

Increase in Efficiency of Reflectogram Comparison Method in Determination of Fault Points and New Obstacles in Power Transmission Lines

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Abstract—In the article, the problems, connected with reflectometric fault points definition and points of obstacles occurrence on power transmission lines, are considered. The method based on reflectogram comparison is considered. The authors show that this method does not always give good results. It is connected with change in time of physical parameters of the supervised line. Using adaptation of the current reflectogram to an exemplary one by means of time scaling is preferable. For the implementation of scaling, the reflectogram should be in a continuous form, but the taken reflectogram is presented in a discrete form. Therefore, the authors offered to apply piecewise and linear interpolation to obtain the current reflectogram in a continuous form. Scaling is carried out by changing the scaling coefficient by one of the known algorithms of optimization. Due to the exact combination of exemplary and scaled current reflectogram, it is possible to increase efficiency of the reflectogram comparison method.

Key words—locating means; reflectogram measuring; power transmission lines obstacle; reflectogram comparison

I. INTRODUCTION

To provide reliable and smooth operation of power lines in electrical power systems, the continuous control of their technical position is necessary [1-8]. The control is exercised in such parameters as insulation resistance, fault point existence, distances to fault points, etc. At the present day for the solution of this task, a large number of various means and ways of control, which are continuously improved [9-16], are used. Accuracy and interference resistance of control devices

increase, their functional capability extends, the ways and techniques of control are improved [17-23].

One of the effective ways of power lines technical position control is based on reflectogram (locational) measurements. During reflectogram measurements one often uses such convenient tool as reflectogram comparison [24-26]. Both reflectograms of different phases of one power line and the reflectogram of one phase received at different times [27] are compared. For comparison, in the latter case, we use the reflectogram received on the fault-free line as an exemplary one.

To search for fault points and new obstacles, one takes the current reflectogram and compares it to the exemplary reflectogram, received from the same phase of the controlled line. Usually the comparison is carried out with the use of a differential reflectogram. The values on a differential reflectogram to the fault point are close to zero, and in the fault point and further there are signals connected with the failure mode or with the nature of emergence of new wave resistance obstacle on the controlled line. The reflectogram comparison, as a rule, yields good results and simplifies fault point search or the appeared power line obstacle.

The reflectogram comparison is used practically in all modern reflectometry devices, both domestic and foreign. Race-105M, Race-205, Race-308, RI-10M, IRK-PRO Alpha, ETDR 10, Riser Bond-1270AU and other devices are rated.

However, during control of long-haul lines the efficiency of reflectogram comparison is low. For interphase comparisons, it is connected with physical distinctions of phases, such as geometry, velocity factor, etc. For monophasic comparison of current and exemplary reflectogram, it is connected with temporary change of physical parameters of the controlled line. For long-haul lines such parameters as the physical length of the line that are caused by gust loading, icing, change of temperature, both on line sections and along all its length, are subject to changes. At the same time on the received differential reflectogram there are values significantly different from zero even in the absence of damage or the appeared obstacles, which is connected with temporary non-compliance (delay or advance) of the current reflectogram in relation to an exemplary one. As a result, the efficiency of the reflectogram comparison method when determining fault points and new obstacles decreases.

II. BRIEF DESCRIPTION OF THE OFFERED METHOD

One of the solutions of the current reflectogram temporary non-compliance in relation to an exemplary one, during application of the differential reflectogram method, can serve a way of adaptation of the current reflectogram to an exemplary one, offered in [28].

In the offered method, prior to control over the line, we take an exemplary reflectogram. For this purpose, we send the exploratory tension impulse to the experimental line, receive the returned signals, store the exemplary reflectogram in the form of array data. In the course of line control, we take the current reflectograms. After receiving the current reflectogram and its recording into the array, we make scaling on time of this array. At the same time we make spline interpolation for each of two values corresponding to adjacent time points; therefore, an interpolational continuous function comes out. Afterwards, the scaling on time of the current reflectogram is implemented by change of the scaling coefficient by one of the known optimization algorithms. For various scaling coefficient values on time, we repeatedly receive the new scaled arrays which are compared to array data of the exemplary reflectogram before the achievement of the minimum difference between them.

III. MATHEMATICAL DESCRIPTION OF THE OFFERED METHOD

The exemplary reflectogram represents array data $U0[i]$ ($i=0, 1, 2..N-1$), corresponding to time points $t_0, t_1, t_2..t_{N-1}$, where N is a total of the received values. The current reflectogram represents array data $U1[i]$ ($i=0, 1, 2..N-1$) [**Ошибка! Источник ссылки не найден.**].

