Induction Method for Parameters Control of Cable Lines laying at the Electricity Distribution Network Polygon

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***Abstract*—This research paper investigates the specifics of the induction method in the tasks of controlling cable lines laying parameters. The goal of this paper is to look for opportunities to improve the induction method when solving the issues related to optimizing the cost of cable line excavation. For this purpose, we used line locator and research facilities at the university electricity research and training polygon at the middle voltage cable test and diagnostic laboratory. Such parameters for laying cable line in the ground as location and depth were determined during research, which made it possible to compare with the project documentation and identify minor deviations from the planned parameters. The signals of the line locator were tested in the places where the cable line is laid in the pipes and the possibility of finding their boundaries was revealed. Based on these results, the methodology has been developed that complements the existing induction method in pipe boundary detection tasks and makes it possible to identify locations for subsequent excavations. The obtained results are recommended to be used in the work of repair personnel on replacement and serviceability restoration of cable lines laid in pipes in the ground, and in the training process when developing professional competences of the personnel in electric power training areas.**

Keywords—induction method, transient resistance, control, cable line, polygon, insulation defect, screening effect.

I. INTRODUCTION

The increased electrification activity in the last decade is caused by the fastest and most efficient ways of laying cable lines (CLs), such as: overhead and underground. Underground methods of laying utilities lines are more commonly used in residential areas and are either trenched or trenchless: puncture method, plough method, horizontal directional drilling, ground punching, etc. Due to the extensive use of trenchless methods in urban environments, it is becoming more and more difficult to find the lines with power cables laid [1-2]. The relevance of the work is in the need to improve the methods of the methods for damage location in CLs and to develop appropriate methodologies that take into account the specifics of the development of underground power networks in Russia.

It is important to note that each of the laying methods can affect the life of the cable. The most convenient and cost-effective way: horizontal deviated drilling and punching does not require much space for work, has a smaller effect on the existing infrastructure, and also involves laying of a special pipe. The pipe serves as a protective measure and facilitates pulling the cable through without damaging its sheath. However, cable can be damaged inside pipes due to accumulation of moisture and water at its lowest point. Elimination of damage inside pipes is a common problem faced by repair brigades [3-4].

During commissioning of the line, insulation resistance is tested using a megohmmeter. Damaged CL has resistance values lower than those permitted by the relevant regulations. In such cases, CL is deemed unserviceable and a search is made for current leakage through the insulation in the area of reduced resistance. The insulation resistance assessment method does not allow us to determine location of this damage - the induction method is used for this purpose, which requires prior reduction of the transient resistance. This is achieved by burning the cable insulation at the place of damage. The faulty phases are subjected to voltages sufficient to cause an insulation puncture at the place of damage. After a certain time of repeated punctures, the transient resistance at the place of damage decreases, the discharge voltage decreases and the discharge current increases. The insulation is burned through by this current, the transient resistance at the place of damage is reduced and it becomes possible to search for the damage place using special methods [5-6]. The induction method chosen for this study is based on the principle of capturing the electromagnetic field on the ground surface as alternating current of sound frequency range flows from the generator connection point to the low impedance CL damage and back to the generator.

The researcher walks with antenna sensor where electromagnetic signal is induced and converted into sound in headphones being part of line locator system. The sound intensity identifies location of the cable line being tested before the damage. After damage, there is no current and therefore no sound signal. The strength of the sound signal in the headphones of the line locator system depends on the ground, depth, method of laying the cable line and parameters of the pipe such as material, thickness and length. Often, laying CLs in metal pipes makes signal location difficult because of the shielding effect, and the presence of the pipe itself complicates recovery operations if its boundaries are not known [7-8]. Therefore, improving the induction method for pipe boundary detection is an important technical task. The scientific purpose of this work is to conduct research into the induction method for detecting the boundaries of steel and PVC pipes as the most commonly used in cable laying. The scientific significance of the article lies in the development of the new methodology that allows locating of the pipe in which tested CL is located. On the basis of the proposed methodology, testing was performed at the CL polygon, and pipe boundaries were found as a result of the experiments. Thus, the research performed can serve as an example to contribute to the development of practical features of damages location in modern urban power systems.

