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THE ROLE AND IMPORTANCE OF MEASURING CIRCUITS IN THE MANAGEMENT AND MONITORING OF ENERGY SYSTEMS

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Abstract: *This paper presents the testing of two power transmission cables with different voltage levels. The first test involved a 10 kV cable connecting the 10/0.4 kV substations "Milenka Stojkovića" and "Studenička." The second test concerned a 35 kV outgoing cable from the "OMP Solar Aleksandrovo" substation to the trench along the route of the 35 kV "Tehnovas-Merošina" overhead line. The use of modern measurement and diagnostic methods enabled a reliable assessment of the operational condition of both cables, confirming their readiness for service. The results emphasize the importance of regular cable testing as a key factor in maintaining the reliability and safety of the power transmission system.*
Keywords: power transmission cables, cable testing, diagnostics, ARM method.

1. INTRODUCTION

Underground power transmission cables are key elements of power systems, ensuring reliable and efficient delivery of electricity from generation facilities to end consumers. Due to their construction and location, their maintenance and diagnostics require specialized methods and equipment. Timely and accurate testing allows for the detection of existing and potential damage, reducing the risk of downtime and increasing system safety.

Within the framework of the research, tests of two power cables of different voltage levels are described. The first test refers to the 10 kV cable connecting the transformer substations 10/0.4 kV "Milenko Stojkovića" and 10/0.4 kV "Studenička". The second test was carried out on the 35 kV cable – output cable from the 35 kV plant "OMP Solar Aleksandrovo" to the trench in the route of the 35 kV transmission line "Tehnovas-Merošina". The test procedures carried out included the application of modern methods of location and diagnostics to assess the correctness and readiness of the cables to work in the network.

2. BASIC INFORMATION ABOUT MEASURING CARS

Since the mid-20th century, when the Electric Power Industry of Serbia began to talk about the introduction of underground power cable networks, there have been significant doubts regarding the method of detecting and eliminating defects in long cable lengths, especially in the case of physical damage that occurs during exploitation. The question that arose was how to effectively locate and eliminate the fault when the cable line was laid underground. Over time, with the development and introduction of measuring circuits, these doubts have been significantly reduced, which enables reliable detection and elimination of faults, as well as safe release of live cable lines in underground installations.

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2.1 INTRODUCTION TO MEASURING CIRCUITS

Measuring circuits are specialized equipment designed to detect the location of a fault in underground cable lines, whether the fault is visible or hidden. In addition, they are also used to test power cable lines before they are put into operation, whether they are new installations or cables that have previously been used for the transmission of electricity.

These measuring circuits are equipped with various devices and components that enable the realization of all necessary measurements and tests. Among the basic elements of the measuring circuits are: the high-voltage cable drum, the connection plug of the measuring object, the high-voltage connection with earthing connection, the main earthing terminal, the protective earthing cable, the holder with probe and hammer, the protective conductor drum, the circuit breaker connection box, the mains cable drum, the mains connection plug and the spare connection housings.

The central part of the measuring circuits is the control unit, which functions as the "brain" of the system and allows adjustments depending on the type of test. For example, it can be used to locate a fault or for VLF (eng. *Very Low Frequency*) tests. On the control unit there are the following elements:

- Matrix display,
- Phase selection buttons,
- Buttons for one stroke generator,
- Self-test button,
- Taster *Esc,*
- Cursor keys,
- Shift button (without function),
- A key to confirm the entry,
- Measurement of reflection using *the Teleflex* device,
- Tonski generator,
- External resistance measurement,
- Ommeter,
- 0.1 Hz frequency testing (VLF option),
- Burner 15 kW,
- Arc surge procedure 3/6/12 kV (ARM),
- Arc surge procedure 50 kV (ARM)
- Surge test 3/6/12 kV,
- Impact test 25 kV,
- Surge test 50 kV,
- High Voltage Test
- Inclusion of high-voltage testing,
- Switching the control unit device on and off.

