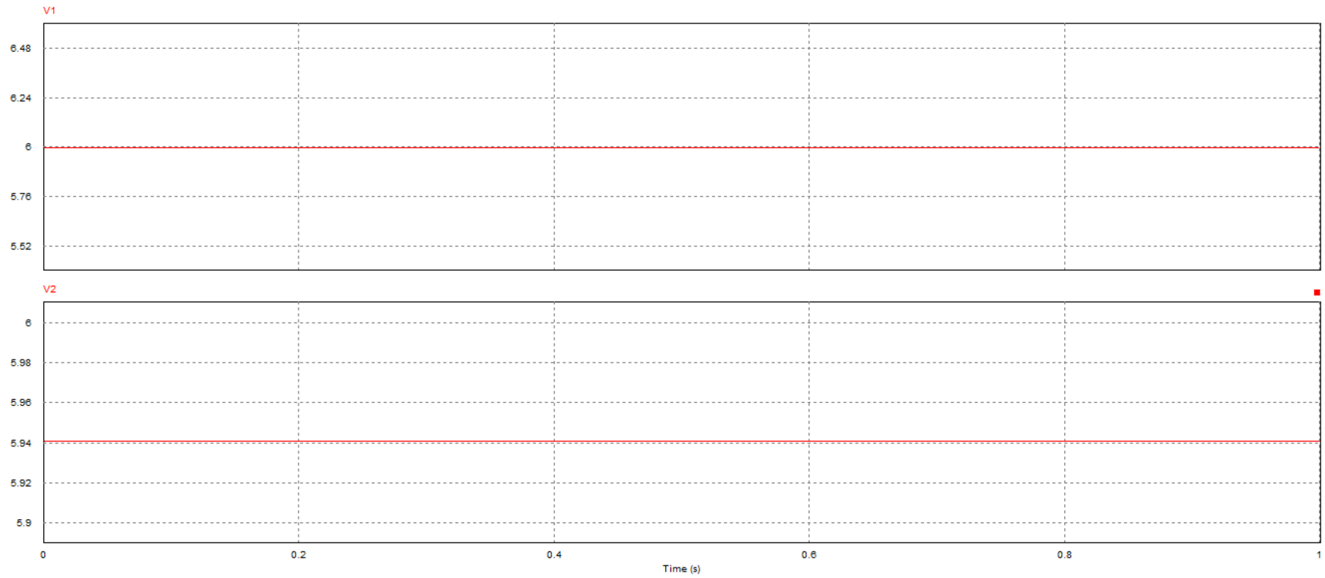

Fig. 4: Voltage diagram of the feedback regulation method without influence of external factor

Scheme which is presented in Fig. 3. does not include impact of external factors like, for example, negative ambient temperature. In real conditions ambient temperature is strong factor that influences heating process and therefore this method has significant drawback in real operating conditions. As shown in Fig. 5, as the ambient temperature factor is added in the scheme, the output value V2 is significantly lower than compared to Fig. 4.