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II. Materials and Methods

The choice of method for monitoring the cable line laying parameters in cable damage location tasks depends on the nature of the damage, place of laying and the transient resistance at the place of damage. Acoustic, loop, capacitive, pulse, and oscillating discharge methods do not involve tracing as they are used to find a line puncture. This is why the induction method was used, it was based on electrical generator and electromagnetic harmonic signals search device. Line locator systems for implementing the induction method are based on the generation of electric current of 15-20 A at 800-1100 Hz in CLs. The appearance of the selected GZCH-2500 generator with sinusoidal current frequency of 1024 Hz at the current strength of 11.8 A is shown below (Fig.1)

Fig .1. Audio frequency generator readings

The instrument chosen to search for CLs is AP-027 receiver with EMD-247 electromagnetic sensor, which captures the induced generator signal and displays its level in conventional units on the LCD screen. The optimum amperage of 11 to 13 A is determined on the audio frequency generator for the selected cable lines. With this current, there is no overheating of the audio frequency generator and the desired signal level in the receiver is observed along all the CLs being tested.

Fig .2. Line locator system receiver

Position of the sensor in space affects the induced signal. The schematic explanation shows the horizontal sensor position used in the 'maximum method' (Fig.3).

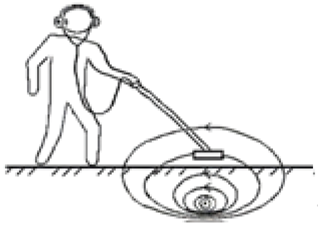

Fig .3. Induced signals in the induction method.

Once the location of the cable line has been determined, the depth of the cable must be estimated. For this purpose, a location marker is placed over the passing cable line. Depth determination is made according to the "45 degree" method, when the electromagnetic sensor is located at the angle of 45 degrees relative to the CL and the place where the signal will become minimal is determined. According to the rule of isosceles triangle, the distance h on the ground is equal to the depth of the CL laying. The figures below provide the theoretical explanation of this method, as well as illustration of inductive measurement using a 45-degree tilt sensor on the electricity distribution network polygon (Fig.4-5.).

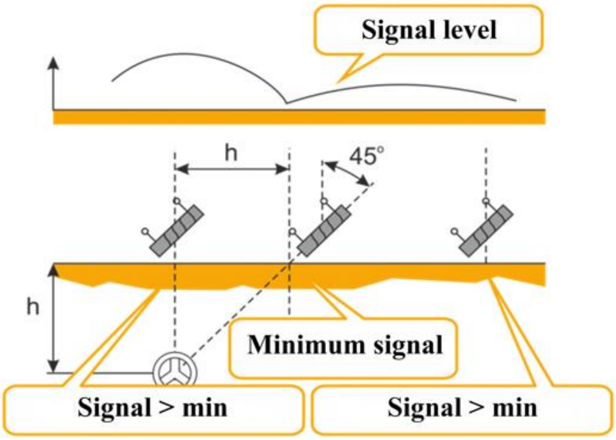

Fig .4. The theoretical explanation of 45 degree method

Fig .5. The practical application of 45 degree method

The training and research polygon of the electricity distribution network at the laboratory for testing and diagnostics of cable lines of Kazan State Power Engineering University was chosen as the electricity distribution network, it's scheme is shown in Fig.6.