3. PROBLEMS OBSERVED ON CABLE LINES

The problems that are analyzed in this paper relate to two basic situations:

1. A fault in the underground power line, and
2. Difficulties that arise when re-energizing it after the repair has been carried out.

These problems pose a significant challenge in terms of the reliability and safety of the operation of power systems.

4. BASIC PARAMETERS OF THE CABLE LINE

The power cable line (PCL) used during the test is type XHE 49-A 3x1x150 mm^2, with rated voltages of 12/20 and 20/36 kV. Aluminum foil type XHE-49 (-A) cable is a single-core cable constructed from a copper or aluminum compact wire that serves as a conductor. Semiconductor layers (screens) are placed over the conductors and insulation, while below and above the electrical protection, made of copper wires and copper tape, there is a semiconductor swelling tape. Under the outer sheath of polyethylene is an aluminum copolymer foil. This construction, in addition to the use of high-quality materials, also includes additional protection measures – an outer sheath made of polyethylene and aluminum foil that prevent the penetration of water, as well as swelling strips that prevent its spread along the cable.

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5. TEST METHODOLOGY Power Cable Line (PCL)

For the successful location and testing of power cable lines, it is necessary to know the appropriate methods to achieve the desired result in practical implementation. In this paper, special emphasis is placed on the application of the arc reflection method (ARM method), which was used in a practical example.

5.1. ARC REFLECTION METHOD (ARM METHOD)

The arc reflection method is a modified version of the surge wave method, supplemented by a pulse formation and shaping circuit (O/mp) and an RFE filter, which prevents the passage of pulses from the surge generator to the radar.
In the first phase of the test, the radar sends pulses through the cable, recording a reference curve – whereby the malfunction is not visible.
In the second phase, the shock generator is switched on, which causes a jump at the fault site (the so-called "burning" of the fault), which reduces the resistance at that point and enables its precise detection.

6. PRACTICAL EXAMPLE OF PCL TESTING USING MEASURING CIRCUITS

Before proceeding with the location of the fault and testing of the PCL using measuring circuits, it is necessary to comply with the prescribed sequence of operations, to ensure the reliability of the results and the safety of operations.
In the continuation of the paper, the method of connecting the equipment and the implementation of the test is described, including the procedures for finding the fault route and verifying the correctness of the PCL after repair using the very low frequency (VLF) method.

6.1. CONNECTION AND REALIZATION OF PCL TESTING

Before starting the test, it is necessary to carry out detailed preparation to ensure safe operation. The procedure includes:

- Untying the cable on both sides,
- Testing the insulation of the EKV with a megameter on all three phases (sufficient on one side, where the generator will be connected to locate the fault),
- Grounding of measuring cars,
- connection of the high-voltage cable of the measuring object to the defective wire (depending on the number of defective wires),
- Grounding of the correct wires (if any), as well as cable braids, connected to the ground in the substation.

6.1.1. FAULT LOCATING TEST USING MEASURING CIRCUITS

After the proper connection of the measuring circuits to the PCL, the equipment is adjusted, and the test is carried out. Upon completion of checking the joints and securing the life-threatening zone, work with the control unit of the measuring wheels begins with.
The first step is to determine the permissible voltage for the surge generator, which is calculated according to the formula:

$$U_s = 2.5 * U_n \qquad (1)$$

where is:

- U_n – Nominal voltage PCL (6 kV),
- U_S –Surge voltag*e*.

By substituting the value, we get:

$$U_s = 2{,}5 * 6 = 15 \text{ kV} \qquad (2)$$

After that, the device is turned ON on the control unit, and then the TDR (eng. *Time Domain Reflectometer*), which measures the length of the cable line (the diagram is shown in Figure 1).

