Graphic-Analytical Method for Detecting the Relay Protection False Tripping Zones

Pavel Pinchukov[a] and Svetlana Makasheva[b]
Power Engineering Institute, Far East State Transport University, Seryshev Street, Khabarovsk, Russia

Keywords: Traction Power Supply System, Catenary Feeder, Relay Protection, R-X Diagram.

Abstract: The relay protection devices of a traction power supply system should work correctly and steadily to provide uninterrupted traffic. High intensity of heavy haul traffic significantly increases a load on all elements of the traction power supply system. Heavy haul traffic causes several problems in catenary feeder's relay protection operation. Increased currents values while the heavy haul traffic can reach values of short-circuit currents. In this case, the relay protection devices will tripping false and switch off a supply line without any damages. Unnecessary relay protection false tripping leads to a pause in heavy haul traffic and brings significant financial loses. Experimental long-term observation suggests that the current relay protection detuning technology is not well optimized and needs to be improved. Identification of operating conditions of the relay protection devices at the particular railway section was clarified by current research. Proposed the graphic-analytical method allows simplifying the relay protection detuning from the traction load characteristics. That makes it possible to reduce the number of cases of the relay protection false operation. The method based on the comparison between the real load areas and the installed relay protection characteristics. Examples of the successful correction of protection parameters in order to tune out from the load zone are shown in details.

1 INTRODUCTION

It is difficult to overestimate that electricity is critically important for a modern person's life. The electricity is an irreplaceable resource for human's needs for almost all types of activity. It is worth to noting that a presence of electricity in modern production processes is natural and familiar to all consumers. In this regard it is of interest that, if the consumers assess any prospects for development of a production processes, they usually take as granted the electricity existence and do not think about such possibility problems with a power supply like a power interruption or a poor power quality. At the same time, power outages are perceived by consumers as something out of the ordinary (Makasheva et al., 2020).

Nevertheless, reliability and uninterrupted power supply are two major conditions for economy and efficient of production processes (Esen and Bayrak, 2017; Makasheva and Pinchukov, 2016). When an emergency situation appears in a power supply system, it is necessary to quickly eliminate an accident and then restore the power supply.

Currently, a responsibility for timely disconnection of a damaged part of an electrical system is assigned to the relay protection (RP) devices. In turn, the automatic reclosing devices are in charge of the inclusion the undamaged part of power supply system (Alstom, 2011; Ciufo and Cooperberg, 2021; Hill, 1994; IEEE, 2016; Ma and Wang, 2018). RP should respond only to a damage that occurs in the protected area. To do this, relay protection devices are assigned a strictly defined algorithm and trigger conditions.

Also, it is important the RP devices to satisfy two major requirements (Alstom, 2011; IEEE, 2016; Saha et al., 2010):

- Should trigger only while the emergency modes, and disconnect only an area with a damage;
- Should not trigger in the load modes.

If the RP triggers in the load mode, the undamaged area of the power supply system

[a] https://orcid.org/0000-0001-9461-6620
[b] https://orcid.org/0000-0002-0329-3836

Pinchukov, P. and Makasheva, S.
Graphic-Analytical Method for Detecting the Relay Protection False Tripping Zones.
DOI: 10.5220/0011947800003612
In *Proceedings of the 3rd International Symposium on Automation, Information and Computing (ISAIC 2022)*, pages 397-404
ISBN: 978-989-758-622-4; ISSN: 2975-9463

disconnects and a forced consumers interruption occurs up to the moment of automatic reclosing operation. In some cases the power supply interruption leads to power outages and a violation of the operating conditions of electrical consumers. Such a RP functioning is regarded as a false operation and named as a false tripping (Alstom, 2011; IEEE, 2016; Saha et al., 2010).

Responsible consumers suffer from power outages because even a short interruption in the power supply can lead to the technological process destroying, can associate with a risk tohuman life and health, and can bring significant material losses (Alstom, 2011; Mason, 1956; Saha et al., 2010). The electric rolling stock of the AC electrified railways is a very good example of the responsible consumer which needs an uninterrupted power supply for a non-stop transportation process. Taking into account technical needs and importance of the railway transport, the RP false tripping is unacceptable.

Concern for the PR false tripping was prompted by increasing of incorrect RP functioning cases while heavy hauling especially for Far Eastern Railways of Russia (Pinchukov and Makasheva, 2019). It is tempting to consider RP functioning in view of new data from railway observation practice based on automated monitoring systems (Andrusca et al., 2021; Makasheva, 2016; Mariscotti, 2022).

Many researchers studied problems of determining parameters of the RP devices as follows:

- A wealth of information about the RP basic theory and main principles of operating are available now. For example, main calculations of tripping zones parameters and relay settings are given in (Ciufo and Cooperberg, 2021; Hill, 1994; IEEE, 2016);
- New adaptive RP parameters for nowadays are given in (Moyo et al., 2019; Sezi and Menter, 1999);
- application examples of RP operation algorithms for AC railway lines are shown in (Han et al., 2012; Makasheva et al., 2020; Pinchukov and Makasheva, 2019);
- Protection aspects are described in (Andrusca et al., 2021; Moyo et al., 2019) for the traction power supply system operation under present conditions for a normal mode and a short circuit mode;
- There is some intresting, but scanty information, that the modern feeder distance protection and overcurrent protection can not successfully protect from short circuits, that is discussed in (Andrusca et al., 2021; Han et al., 2012).