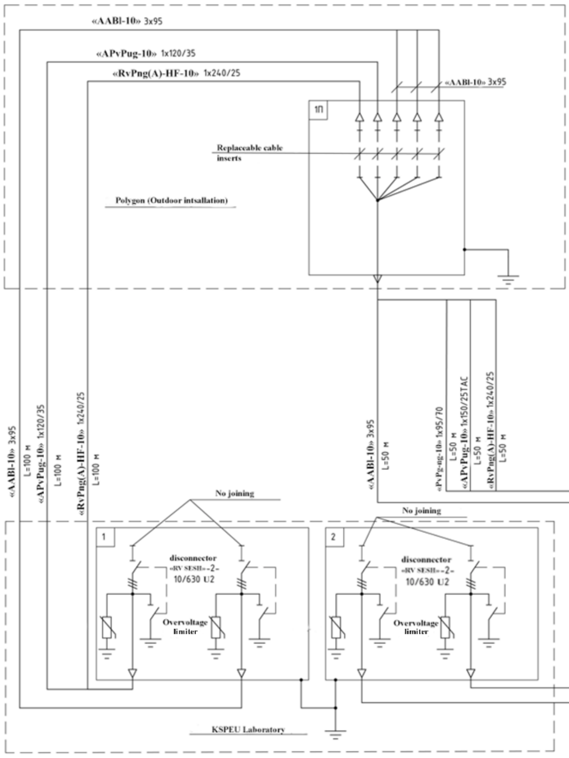

Fig .6. Diagram of 10 kV cable lines polygon

Three types of 10 kV cables were tested for defects: APVPug-10 1x120/35 (high-voltage power cable with aluminum conductor cross section of 120 square millimeters in XLPE insulation with shield made of copper wires with cross section of 35 mm2, in polyethylene sheath), AABl-10 3x95 (power cable with 3 aluminum conductors, cross-section 95 square millimeters, paper impregnated insulation, aluminum sheath and steel tapes armor), RvPng(A)-HF-10 1x240/25 (power cable with multi-core copper conductor core with high strength ethylene propylene rubber insulation). Each of the cables was alternately earthed at the ends with PZRU-1E portable earthing switch. In a single-service prefabricated chamber (SSC), the connection was as follows (Fig.7.)

In the tested area, 125 metres of defect-free cable lines were to be tested - they are shown in the left-part of the diagram. The following dependencies for the received signal are established when using the 45 degree induction method:

1) the composition of the ground surface affects the signal strength,

2) the pipes partially shield the signal,

3) the ground loop of the substation close to the research place introduces distortions to the signal distribution.

Fig .7. Connection of audio frequency generator to AABl-10 3x95 cable

III. RESULTS

Figures 8-10 show the pilot drilling designs for the 27 m section of the tested CLs. Materials are taken from the project documentation.