The parameters instability of the controlled line influences the reflected impulses (signals) recovery time. As a result, the array time scale $U1[i]$ differs from the array time scale $U0[i]$. That makes it difficult to trace again arisen faults and obstacles by the method of comparison of exemplary and current reflectograms, especially under the control of long lines. To make these scales identical in the offered method, the time scaling coefficient K is introduced, in proportion to which the array $U1[i]$ is "strained" or "expanded" in the course of time. Considering that the arrays $U0[i]$ and $U1[i]$ are discontinuous, it is difficult to use an arbitrary time scaling

coefficient K . To implement this procedure, we offer to use spline interpolation of the 1st order for the array $U1[i]$, which means that we use piecewise and linear interpolation. The example of piecewise and linear interpolation is given in Fig. 1.

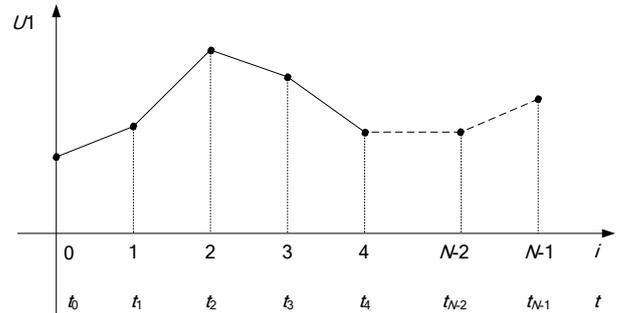


Fig. 1. The line graph illustrating piecewise and linear interpolation

In Fig. 1, $U1$ is a returned signal value; $t_0, t_1, t_2..t_{N-1}$ are time points at which returned signal values are determined; i is a time point number; N is total of places. In this connection the interpolating lines amount is $N-1$.

Let us assume that we have received N values, which are recorded in the array $U1[i]$ ($i = 0, 1, 2..N-1$). For each two adjacent tension values $U1_i, U1_{i+1}$, corresponding to the time points t_i, t_{i+1} , we perform spline interpolation. As the result we receive the interpolational continuous function $U1(t)$ of type:

$$U1(t) = \begin{cases} a_1 \cdot t + b_1 & \text{when } t_0 \leq t < t_1 \\ a_2 \cdot t + b_2 & \text{when } t_1 \leq t < t_2 \\ a_3 \cdot t + b_3 & \text{when } t_2 \leq t < t_3 \\ \vdots & \\ a_{N-1} \cdot t + b_{N-1} & \text{when } t_{N-1} \leq t \leq t_{N-1} \end{cases} \quad (1)$$

The values a and b for each part are evaluated in the coordinates of two points $(U1_i, t_i), (U1_{i+1}, t_{i+1})$ using the formulae:

$$a_{i+1} = (U1_{i+1} - U1_i) / (t_{i+1} - t_i); \\ b_{i+1} = U1_i - a_{i+1} \cdot t_i.$$

To scale this function of time, we introduce a new variable t' :

$$t' = K \cdot t,$$

where K is a time scaling coefficient.

Inserting the variable t' into (1), we receive:

$$U2(t) = \begin{cases} a_1 \cdot t' + b_1 & \text{when } t_0 \leq t' < t_1 \\ a_2 \cdot t' + b_2 & \text{when } t_1 \leq t' < t_2 \\ a_3 \cdot t' + b_3 & \text{when } t_2 \leq t' < t_3 \\ \vdots & \\ a_{N-1} \cdot t' + b_{N-1} & \text{when } t_{N-1} \leq t' \leq t_{N-1} \end{cases} \quad (2)$$

Using the time values range $t_0, t_1, t_2..t_{N-1}$, we receive the values range $t'_0, t'_1, t'_2..t'_{N-1}$. Inserting these values into (2), we receive the values range of $U2[i]$ ($i = 0, 1, 2..N-1$).

To choose time scaling optimum coefficient K , we complete the iterative procedure, which is as follows. For

various values K the array scaling due time is implemented $U1[i]$. Obtained from the formula (2), the array $U2[i]$ is compared with the array $U0[i]$ each time. The comparison can be carried out both by diminution and with the use of the correlation coefficient.