There is no doubt that the RP devices characteristics determinate by standard methods of calculation and tuning. The methods do not take into account the increased currents while the heavy haul traffic, therefore, the RP devices with parameters selected in such a calculated way, do not work correctly. Thus, it was found from the mentioned literary analysis, that most previously recommendations are given in general terms and cannot take into account the influence of the local characteristics of the real railway lines, especially due heavy haul traffic. As a result, there is no method for identification the reasons of the RP false tripping. It would be interesting to consider ways for identifying the RP false tripping zones for reducing the number of the RP incorrect operation.

The present study is aimed at the complex analis of the RP false tripping problem and finding possible ways to detuning the parameters of the RP devises from the load mode especially due the heavy hauling.

To begin with, the causes leading to the RP false tripping cases need to be investigated. Then, it can be possible to exclude incorrect functioning leading to disruption of the transportation process and power supply interruptions. There is a definite possibility that creation a method can be used in RP parameters detuning.

The results of monitoring system's database analisis offer a unique opportunity to apply this data to the RP detuning process. Data processing from the monitoring systems set at real railway sections will allow taking into account the regional local specificity. So, now it is possible to take into account the regional component while RP detuning and to propose a quite simple and understandable detuning method

Finally, the method to identify zones of RP false operation and to eliminate false tripping by adjusting the RP parameters can be proposed. Also,the findings can be useful for the RP developers who interested in creating of new algorithms for RP operating under overload conditions.

2 METHODOLOGY

The motivation of this research is to define a framework and conditions for correct detuning the AC catenary feeder's RP devices from the load mode due the heavy hauling. This encourages to reduce the number of cases of the AC catenary feeder's RP devices due to a better choice of their parameters.

The core of the research is the development of method for graphic analysis of RP device parameters and load parameters of a real railway section. The facts of the existing theory were used as a basis for testing the hypothesis that proposed technique for analysis is suitable for the complex engineering task.

The detecting of the RP false tripping zones was carry out by means of graphical analysis for the AC railways power supply system. To begin with, one of the inter-substation zones between the AC traction substations was choosen. Then, the operation of RP devices at 25 kV feeders catenary network at freight direction was examined.

Statistic data from the monitoring systems installed on the particular railway section have been accumulated during the 2021-2022 years. During this period, the intensity of heavy haul traffic increased by by 1.25 times. Also, lots of cases when the well-known algorithms for RP devices cease to work were detected (Pinchukov and Makasheva, 2019).

The proposed methodology for decreasing the amount of the RP false tripping at the AC catenary is based on a five-step approach as follows:

- Accumulation measured data from monitoring system and their representing in the R-X diagram;
- Determination load characteristics of catenary feeders for a particular inter-substation zone while increasing traffic volumes and train weights in the R-X diagram;
- Representation the set RP characteristics for particular feeder in the R-X diagram including simulation results;
- Identification areas of overlapping of retractable RP parameters in the load zones characteristics;
- Detuning RP parameters from the load zones characteristics.

The first step of the process refers to the monitoring system data acquisition and analysis. Based on the analysis of the feeder's current and voltage data with heavy hauling conditions it can be possible to perform an initial step of analysis to extract meaningful insights and transform into the graphical view. Next, each step of the proposed technique was expounded in the sections that follow.

2.1 Research Object Structure

A particular section of the AC railway with installed distance relay protection devices, as depicted in Figure 1, was taken for further consideration as the research object. The section is located on the eastern freight direction of the Russian AC 25 kV electrified railways.

Numbers from 1 to 8 in Figure 1 correspond to the serial numbers of the protective set of relay protection devices for the AC catenary feeders.

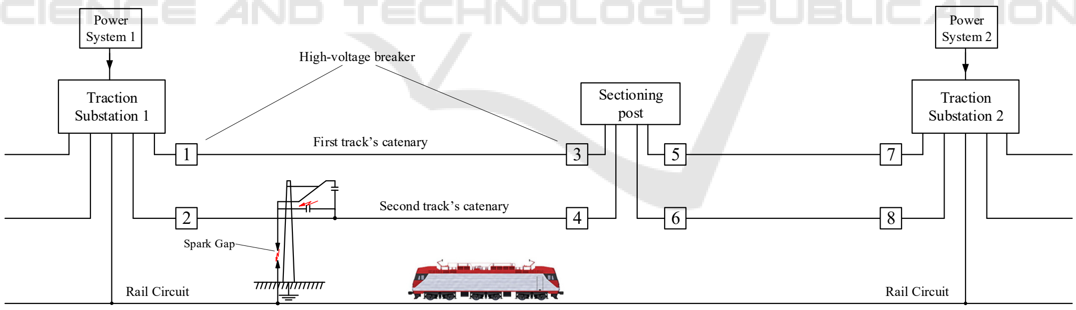


Figure 1: AC 25 kV Electrified Railway Section.