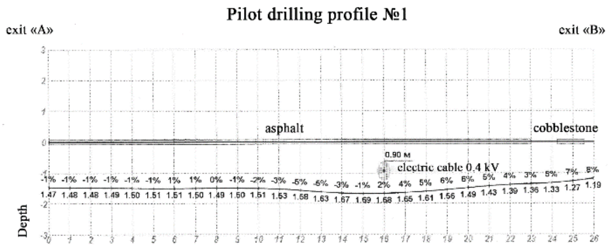

Fig .8. Pilot drilling profile of cross-linked polyethylene insulated cable

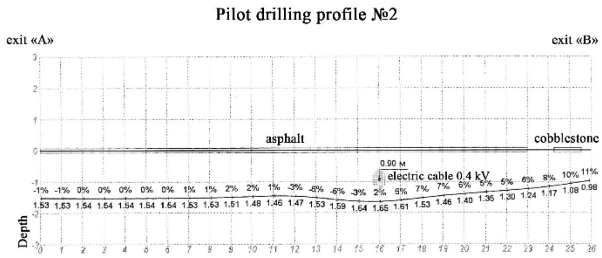

Fig .9. Pilot drilling profile of paper-insulated cable

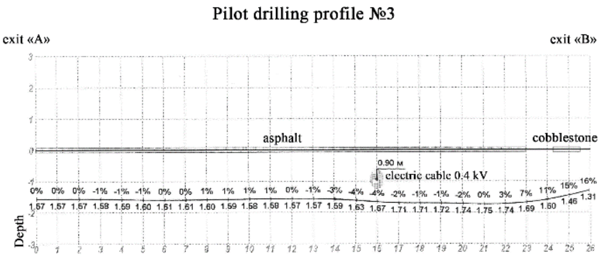

Fig .10. Pilot drilling profile of ethylene propylene insulated cable

The experiment revealed a discrepancy between the pilot drilling profiles and the actual measurement data received by the induction method. Figures 11-13 show graphs of the actual depth of the tested CLs in three parts of 27 meters long section.

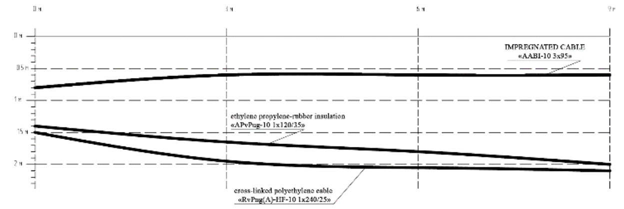

Fig .11. The depth of the CL along the length in the first part in the section from 0 to 9 meters

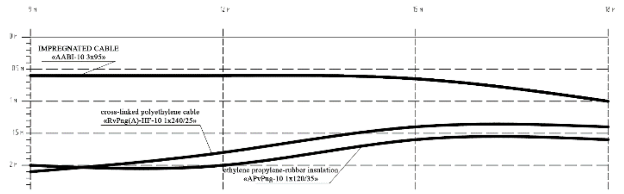

Fig .12. The depth of the CL along the length in the second part in the section from 9 to 18 meters

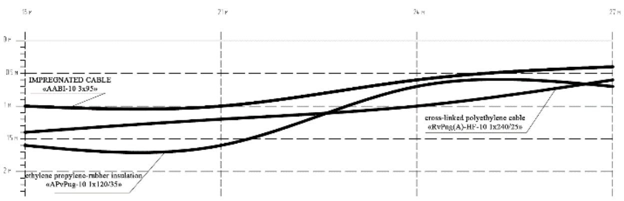

Fig .13. The depth of the CL along the length in the third part in the section from 18 to 27 meters

If damage occurs inside the pipe laid due to complex underground utilities, it is not rational to excavate in the area of the damage, as there is a possibility of damaging the surrounding utilities and the pipe has to be destroyed or the homogeneity of its material disturbed. It is much more advantageous to excavate at one end of the pipe, as the scope of work when repairing the cable line is considerably reduced and fewer specialists are needed to complete the work. PvPg-ng-10 1 × 95/70 cable (power cable with a round multi-wire aluminum compacted core, with extruded cross-linked polyethylene, layer of electrically conductive paper and copper tape) 125 m long was chosen as the object of the damage study, on the tested section of the line the cable according to the project is laid in the PVC pipe, but the exact location of the ends of the pipe is not specified.

It is necessary to keep the generator output current stable in order to identify the main influencing factors on the receiver signal variation. When this condition is met, the receiver signal is mainly influenced by the factors shown in the table (TABLE 1).

TABLE 1. REASONS FOR RECEIVER SIGNAL CHANGES

Influencing factor	The nature of the effect on the received signal
1. Deviation of the sensor from the CL route	If the sensor is not positioned strictly above the cable, but with a slight deviation horizontally, the signal level can be less than the maximum possible
2. Depth of CLs laying	The signal strength decreases as the depth of CL increases
3. Way of laying CLs	The permeability of the signal through the pipe is lower than through the ground. If the CL is laid in a pipe, the signal strength above it is lower