The comparison by diminution is as follows. Let us assume that we have the array $U0[i]$ corresponding to the exemplary reflectogram, and the array $U2[i]$ received from the current reflectogram with some value of time scaling coefficient K . It is necessary to characterize using one number to what extent the array $U0[i]$ is closer to the array $U2[i]$. For this purpose, it is appropriate to use the procedure of estimation evaluation of the first norm of the column. At the same time the differences of elements of the arrays with identical numbers are calculated; the moduli of these diminutions are summed up:

$$A = \sum_{i=0}^{N-1} |U2_i - U0_i|,$$

where A is a subtraction result expressed by one number.

The value A is the value of the objective function for the optimization procedure which searches for the minimum A at different values K .

The comparison with the use of the correlation coefficient is as follows. Let us assume that we have the array $U0[i]$ corresponding to the exemplary reflectogram, and the array $U2[i]$ received from the current reflectogram with some value of time scaling coefficient K . It is necessary to characterize using one number to what extent the array $U0[i]$ is closer to the array $U2[i]$. For this purpose, it is appropriate to use the correlation coefficient which is evaluated using the formula:

$$B = \frac{\sum_{i=0}^{N-1} (U0_i - \overline{U0}) \cdot (U2_i - \overline{U2})}{\sqrt{\sum_{i=0}^{N-1} (U0_i - \overline{U0})^2} \cdot \sqrt{\sum_{i=0}^{N-1} (U2_i - \overline{U2})^2}},$$

where $\overline{U0}$ and $\overline{U2}$ are average values, viz:

$$\overline{U0} = \frac{\sum_{i=0}^{N-1} U0_i}{N}, \quad \overline{U2} = \frac{\sum_{i=0}^{N-1} U2_i}{N}.$$

The value B is the value of the objective function for the optimization procedure, which searches for the maximum B at different values K .

The result of the optimization procedure is the optimum value K , with the help of which we receive the scaled array $U2[i]$ providing the minimum time irrelevance of the current reflectogram, relative to the exemplary one [**Ошибка! Источник ссылки не найден.**].

The fault point or the obstacle appearance point is defined with the use of the differential reflectogram received from the scaled current and exemplary reflectograms corresponding to the arrays $U2[i]$ and $U0[i]$. In the absence of damage or an appeared obstacle of the differential reflectogram, the value is close to zero at any values i . In the emergence of damage or

obstacle, the values, different from zero, appear. According to the numbers i of these values, it is possible to calculate the distance to the fault [27].

The calculation of the distance to the fault point or obstacle is carried out using the delay time from the moment of the controlled line probing up to the point of the reflected impulse (signal) emergence. Here the following formula is used:

$$l_K = \frac{1}{2} \cdot V \cdot t_3,$$

where l_K is the distance to the fault and obstacle; V is the electromagnetic waves spreading speed in the controlled line when recording the reflectogram; t_3 is the delay time of the reflected impulse (signal) from the fault or obstacle, relative to the probing one [**Ошибка! Источник ссылки не найден.**].

VI. RESULTS OF PRACTICAL IMPLEMENTATION OF THE PROPOSED METHOD

The proposed method was used when developing a reflectometric complex for monitoring power overhead transmission lines of 35-220 kV to determine the locations of their damage and glaze-ice accretion on wires in order to improve its metrological and technical characteristics.

The pulse method of monitoring overhead power transmission lines is at the heart of the complex. Determination of fault points and new inhomogeneities, as well as parameters of ice loadings, is carried out using the method of comparison of reflectograms, that is, a comparative analysis of current, exemplary and difference reflectograms.

Development was carried out at the enterprise "OOO RPE "IMET"" (Limited Liability Company of the Research and Production Enterprise "Information-Measuring Equipment and Technologies, Novocherkassk, Russia) by request of PAO Kubanenergo (Public Joint-Stock Company of Power Engineering and Electrification of Kuban, Krasnodar, Russia). Testings and trial operation of the developed complex was carried out at 110 kV substations of PAO "Kubanenergo".

The developed complex is meant for continuous monitoring of five overhead transmission lines of 35-220 kV for the purpose of automatic detection of fault points, detection of the presence and nature of ice loadings on the wires of overhead power transmission lines.