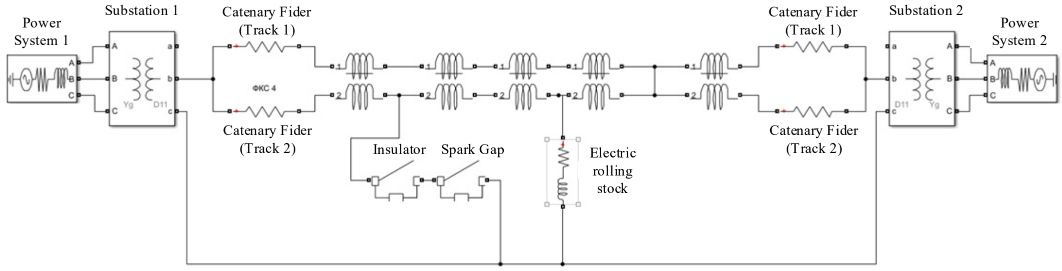


Figure 2: Simulation Model Scheme

2.2 Simulation Model

The simulation model of power supply system for AC 25 kV railway section ander consideration was created by MATLAB-based graphical programming environment Simulink 9.8 as shown in Figure 2.

As depicted in Figure 1 and 2 the section contains AC traction network between two traction substations. The model includes the equivalents of two energy systems of limited capacity, two traction substations, catenaries the first and second tracks, and a rail circuit. The catenary pole is integrated into the model for a short circuit simulation. It is possible to simulate the breakdown of the cantilever insulator. Also the model has the possibility to change the operating mode of the spark gap. Simulation of electric rolling stock is also provided. The model allows to change both the location and power of the electric rolling stock.

The model provides changing the parameters of power systems and traction transformers at substations. The results of the short-circuit mode calculation are given for the power of 40 MVA traction transformers at both traction substations. This is the most common transformation power for traction substations of AC electrified railways. The output power of the power systems was setting in the range from 1500 MVA to 2000 MVA that is closest to the output power at a voltage of 110-220 kV nominal level.

2.3 Data Acquisition and Analysis

The considered section has a automated system for monitoring the parameters of normal and emergency modes. All feeder's measured data like voltage, current and phase angle between them, are written to the database in real-time mode (Makasheva, 2016).

The results full-scale measured and calculated characteristics of the operating modes were put on the R-X complex diagram. Thus, a data base from field measurements in operating conditions for a load mode was collected.

After that, the input resistances measured by RP in short circuits mode were calculated. Then, data were put on the R-X diagram as dots. Thus, the areas at the R-X diagram that correspond to every single measurement were completed. Next, the angular characteristics of the distance protection zones while RP tripping on the R-X diagram were put. After that, the parameters of possible short circuits were calculated based on simulation model and also put on the same R-X diagram. Each time, step by step, new data was gradually applied to the R-X diagram, forming the so-called surface layers.

Finally, obtained three-layers R-X diagram makes it possible to study the conditions of the RP functioning and detect the RP false tripping causes.

3 RESULTS

Currently, the RP devices used at the considered section of the AC railway contain four zones of distance protection (DP) (Andrusca et al., 2021; Moyo et al., 2019; Pinchukov and Makasheva, 2019). Three of them react to metal short circuits at a catenary feeder and have the pie-shape. The forth DP zone has a quadrilateral shape. The forth zone reacts to short circuits that occurs through a large contact resistance. That can arise, for example, while a short circuit occurs through a catenary pole body (Alstom, 2011; Saha et al., 2010). First and second zones are used as main protections for the catenary feeder and the third one reserves the adjacent protection in case of their failure. An example of the step-by-step constructing of R-X diagram with comprehensive characteristic as a graph with several layers are described below in details.

3.1 Two-Layer Diagram

Load parameters of the 25 kV catenary feeder were measured experimentally in real operation conditions for AC railway section at the most freight track. The RP characteristics was calculated and analysed based on the measured data. Based on the measured characteristics of current, voltage and the phase angle between them, the characteristics of the feeder's relay protection were calculated in a well-known way by means of the classical method for calculating DP characteristics as shown in (Alstom, 2011; IEEE. 2016; Saha et al., 2010).

RP input resistances in load mode are shown for one of feeders in Figure 3. The field of red dots in Figure 3 is consists of the values R-X characteristics of the DP in the operating load mode. They are obtained on the basis of the measured parameters. The field forms the first layer of the R-X diagram, in other words, the layer of the measured RP characteristics.

The second layer is formed by the angular characteristics of the DP from the first to the fourth zones, named in Figure 3 as 'DP 1st zone', 'DP 2nd zone', etc. The protection zones were recommended by manufacturers of RP terminals. Graphically, these areas are shown as sectors bounded by colourful lines in Figure 3.

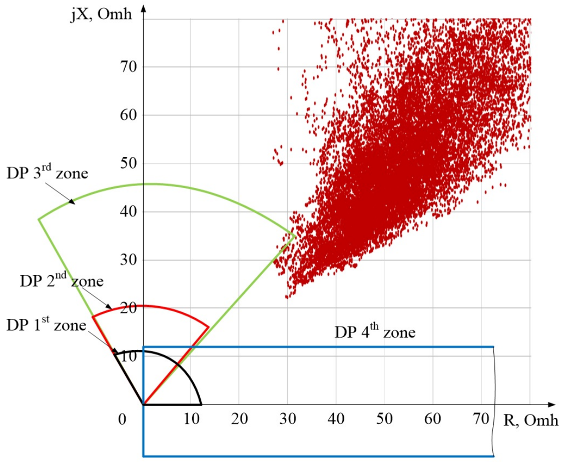


Figure 3: R-X Diagram for AC Catenary Feeder.