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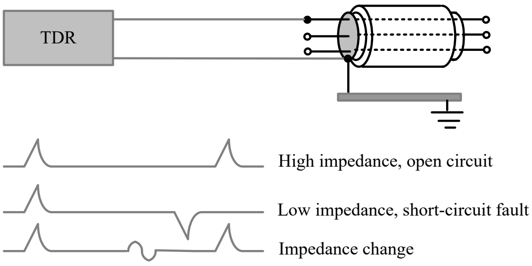

Fig. 1. Connection Scheme TDR-a

After determining the 4.3 km long section of the cable line, the device is adjusted through the control unit using the ARM method. A voltage of 15 kV is then set on the surge generator, and a device is switched on on the high-voltage unit, which is ready for fault location. Figure 2 shows the measurement method that registers the *Teleflex* device. A detailed analysis of the localized fault test will be presented in Chapter 7.

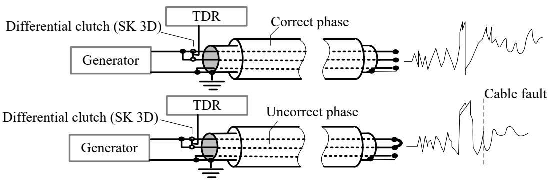

Fig. 2. (1) Reference curve and (2) fault curve on the "Teleflex" device

6.1.2. TEST OF EQ AFTER FAULT LOCATION USING VLF METHOD USING MEASURING CIRCUITS

Upon completion of the repair of the defect in the EKV, it is necessary to conduct an additional test to confirm the success of the repair and determine whether there is any other hidden defect in the water. The first step involves determining the voltage to be applied in the VLF test. For cables that have been in long-term exploitation, the formula is used:

$$U_{VLF}=1,7*U_N \qquad (3)$$

where is:

- U_{VLF} – voltage VLF testing,
- U_N – nominal voltage (6 kV).

A value exchange is obtained:

$$U_{VLF}=1,7*6=10,2 \text{ kV} \qquad (4)$$

After the voltage value has been determined, the device starts by turning on the control unit and selecting the VLF option. On the VLF device itself, the voltage is then adjusted to 10.2 kV, and then the high-voltage unit is activated. To achieve optimal efficacy, a test duration of 60 minutes is recommended, according to the data shown in Table 1.

Table 1: Effectiveness in testing PCL with the help of the VLF method

Time of the examination period PCL test	Percentage of success and safety of the PCL test
5 minute	60%
15 minute	80%
30 minute	90%
60 minute	95%

7. TESTING OF POWER TRANSMISSION CABLES

As part of the activities carried out on the control and maintenance of the electric power infrastructure, tests of high-voltage cables intended for the transmission of electricity around competence of "Electric Power Distribution of Serbia" were carried out. The tests included measuring electrical quantities and checking the correctness of the cables, with the aim of determining the possibility of their safe release.

The first test refers to the 10 kV cable connecting SS 10/0,4 kV "Milenka Stojkovića" and SS 10/0,4 kV "Studenička". Testing was carried out on 29.05.2025 in the consumption area of the Niš Branch. The test was carried out by measuring the resistance of the insulation and the current of the drain at different stages, whereby it was determined that the cable was in good working order and could be put under voltage.

A test report of this cable can be seen in Figure 3.

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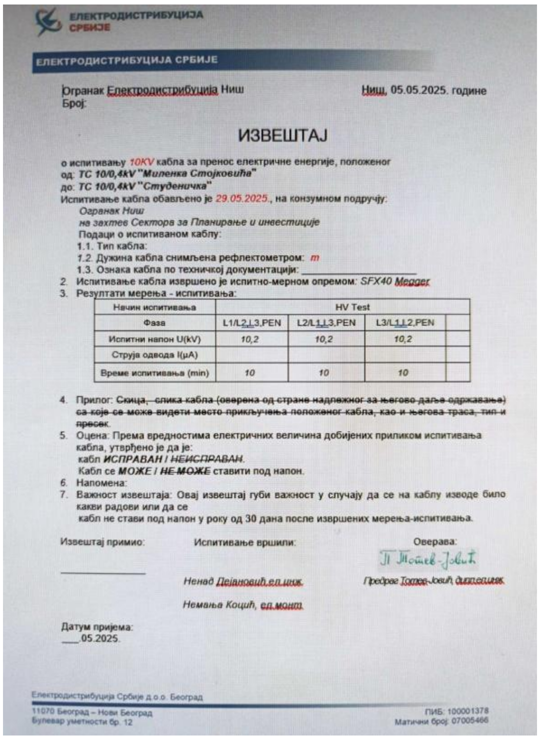
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ЕЛЕКТРОДИСТРИБУЦИЈА СРБИЈЕ