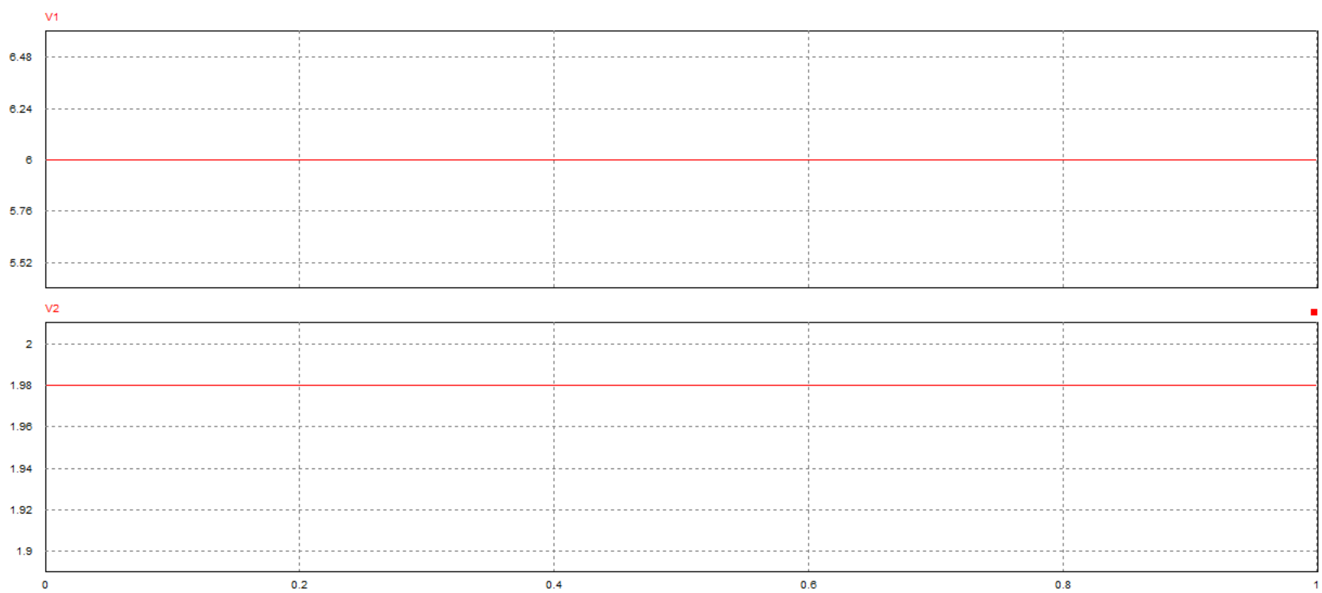

Fig. 5: Voltage diagram of the feedback regulation method with influence of external factor

Resulting voltage diagram of negative feedback regulation method with influence of external factor is presented above. In this diagram it can be seen that if voltage is supplied to heating element considering external factor and with feedback link, then measured signal is very far from the set one. Calculated fault reaches around 67 percent:

$$\Delta\Theta = \frac{\Theta_{set} - \Theta_{meas}}{\Theta_{set}} * 100\% = \frac{6-1.98}{6} * 100 = 67\% \quad (1)$$