Thus, there are two layers were applied in Figure 3 as below:

- The first layer is the measured characteristics (as the area of red dots);
- The second layer is the set distance protection parameters adopted in operation (as the colored pie sectors named DP).

In order to find out whether the DP was correctly tuned from the load mode, it was needed to plot both the load area and the short circuit area on the same R-X diagram. As shown in Figure 4, there are two zones in the R-X diagram.

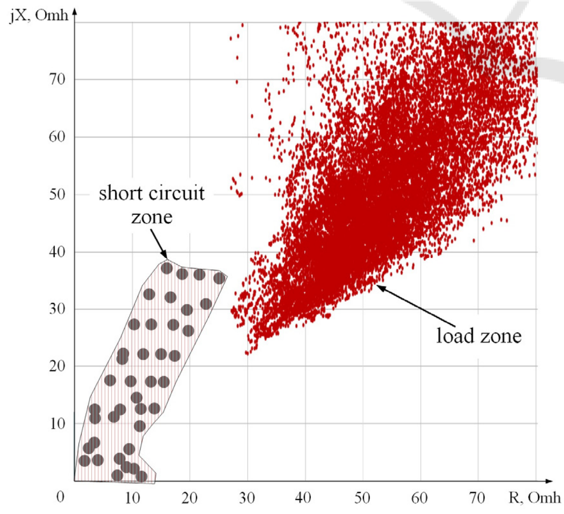


Figure 4: Calculated Short Circuit and Measured Load Mode Parameters.

The red dots area is named as the 'load zone'. Each red dot was measured by DP in the load mode and then plotted to R-X diagram as the DP input resistance value. The grey dots area is named as the 'short circuit zone'. Each grey dot was calculated for DP in the short circuits mode by means of simulation modeling and the classical well-known calculation method for the DP parameters (Alstom, 2011; IEEE. 2016; Saha et al., 2010).

Summary, both areas form the two-layer superimposition at the same R-X diagram. As shown in Figure 3 and 4, the short circuit zones and the load zone do not overlap. Thus, the distance protection should work correctly. Meanwhile, several cases of the DP false operation have been recorded at the feeder during the observation period. Operating experience shows that the DP was tripped false not once. Thereby, such analysis of Figures 3 and 4 does not give a clear answer to the question why the RP false operation still occurs. Further, to find out the answer, it will be also necessary to analyze the operation of automatic reclosing devices.

3.2 Number and Causes of Automatic Reclosing Trips

The statistics facts of automatic reclosing (AR) in cases of RP devices tripping for the feeder under consideration for last 4 years were collected and analyzed. The results are shown as pie chart-diagrams in Figure 5.

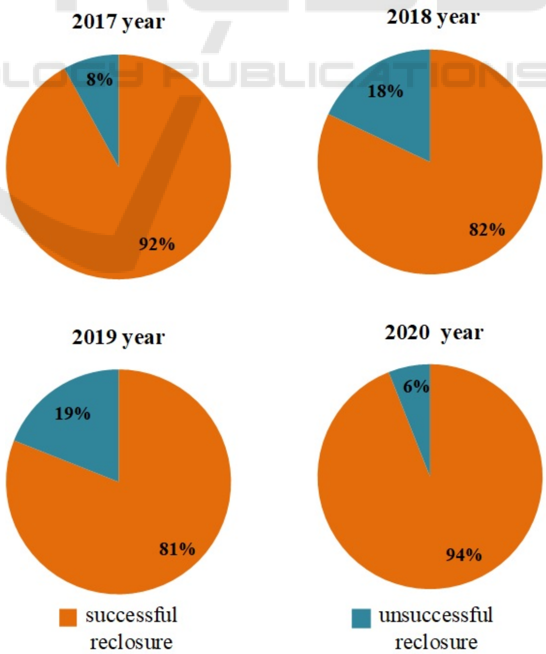


Figure 5: Number of Automatic Reclosing Trips.

The pie chart diagrams in Figure 5 allow interpreting the actions of the AR and the RP devices in relation to load and emergency modes. In order to find out the causes of false tripping, it is necessary to consider a number of characteristics that can be probably added as the third layer to the previously constructed two-layer R-X diagram.

3.3 Three-Layer Diagram

The third layer was formed from the angular characteristics of the DP zones, shown in Figure 6 as colored lines.

The green line in Figure 6 is indicated the angular characteristic of the DP 3th zone, which is currently being operated on the feeder under consideration. The red line is indicated the characteristic that is recommended by manufacturers of RP terminals to increase the efficiency and stability of their setting.

Figure 6 shows two angular characteristics of the DP third zone. The green sector in Figure 6 is a DP characteristic which is used on the catenary feeder.