Огранак Електродистрибуција Ниш — Ниш, 05.05.2025. године
Број:

ИЗВЕШТАЈ

о испитивању 10KV кабла за пренос електричне енергије, положеног
од: *ТС 10/0,4kV "Миленка Стојковића"*
до: *ТС 10/0,4kV "Студеничка"*
Испитивање кабла обављено је 29.05.2025., на конзумном подручју:
Огранак Ниш
на захтев Сектора за Планирање и инвестиције
Подаци о испитиваном каблу:
1.1. Тип кабла:
1.2. Дужина кабла снимљена рефлектометром: *m*
1.3. Ознака кабла по техничкој документацији: ______________________

2. Испитивање кабла извршено је испитно-мерном опремом: *SFX40 Megger*
3. Резултати мерења - испитивања:

Начин испитивања	HV Test			
Фаза	L1/L2,L3,PEN	L2/L1,L3,PEN	L3/L1,L2,PEN	
Испитни напон U(kV)	10,2	10,2	10,2	
Струја одвода I(μA)				
Време испитивања (min)	10	10	10	

4. Прилог: ~~Скица, слика кабла (оверена од стране надлежног за његово даље одржавање) са које се може видети место прикључења положеног кабла, као и његова траса, тип и пресек.~~
5. Оцена: Према вредностима електричних величина добијених приликом испитивања кабла, утврђено је да је:
кабл ***ИСПРАВАН*** / ~~***НЕИСПРАВАН***~~.
Кабл се ***МОЖЕ*** / ~~***НЕ МОЖЕ***~~ ставити под напон.
6. Напомена:
7. Важност извештаја: Овај извештај губи важност у случају да се на каблу изводе било какви радови или да се
кабл не стави под напон у року од 30 дана после извршених мерења-испитивања.

Извештај примио: ______________

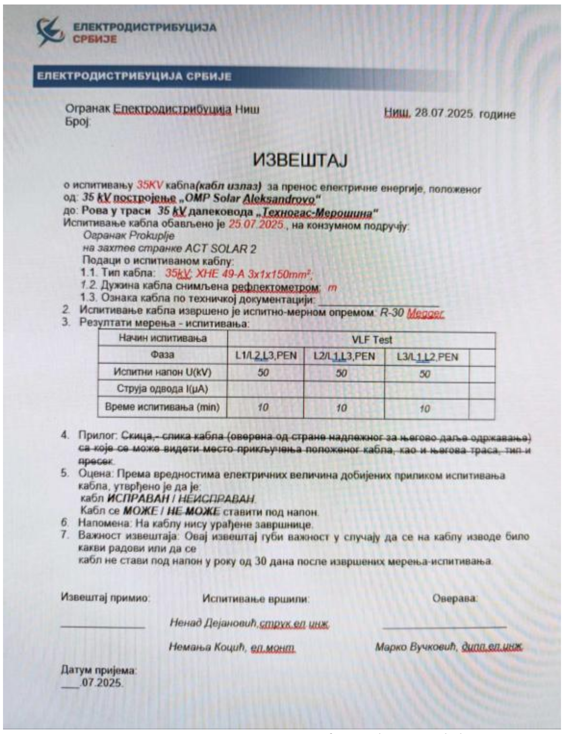
Испитивање вршили: *Ненад Дејановић,ел.инж.* / *Немања Коцић, ел.монт.*

Оверава: *Предраг Тотев-Јовић, дипл.ел.инж.*

Датум пријема:
___.05.2025.