In order to make conclusion about the influence of factor 3 on changes in the measured signal, the influence of factors 1 and 2 must be evaluated. For this purpose, the methodology has been developed where actions are taken to eliminate the influence of factors 1 and 2, then signal studies are made for factor 3 and the location of pipe boundaries is established. The "minimum method" is used to reduce the influence of factor 1, in this method the sensor is placed vertically and the minimum value above the CL is found. This improves the accuracy of the cable route in the horizontal plane. The influence of factor 2 is then evaluated: "45 degree method" measurement is made on the same section and the vertical coordinate of the cable position at the measured points of the CL route is determined. Using the results received, the final measurement is made according to the "maximum method", when the sensor is positioned horizontally. By comparing the values of the measured signals at different points along the length of the tested section, the area with a pronounced gradient is determined, indicating that a pipe boundary has been detected. The method described allows us to find the beginning and the end of the route section where the cable is laid in the pipe, in the ground uniform in length.

During tracing the study area, the proposed methodology was tested and shielding elements were found: polyvinyl chloride pipe, which is characterized by insignificant signal blanking, and 5-meters steel pipe, which significantly shields the signal. No excavation of the site has been made.

As a result of the work, the authors obtained the following results:

Scientific: On the basis of three types of the induction method, the methodology has been developed to determine the boundaries of pipes used to lay cable lines in the ground.

Training: working skills have been received at the training and research polygon of 10 kV cable lines with use of the line locator system based on the induction method for the development of teaching materials for students; the induction method has been learned and the competencies necessary for tracing have been formed; the best settings for equipment to determine the trajectory and depth of CLs have been selected; the material has been collected for laboratory work to teach the induction method to determine the location of CLs.

Practical: tracing of 10 kV CLs was performed at the training and research polygon of Federal State Budgetary Educational Institution of Higher Education Kazan State Power Engineering University and discrepancies with the requirements of project documentation were found; control of parameters of CLs' pipe laying at the polygon was performed. During the measurements, it was found that there were signal strength dependencies on: soil composition (asphalt, gravel, earth), depth of laying, presence or absence of a pipe.

The proposed methodology is recommended for use in the educational process as part of the educational program: 13.04.02 - "Electric power and electrical engineering". In particular, practical classes have been provided for a group of students at Federal State Budgetary Educational Institution of Higher Education Kazan State Power Engineering University using the methodology presented. The material required for laboratory work to teach the induction method to locate CLs has been collected, the instrumentation has been selected and the best settings have been selected to determine the trajectory and depth of the CLs.

IV. Discussion

The methodology developed will allow searching for locations where excavation for repairs and emergency repair work is made when CLs are damaged inside the pipe with reduced risks of damage to adjacent infrastructure. The proposed methodology minimizes damage to the road surface (asphalt, block paving, etc.) over the damage place, which restoration incurs substantial losses and requires introduction of organizational measures to enclose the repair site.

Taking into account the results obtained, we can say that the induction method, when examining the cable line route, allows the control of parameters such as: change of laying method (directly in the ground or in the pipe), the trajectory and depth of the cable line. After reviewing the sources used it can be stated that the induction method has potential for research and improvement, works in this area will help to use the lines detection equipment in the most efficient way.

V. Conclusions

This study examines the effect of shielding pipes on the strength of the sound signal captured by the receiver of the line locator system. Based on the work of other authors, the study takes into account: methods of laying CLs, methods of damage location in underground CLs, outline diagrams of the CLs training and research polygon with the relevant project documentation, parameters and settings of the line locator system used. The authors propose the methodology for the induction method use for the tasks of locating cable lines laid in pipes in the ground. With this information, work to repair damage occurring in the described areas is performed with fewer financial and time resources: the repair work is optimized as the existing infrastructure is not disturbed and the risks of damaging nearby utilities are reduced. Based on the results of the surveys of cable lines of the electricity distribution network polygon the existing project documentation has been structured and methodological materials for new laboratory work have been collected in order to introduce them into the training process of the personnel of the electricity sector.

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