The application of the proposed method ensured the achievement of the following metrological and technical characteristics:

- detection of fault points and glaze-ice accretions on overhead transmission lines of 35-220 kV at distances up to 150 km from the installation site of the complex;
- detection of fault points of all kinds on lines with a tree-type structure of 35-220 kV with an accuracy up to 0.01% with a resolution of 5 m;
- detection of fault points of all kinds on lines with a tree-type structure of 35-220 kV or on lines with a large number of branches with an accuracy up to 1% with a resolution of 5 m;

- control of parameters and nature of glaze-ice accretions in the range of $0.1 \div 100$ mm / $0.2 \div 0.9$ g/cm³ (accretion thickness / accretion density);

- detection of presence of places and the nature of glaze-ice accretions on the wires of overhead power transmission lines along the entire length of power lines on lines with a linear structure of 35-220 kV with a distance error of not more than 2%, with a parameters error of glaze-ice accretions of not more than 10%;

- detection of presence of places and the nature of glaze-ice accretions on the wires of overhead power transmission lines along the entire length of power lines on lines with a tree-type structure of 35-220 kV or on lines with a large number of branches with a distance error of not more than 5%, with a parameters error of glaze-ice accretions of not more than 20%.

IV. CONCLUSION

Thus, due to the exact combination of the exemplary and scaled current reflectograms, it is possible to minimize temporary discrepancy of the current reflectogram in relation to an exemplary one. It allows increasing efficiency of the method of reflectogram comparison when determining fault points and new obstacles on power transmission lines [28].