Електродистрибуција Србије д.о.о. Београд
11070 Београд – Нови Београд
Булевар уметности бр. 12
ПИБ: 100001378
Матични број: 07005466

Fig. 3. Test Report of 10kV Cable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ЕЛЕКТРОДИСТРИБУЦИЈА СРБИЈЕ

Огранак Електродистрибуција Ниш — Ниш, 28.07.2025. године
Број:

ИЗВЕШТАЈ

о испитивању 35KV кабла***(кабл излаз)*** за пренос електричне енергије, положеног
од: ***35 kV постројење „OMP Solar Aleksandrovo"***
до: **Рова у траси *35 kV* далековода *„Техногас-Мерошина"***
Испитивање кабла обављено је 25.07.2025., на конзумном подручју:
Огранак Prokuplje
на захтев странке ACT SOLAR 2
Подаци о испитиваном каблу:
1.1. Тип кабла: *35kV; XHE 49-A 3x1x150mm²;*
1.2. Дужина кабла снимљена рефлектометром: *m*
1.3. Ознака кабла по техничкој документацији: ______________________

2. Испитивање кабла извршено је испитно-мерном опремом: *R-30 Megger*
3. Резултати мерења - испитивања:

Начин испитивања	VLF Test			
Фаза	L1/L2,L3,PEN	L2/L1,L3,PEN	L3/L1,L2,PEN	
Испитни напон U(kV)	50	50	50	
Струја одвода I(μA)				
Време испитивања (min)	10	10	10	

4. Прилог: ~~Скица, - слика кабла (оверена од стране надлежног за његово даље одржавање) са које се може видети место прикључења положеног кабла, као и његова траса, тип и пресек.~~
5. Оцена: Према вредностима електричних величина добијених приликом испитивања кабла, утврђено је да је:
кабл ***ИСПРАВАН*** / ~~***НЕИСПРАВАН***~~.
Кабл се ***МОЖЕ*** / ~~***НЕ МОЖЕ***~~ ставити под напон.
6. Напомена: На каблу нису урађене завршнице.
7. Важност извештаја: Овај извештај губи важност у случају да се на каблу изводе било какви радови или да се
кабл не стави под напон у року од 30 дана после извршених мерења-испитивања.

Извештај примио: ______________

Испитивање вршили: *Ненад Дејановић,струк.ел.инж.* / *Немања Коцић, ел.монт.*

Оверава: ______________ *Марко Вучковић, дипл.ел.инж.*

Датум пријема:
___.07.2025.

Fig. 4. Test report of 35 kV cable.

The second test relates to the 35 kV cable (output cable) from the 35 kV plant "OMP Solar Aleksandrovo" to the trench in the route of the 35 kV transmission line "Tehnovas-Merošina".

Testing was conducted on 25.07.2025 in the consumption area of the Prokuplje Branch. The test included measurements at a test voltage of 50 kV, and the results confirmed that the cable was in good working order and could be energized.

A test report of this cable can be seen in Figure 4.

Both tests have shown that the cables meet the prescribed technical conditions and can be safely put into operation, noting that the reports are valid within 30 days if no work is carried out on the cables in the meantime.

CONCLUSION

The results of the tests have shown that properly performed measurement procedures, with the use of appropriate equipment, allow a reliable assessment of the technical condition of power transmission cables. Testing of the 10 kV cable between the Milenka Stojkovic substation and the Studenica substation confirmed that the cable is ready for exploitation without any malfunctions. The 35 kV cable, which connects the OMP Solar Aleksandrovo plant with the route of the Tehnovas-Merošina transmission line, also confirmed the correctness and readiness for operation.

The application of appropriate location and diagnostic methods significantly contributes to reducing the risk of unplanned power outages, optimizing maintenance and extending the service life of the infrastructure. Based on the results obtained, it can be concluded that regular cable tests play a key role in maintaining the reliability of the power system.

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