2.3. Regulation with negative feedback and control of influence of interference

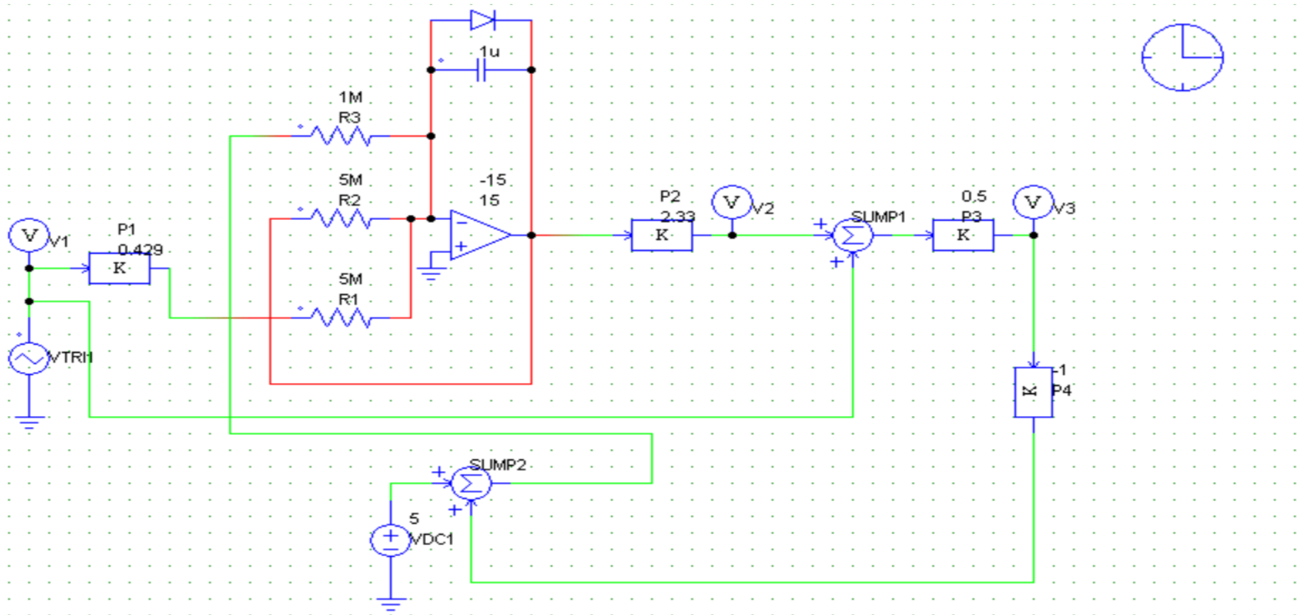

Fig. 6: Operating scheme of the feedback and controlled interference regulation method

By extending the previous circuits with additional elements, a circuit with the effect of interference can be created, which sends a signal to the second adder unit, thus amplifying the value of the input signal.

The signal source is a triangular signal source which is connected to the electric heating unit via the amplification unit and further passes through the adder S1 to the adder. The heating unit consists of three active resistors closed in parallel with nominal values of 1 MΩ, 5 MΩ and 5 MΩ. After the adder SUMP1, where the heated rail is already schematically located, a gain factor of 0.5 is placed, which divides the expression by 2 according to equation 2.33. This is followed by the next gain factor (-1), which performs the feedback function. The set temperature (+5) is supplied from source VDC1, which is then switched on in the electric heating unit.

Diagram above consists of sections, the main ones being the summing stages ∑ (SUMP1 and SUMP2), the control object P3 and feedback is the link between P3 and SUMP2 and SUMP2 and R3. Each stage has its own algebraic transfer function ($W_R(s)$, $W_{ob}(s)$ and $W_{fdb}(s)$), respectively, which makes it possible to describe the whole system with a common algebraic transfer function.

In the technical example shown, the adder unit in which the input signal Θ_0 and the feedback output signal $-X_{out}(s) * W_{fdb}(s)$ are summed. The controller is an amplifier P with a reduced error $\sigma_{xr}(s)$ at its input: in this example the temperature sensor signal enters the control system and the difference between the set reference temperature and the measured one is the basis for the control system to act on the control object. Like in the previous method, the object is a heating element that is attached to the switch frame rail, which can be replaced in a reduced way in the diagrams and calculations with active resistance.

The simplest way to create an electric heating control system for railway points is a closed control system with a rail temperature sensor S_{rail}, the output signal of which corresponds to the rail temperature Θ_{rail}. This signal is reduced to a value $-\Theta_{rail}$ through the measuring element and compared with the set temperature signal Θ_0, and the difference signal $\Theta_0 - \Theta_{rail}$ acts on the electrical power converter connected to the heating elements, the output power of which is:

$$P = k_c * (\Theta_0 - \Theta_{sl}) \geq 0 \tag{2}$$

This power determines the temperature generated by the heating elements $\Theta_1 = W_s(S) * k_c * (\Theta_0 - \Theta_{sl})$, where $W_s(S)$ is the transmission function of the heating element system (output to input), S is the change operator. In general, this transfer function can be considered according to the first-order aperiodic phase function with the gain coefficient k_c and the time constant T_s:

$$W_s(S) = \frac{k_s}{1+T_s*S} \quad (3)$$

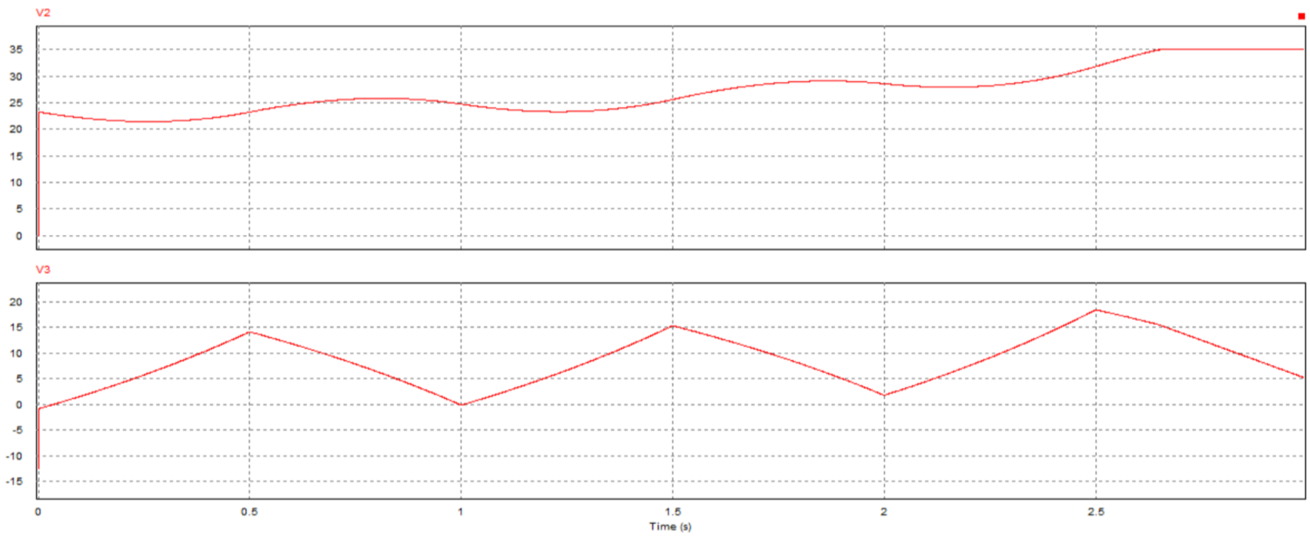

Fig. 7: Diagram of control circuit with feedback and interference effects

Analysing the diagram of the signals (Fig. 7), it can be concluded that the temperature of the heating element rises relatively slowly and reaches the maximum and stabilizing mode with a temperature level of +35 degrees in 2.5 seconds. In turn, the rail temperature increases according to the triangular shape, because the input signal is also triangular. After a simulation of 2.5 seconds, the rail temperature reaches a level of approximately +18 degrees and does not fall below 0 at the lowest point. Calculated fault according to (1) reaches around 21-25%. At first such fault seems high, but it must be considered that with more precise source of interference which will simulate ambient temperature and technical solution which will limit heating when ambient temperature reaches +5 °C lower fault level can be achieved.

3. Conclusion

Point electric heating will continue to be introduced in future railway stations in Latvia thanks to its simplicity and efficiency in terms of cleaning points from snow and ice. Unfortunately, currently PEH regulation methods require upgrade in order to reduce electrical energy consumption. This article presents comparison of different regulation methods for improving regulation of classic point electric heating system. After comparison of three different regulation methods it is obvious that direct regulation with no feedback is the least effective and distinctive feature of this approach is that nor the Operator, nor the system can monitor status of heating and measured temperature.

In second method smooth control of heating also cannot be achieved in real operating conditions due to simplicity of the scheme and strong effect of interference when that is added. Such regulation method allows to reduce power consumption only by little amount compared to first method. The poor effectiveness of the second method is confirmed by the experimental results and calculated fault, which show fault at 67%.

Third method of regulation with negative feedback and control of influence of interference proves to be the most efficient amongst all three methods that were reviewed in this article. Experimental results show that when influence of interference is controlled by scheme, then fault level can be achieved at around 21-25% which in winter operating conditions are acceptable because point is kept free of snow and ice. For a more precise regulation, more precise source of interference which will simulate ambient temperature is needed and technical solution which will limit heating when ambient temperature reaches +5 °C shall be applied in the scheme. Another method is to calculate influence of different interfering factors like ambient temperature, wind speed, intensity of snowfall and simulate their influence in the scheme. This is topic for future research which authors shall follow and explore. As the problem of energy consumption and CO_2 emissions are of the utmost importance nowadays, this article and area of research shows example of achieving goals of energy savings and discussed solution can be implemented in different operating PEH control systems [11].

Developed regulation method is usable as a basis for simulating interference inputs using fuzzy logic in future researches [14]. In different regions of Latvia climatic conditions are different and impact cleanliness of railway points differently in winter. Therefore, it will be useful to simulate interference inputs using fuzzy logic and create different models for different geographic regions [12], [13]. Different climatic conditions would be valuable input for creating and training neural network in order to improve PEH control system.

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