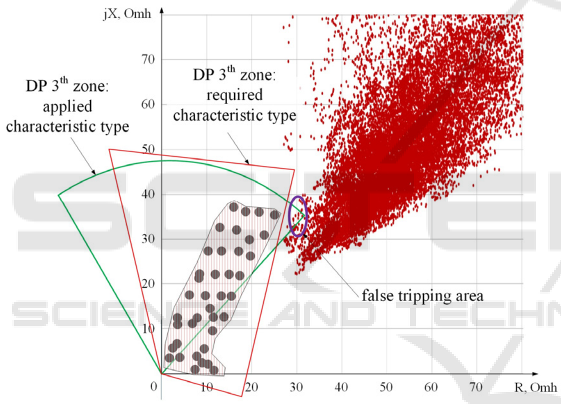


Figure 6: Three-Layer Diagram.

This type of distance protection is used on the entire Russian AC railway network. As shown in Figure 6 there is practically no margin between the zone of red dots and the zone limited by the green sector. It means that there is no DP detuning from the load zone. Thus, the common third DP zone's characteristic does not provide DP detuning from the load zone.

So, when the third layer was applied to the R-X diagram, it can be possible to finally identify the zone of RP false tripping. It is shown in Figure 6 as the purple oval. Also, the sector circled in red in Figure 6 is the DP characteristic which could provide detuning from the load area.

Such a quadrangular characteristic is one of the types of distance protection, which is used in power systems. There are no devices in Russia with such characteristics for catenary feeders. Therefore, their development for areas with high load currents is extremely important especially due heavy hauling.

4 DISCUSSION

Using the full-scale measurements and simulation results as input data, it is possible to graphically evaluate the RP characteristics for their better detuning from the load modes.

The findings gave reason to suggest that the two-layer R-X diagram does not able to qualitatively figure out the relay protection parameters for detuning from the load area. Therefore, the assumption of the third layer applying's advisability gave a positive effect.

As Figures 1, 2 and 3 show, the main part of the resistance values is concentrated in the first quarter of the Cartesian coordinate system. They form areas with the angles from 30 to 50 degrees. Therefore, the first quadrant of the complex resistance plane was limited for better clarity and understanding.

Notoriously, that automatic reclosure is used to recover the original status of the network. Obtained data point to facts, that after the successful automatic reclosure, the voltage is reapplied to the contact network both in the event of unstable short circuits and in the event of a false tripping of the relay protection. In most cases, the main reason for false RP operation is the RP response to a significant current load in normal mode.

As follows from Figure 5, the percentage of cases of successful automatic reclosure for the investigated feeder was over 80 percent during all four years. The specified share of the successful automatic reclosure is not typical for similar sections of AC railways that have lower load intensity as described in (Han et al, 2012; Hill,1994.).

A significant percentage of successful automatic reclosure indicates that automatic reclosing does not occur in emergency mode, but in load mode. That proves the absence of RP detuning from the load mode. Accordingly, our findings clearly show the existing problem in the mechanisms of detuning the RP parameters from the load characteristics of inter-substation zones with heavy haul traffic at the 25 kV power supply system of the railway transport. Thus, the observation of lots of successful AR cases also constitutes the evidence that the reason of big percentage is the RP false tripping.

Next, it was proposed to use the graph-analytical method to analyse the reasons for the RP false tripping. After preparation and selection of measurement data, the two-layer R-X diagram was created, but it was found, that the two-layer diagram does not allows immediately identify the reason of the RP false tripping.

Thus, the problem was solved by simultaneously considering all characteristics on unified R-X diagram. Consequently, the shortcoming in the currently used DP characteristic at catenary feeders was identified. It was clearly proved that with the heavy traffic and a further loads increasing, it is almost impossible to ensure reliable DP detuning from the load area.

As a result, the proposed graphic-analytical method for detecting the relay protection false tripping zones makes it possible to evaluate the efficiency of the form of the DP angular characteristic. The described method's application can be recommended on heavy haul traffic AC railways areas of with AC/DC electric locomotives.

At the same time, the described method can be also used for the RP detuning for power supply lines of industrial or agricultural enterprises with similar problems. To continue and develop research in this direction it is advisable to use the considered mechanisms to reduce the amount of RP false tripping in the long term.

5 CONCLUSIONS

The results obtained in the present research demonstrate that visualization and graphical analytics can be applying for solving the specific engineering task. Current results proposed a framework for analyzing PR detuning and elimination of the RP false tripping.

The obtained results lead to the following conclusions:

- The electrical characteristics of catenary feeders from monitoring systems databases and revealed an increase in loads during heavy haul traffic were collected and analyzed
- From the automatic reclosing cases analysis it was confirmed that the automatic reclosing does not occur in emergency mode, but in load mode;
- Shortcomings of the applied DP type while the heavy haul traffic were highlighted and explained by visual means with a high probability;
- New method for visually determination zones of the load, the short circuit and the DP angular characteristics was proposed and described in details;
- It was found out that the existing DP devices are almost impossible to detuning from the load area in the conditions of the heavy traffic increasing, therefore, an urgent need has been identified for the development of new RP types for the catenary feeders as soon as it possible.