References

- [1] V.I. Lachin and K.U. Solomentsev, "Increase in high-speed performance of electrical network parameters measurement," 2017 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), 16-19 May 2017, St. Petersburg, Russia. St. Petersburg: IEEE, 2017. Retrieved from: <https://ieeexplore.ieee.org/document/8076264/>
- [2] K.U. Solomentsev et al. "Identification of control object parameters," Proceedings of 2016 International Conference on Physics and Mechanics of New Materials and Their Applications. New York: Nova Science Publishers, pp. 739-744, 2017. Retrieved from: https://www.novapublishers.com/catalog/product_info.php?products_id=61270.
- [3] S.G. Yanvarev, K.D. Savvina, K.U. Solomentsev, V.A. Kucherov, and D.D. Savvin, Method of determining damage location of power lines with large number of irregularities, Pat. 2654378 Rus. Federation, G01R 31/11 – No. 2017118107; applic. 05.24.2017; publ. on 05/17/2018 Bull. No. 14.
- [4] S.G. Yanvarev, K.D. Savvina, V.A. Kucherov, K.U. Solomentsev, and D.D. Savvin, Method of determining topology of overhead power lines, Pat. 2656004 Rus. Federation, G01R 31/11 – No. 2017126912; applic. 07/26/2017; publ. on 05/30/2018, Bull. No. 16.
- [5] V.I. Lachin, K.U. Solomentsev, K.U. Nguyen, and I.G. Balaban, Device for measuring insulation resistance of electrical networks: Pat. 149247 Rus. Federation, G01R 27/00 - No. 2014127026/28; applic. 07/02/2014; publ. on 12.27.2014, Bull. No. 36.
- [6] V.I. Lachin, K.U. Solomentsev, and K.U. Nguyen, Device for measuring insulation resistance of AC networks: Pat. 2554308, G01R 27/18 – No. 2013159135/28; applic. 12/30/2013; publ. on 06/27/2015, Bull. No. 18.
- [7] V.I. Lachin, K.U. Solomentsev, and K.U. Nguyen, Method of measuring insulation resistance and device realizing it: Pat. 2585965, G01R 27/00 - No. 2014154540/28; applic. 12/30/2014; publ. on 06/10/2016, Bull. No. 16.
- [8] V.I. Lachin, K.U. Solomentsev, and K.U. Nguyen, Method of measuring insulation resistance of electrical networks: Pat. 2585930, G01R 27/16 - No. 2014154352/28; applic. 12/30/2014; publ. on 06/10/2016, Bull. No. 16.
- [9] Liang Jun, Zhao Yong, and Che Renfeit, "An accurate fault location. Algorithm based on double ended sampled data," Automation of Electric Power Systems, No. 21(9), pp. 24-27, 1997.
- [10] Mao Weimin, Lu Defeng, and Xiao Xiang, "Application and research of novel and practical fault location algorithm using samples from double ended," Automation Devices of Electric Power Systems, No. 20(2), pp. 26-28, 2000.
- [11] Chen Zheng, Su Jinxi, and Wu Xinrong, "Algorithm for high voltage transmission line fault location based on distributed parameter," Power Systems Technology, No. 24(11), pp. 31-33, 2000.
- [12] V.A. Kucherov and K.D. Savvina, "Modular reflectometers for finding stable damage sites on VL35-500 kV," Research results - 2010: materials of the 59th scientific and technical. conf. of faculty members, science workers, graduate students and students of South-Russian State Technical University (NPI). Novocherkassk: YURGTU, pp. 221-223, 2010.
- [13] T.W. Stringfield, D.J. Marihart, and R.F. Stevens, "Fault location methods for overhead lines," AIEE Transactions, Part III, vol. 76, pp. 518-530, 1957.
- [14] T. Takagi, Y. Yamakoshi, M. Yamaura, R. Kondou, and T. Matsushima, "Development of new type fault locator using one-terminal voltage and current data," IEEE Transactions on Power Apparatus and Systems, vol. PAS-101, No. 8, pp. 2892-2898, 1982.
- [15] L. Eriksson, M.M. Saha, and G.D. Rockefeller, "Accurate locator with compensation for apparent reactance in fault resistance resulting from remote-end infeed," IEEE Transactions on Power Apparatus and Systems, vol. PAS-104, No. 2, pp. 424-436, 1985.
- [16] V. Cook, "Fundamental aspects of fault location algorithms used in distance protection," IEEE Proceedings, vol. 133, No. 6, pp. 359-368, 1986.
- [17] K.D. Savvina, V.A. Kucherov, D.D. Savvin, and O.A. Naugolnov, "Compensators for periodic interference in devices for monitoring parameters of electrical networks and control systems," News of higher educational institutions. North Caucasus region. Series: Engineering, No. S3, pp. 66-71, 2009.
- [18] V.I. Lachin, K.U. Solomentsev, and O.U. Demidov, "Use of numerical optimization in compensating for interference in insulation resistance monitoring devices," Proceed. of higher schools. Electromechanics. No. 4, pp. 85-91, 2017.
- [19] V.I. Lachin et al. "Compensation of sinusoidal noise in measuring insulation resistance," Fundamental principles, theory, methods and means of measurement, control and diagnostics: materials of the 19th Intern. Youth Scientific-Practical Conf., Novocherkassk, Feb. 27-28 2018. South-Russian State Polytechnic university (NPI) n.a. M.I. Platov. Novocherkassk: Lick, pp. 183-185, 2018.
- [20] M.S. Sachdev and R. Agarwal, "Technique for estimating transmission line fault locations from digital impedance relay measurements," IEEE Transactions on Power Delivery, vol. 3, No. 1, pp. 121-129, 1988.
- [21] A.A. Gigris, D.G. Hart, and W.L. Peterson, "New fault location technique for two - and three-terminal lines," IEEE Transactions on Power Delivery, vol. 7, No. 1, pp. 98-107, 1992.
- [22] M. Abe, N. Otsuzuki, T. Emura, and M. Takeuchi, "Development of new fault location system for multi-terminal single transmission lines," IEEE Transactions on Power Delivery, vol. 10, No. 1, pp. 159-168, 1995.
- [23] D. Novosel, D.G. Hart, E. Udren, and J. Garity, "Unsynchronized two-terminal fault location estimate," IEEE Transactions on Power Delivery, vol. 11, No. 1, pp. 130-138, 1996.
- [24] Shu Hongcun, Si Dajun, and Ge Yaozhong, "Practical fault location Algorithm and its realization based on unsynchronized double ended sampled data," Power Systems Technology, No.24(2), pp. 45-49, 2000.
- [25] Su Jinxi, Luo Chengmu, and Xie Zifeng, "Practical fault location algorithm based on double ended sampled data," Journal of Tsinghua University, No. 40 (7), pp. 27-30, 2000.
- [26] K.D. Savvina and V.A. Kucherov, "Reflectometer for finding resistant damage sites on 35–220 kV VL," Student Scientific Spring - 2009: materials of Interregion. scientific and technical conf. of students, postgrad. and young scientists of the Southern Federal District, South-Rus. State Tech. university (NPI). Novocherkassk: SRSTU (NPI), p. 236-239, 2009.
- [27] G.M. Shalyt, "Determination of places of damage in electrical networks," Moscow: Energoatomizdat, 1982.

[28] S.G. Yanvarev, K.D. Savvina, V.A. Kuchero, K.Yu. Solomentsev, and D.D. Savvin, Method of determining location of damage to power lines:

Pat. 2654377 Rus. Federation, G01R 31/11 - 2017118106; applic. 05.24.2017; publ. on 05/17/2018 Bul. No. 14.