The practical benefit of the proposed method lies in its application to tasks of analyses the AC railway catenary feeder protection. The proposed method will further develop in the direction of improving the distance relay protection detuning from the load zones in relation to the existing and planned AC railways' sections.

ACKNOWLEDGEMENTS

This paper was made possible by Russian Railways JSC as grant No.4663593 dated December 27, 2021. The statements made herein are solely the responsibility of the authors.

REFERENCES

Alstom, 2011. *Network protection & automation guide: Protective relays, measurement & control*. Stafford, England, 2nd edition.

Andrusca, M., Adam, M., Dragomir, A., Lunca, E. 2021. Innovative integrated solution for monitoring and protection of power supply system from railway infrastructure. Sensors, No. 21(23):7858. https://doi.org/10.3390/s21237858

Ciufo, J., Cooperberg, A. 2021. *Power system protection: fundamentals and applications.* John Wiley & Sons, Ltd. https://doi.org/10.1002/9781119847397

Esen. Ö., Bayrak, M., 2017. Does more energy consumption support economic growth in net energy-importing countries? *Journal of Economics, Finance and Administrative Science.* Vol. 22 No. 42, pages 75-98. Emerald Publishing Limited.

Han, Z., Dong, Z., Gao, S., Bo, Z. 2012. Protection scheme for out-of-phase short-circuit fault of traction feeding network. *11th IET International Conference on Developments in Power Systems Protection (DPSP 2012)*, pages 1-4. https://doi.org/10.1049/cp.2012.0133https://doi.org/10.1108/JEFAS-01-2017-0015

Hill, R. 1994. Electric railway traction. Part 3. Traction power supplies. *Power Engineering Journal*. No.8(6): 275–286. https://doi.org/10.1049/pe:19940604

IEEE, 2016. *Guide for protective relay applications to transmission lines. (Revision of IEEE Std. C37.113-1999)*, pages 1-141.
https://doi.org/10.1109/IEEESTD.2016.7502047

Ma, J., Wang, Z. 2018. *Basic theories of power system relay protection. Hierarchical protection for smart grids.* John Wiley & Sons, Ltd. https://doi.org/10.1002/9781119304814.ch1

Makasheva, S. 2016. An automated monitoring system as an instrument of lean production of a traction power supply system. *Russ. Electr. Engin.* No.87, pages 107-109. https://doi.org/10.3103/S1068371216020139

Makasheva, S., Pinchukov, P., 2016. Cost reduction ability by electricity tariff selection for construction facilities located in non-price areas. *MATEC Web Conf.,* 86: 05025. https://doi.org/10.1051/matecconf/20168605025

Makasheva, S., Pinchukov, P., Kostin, A. 2020. Increasing the functional stability of distance relay protection for various types of catenary support grounding. In: *Popovic, Z., Manakov, A., Breskich, V. (eds) VIII International Scientific Siberian Transport Forum. TransSiberia 2019. Advances in Intelligent Systems and Computing*, Vol. 1115. Springer, Cham. https://doi.org/10.1007/978-3-030-37916-2_17

Makasheva, S., Pinchukov, P. Szoltysek, J. 2020. The power quality as a pretext for developing smart city concepts. In *2020 International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon),* pages 1-7, https://doi.org/10.1109/FarEastCon50210.2020.9271462

Mariscotti, A. 2022 Non-intrusive load monitoring applied to AC railways. *Energies*, No.15: 4141 https://doi.org/10.3390/en15114141

Mason, C. 1956. *The art and science of protective relaying.* Wiley, New York, 1st edition.

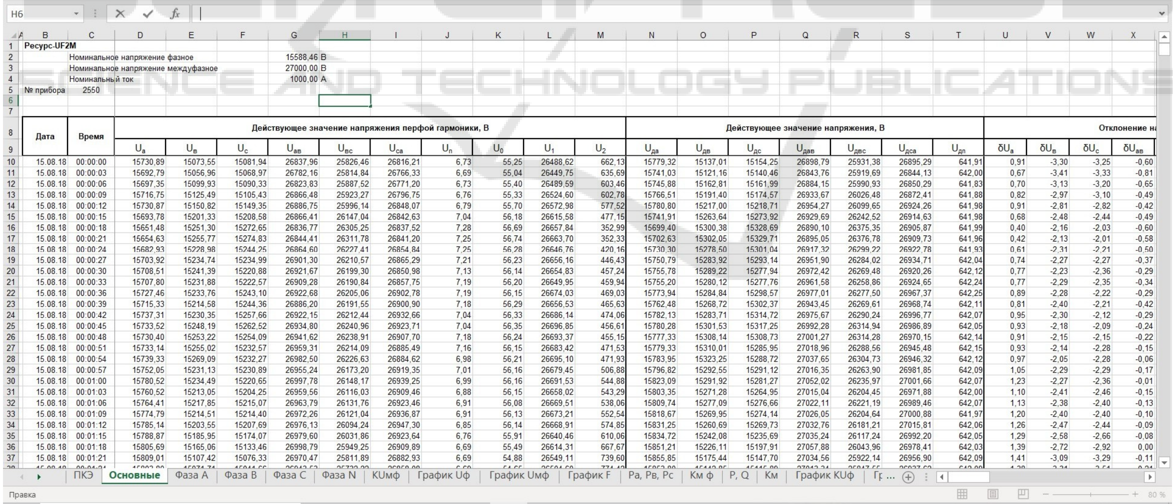
Moyo, N., Bansla, R., Naidoo, R., Sprong, W. 2019. Line impedance measurement to improve power systems protection of the Gautrain 25 kV autotransformer traction power supply system. *IEEE Access* No.7, pages 136962–136974. https://doi.org/10.1109/ACCESS.2019.2940894

Pinchukov, P., Makasheva, S. 2019. Research of AC traction network's relay protection operating under heavy haul traffic conditions. *IOP Conf. Ser.: Earth Environ. Sci.* No. 272: 022069 https://doi.org/10.1088/1755-1315/272/2/022069

Saha, M., Izykowski, J., Rosolowski, E. 2010. *Fault location on power networks,* Springer, London https://doi.org/10.1007/978-1-84882-886-5

Sezi, T., Menter, F. 1999. Protection scheme for a new AC railway traction power system. In *1999 IEEE Transmission and Distribution Conference (Cat. No. 99CH36333)* No.1 pages 388-393. https://doi.org/10.1109/TDC.1999.755383

APPENDIX



Ресурс-UF2M

Номинальное напряжение фазное 15588,46 В

Номинальное напряжение междуфазное 27000,00 В

Номинальный ток 1000,00 А

№ прибора 2550

Дата	Время	Действующее значение напряжения перфой гармоники, В									
		$U_а$	$U_в$	$U_с$	$U_{ав}$	$U_{вс}$	$U_{са}$	U_n	U_0	U_1	U_2
15.08.18	00:00:00	15730,89	15073,55	15081,94	26837,96	25826,46	26816,21	6,73	55,25	26488,62	662,13
15.08.18	00:00:03	15692,79	15056,96	15068,97	26782,16	25814,84	26766,33	6,69	55,04	26449,75	635,69
15.08.18	00:00:06	15697,35	15099,93	15090,33	26823,83	25887,52	26771,20	6,73	55,40	26489,59	603,46
15.08.18	00:00:09	15716,75	15125,49	15105,43	26866,48	25923,27	26796,75	6,76	55,33	26524,60	602,78
15.08.18	00:00:12	15730,87	15150,82	15149,35	26886,75	25996,14	26848,07	6,79	55,70	26572,98	577,52
15.08.18	00:00:15	15693,78	15201,33	15208,58	26866,41	26147,04	26842,63	7,04	56,18	26615,58	477,15
15.08.18	00:00:18	15651,48	15251,30	15272,65	26836,77	26305,25	26837,52	7,28	56,69	26657,84	352,99
15.08.18	00:00:21	15654,63	15255,77	15274,83	26844,41	26311,78	26841,20	7,25	56,74	26663,70	352,33
15.08.18	00:00:24	15682,93	15228,98	15244,25	26864,60	26227,41	26854,84	7,25	56,28	26646,76	420,16
15.08.18	00:00:27	15703,92	15234,74	15234,99	26901,30	26210,57	26865,29	7,21	56,23	26656,16	446,43
15.08.18	00:00:30	15708,51	15241,39	15220,88	26921,67	26199,30	26850,98	7,13	56,14	26654,83	457,24
15.08.18	00:00:33	15707,80	15231,88	15222,57	26909,28	26190,84	26857,75	7,19	56,20	26649,95	459,94
15.08.18	00:00:36	15727,46	15233,76	15243,10	26922,68	26205,06	26902,78	7,19	56,15	26674,03	469,03
15.08.18	00:00:39	15715,33	15214,58	15244,36	26886,20	26191,55	26900,90	7,18	56,29	26656,53	465,63
15.08.18	00:00:42	15737,31	15230,35	15257,66	26922,15	26212,44	26932,66	7,04	56,33	26686,14	474,06
15.08.18	00:00:45	15733,52	15248,19	15262,52	26934,80	26240,96	26923,71	7,04	56,35	26696,85	456,61
15.08.18	00:00:48	15730,40	15253,22	15254,09	26941,62	26238,91	26907,70	7,18	56,24	26693,37	455,15
15.08.18	00:00:51	15733,14	15255,02	15232,57	26959,31	26214,09	26885,49	7,16	56,15	26683,42	471,53
15.08.18	00:00:54	15739,33	15269,09	15232,27	26982,50	26226,63	26884,62	6,98	56,21	26695,10	471,93
15.08.18	00:00:57	15752,05	15231,13	15230,89	26955,24	26173,20	26919,35	7,01	56,16	26679,45	506,88
15.08.18	00:01:00	15780,52	15234,49	15220,65	26997,78	26148,17	26939,25	6,99	56,16	26691,53	544,88
15.08.18	00:01:03	15760,52	15213,05	15204,25	26959,56	26116,03	26909,46	6,88	56,15	26658,02	543,29
15.08.18	00:01:06	15764,41	15217,85	15215,07	26963,79	26131,76	26923,46	6,91	56,08	26669,51	538,06
15.08.18	00:01:09	15774,79	15214,51	15214,40	26972,26	26121,04	26936,87	6,91	56,13	26673,21	552,54
15.08.18	00:01:12	15785,14	15203,55	15207,69	26976,13	26094,24	26947,30	6,85	56,14	26668,91	574,85
15.08.18	00:01:15	15788,87	15185,95	15174,07	26979,60	26031,86	26923,64	6,76	55,91	26640,46	610,06
15.08.18	00:01:18	15805,69	15165,06	15133,46	26998,79	25949,25	26909,89	6,69	55,49	26614,31	667,67
15.08.18	00:01:21	15809,01	15107,42	15076,33	26970,47	25811,89	26882,93	6,69	54,88	26549,11	739,60

Время	Действующее значение напряжения, В							Отклонение на…			
	$U_{да}$	$U_{дв}$	$U_{дс}$	$U_{дав}$	$U_{двс}$	$U_{дса}$	$U_{дп}$	$\delta U_а$	$\delta U_в$	$\delta U_с$	$\delta U_{ав}$
00:00:00	15779,32	15137,01	15154,25	26898,79	25931,38	26895,29	641,91	0,91	-3,30	-3,25	-0,60
00:00:03	15741,03	15121,16	15140,46	26843,76	25919,69	26844,13	642,00	0,67	-3,41	-3,33	-0,81
00:00:06	15745,88	15162,81	15161,99	26884,15	25990,93	26850,29	641,83	0,70	-3,13	-3,20	-0,65
00:00:09	15766,51	15191,40	15174,57	26933,67	26026,48	26872,41	641,88	0,82	-2,97	-3,10	-0,49
00:00:12	15780,80	15217,00	15218,71	26954,27	26099,65	26924,26	641,98	0,91	-2,81	-2,82	-0,42
00:00:15	15741,91	15263,64	15273,92	26929,69	26242,52	26914,63	641,98	0,68	-2,48	-2,44	-0,49
00:00:18	15699,40	15300,38	15328,69	26890,10	26375,35	26905,87	641,99	0,40	-2,16	-2,03	-0,60
00:00:21	15702,63	15302,05	15329,71	26895,05	26376,78	26909,73	641,96	0,42	-2,13	-2,01	-0,58
00:00:24	15730,30	15278,50	15301,04	26917,32	26299,22	26922,78	641,93	0,61	-2,31	-2,21	-0,50
00:00:27	15750,79	15283,92	15293,14	26951,90	26284,02	26934,71	642,04	0,74	-2,27	-2,27	-0,37
00:00:30	15755,78	15289,22	15277,94	26972,42	26269,48	26920,26	642,12	0,77	-2,23	-2,36	-0,29
00:00:33	15755,20	15280,12	15277,76	26961,58	26258,86	26924,65	642,24	0,77	-2,29	-2,35	-0,34
00:00:36	15773,94	15284,84	15298,57	26977,01	26277,50	26967,37	642,25	0,89	-2,28	-2,22	-0,29
00:00:39	15762,48	15268,72	15302,37	26943,45	26269,61	26968,74	642,11	0,81	-2,40	-2,21	-0,42
00:00:42	15782,13	15283,71	15314,72	26975,67	26290,24	26996,77	642,07	0,95	-2,30	-2,12	-0,29
00:00:45	15780,28	15301,53	15317,25	26992,28	26314,94	26986,89	642,05	0,93	-2,18	-2,09	-0,24
00:00:48	15777,33	15308,14	15308,73	27001,27	26314,28	26970,15	642,14	0,91	-2,15	-2,15	-0,22
00:00:51	15779,33	15310,01	15285,95	27018,96	26288,56	26945,48	642,15	0,93	-2,14	-2,28	-0,15
00:00:54	15783,95	15323,25	15288,72	27037,65	26304,73	26946,32	642,12	0,97	-2,05	-2,28	-0,06
00:00:57	15796,82	15292,55	15291,12	27016,35	26263,90	26981,85	642,09	1,05	-2,29	-2,29	-0,17
00:01:00	15823,09	15291,92	15281,27	27052,02	26235,97	27001,66	642,07	1,23	-2,27	-2,36	-0,01
00:01:03	15803,35	15271,28	15264,95	27015,04	26204,45	26971,88	642,00	1,10	-2,41	-2,46	-0,15
00:01:06	15809,74	15277,09	15276,66	27022,11	26221,19	26989,46	642,07	1,13	-2,38	-2,40	-0,13
00:01:09	15818,67	15269,95	15274,14	27026,05	26204,64	27000,88	641,97	1,20	-2,40	-2,40	-0,10
00:01:12	15831,25	15260,69	15269,73	27032,76	26181,21	27015,81	642,06	1,26	-2,47	-2,44	-0,09
00:01:15	15834,72	15242,08	15235,69	27035,24	26117,24	26992,20	642,05	1,29	-2,58	-2,66	-0,08
00:01:18	15851,21	15226,11	15197,91	27057,88	26043,96	26978,41	642,03	1,39	-2,72	-2,92	0,00
00:01:21	15855,85	15175,44	15147,70	27034,56	25922,14	26956,90	642,09	1,41	-3,09	-3,29	-0,11

Figure: Fragment of measurements electrical parameters' database for the catenary feeder by the automatic monitoring system.