MATEC Web of Conferences **210**, 02054 (2018) https://doi.org/10.1051/matecconf/201821002054
CSCC 2018

Impact analysis of changing the neutral treatment solution in an MV electrical station on the system performance

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Abstract. The actual operation of the power distribution systems asks for high standards concerning the performance of the system in terms of continuity and safety in supplying consumers on the one hand and the quality of the delivered energy on the other hand. Thus, the paper aims to present a complete analysis of the impact that the modification of the neutral treatment system in a 110 kV / MV station belonging to Energy Distribution Oltenia (DEO), has on both the number and the type of unwanted events or phenomena as well as on the network parameters and the transient regime which occurs as a result of some defects with the earth. All of these have been analyzed taking into account the new performance standards that distribution systems have to respect.

1 Introduction

Distribution companies that activates in Romanian energy field used in our days a global polity to improve the power distribution and security service, concerning the users supplying, according to the new standards in this field provided by the Romanian Energy Regulatory Authority order number 11/2016, modified and completed by order 47/2017 [1], [2].

The most valuable and important facts that concerns the companies who are involved in this process, are to made significant efforts to increase the quality of the electrical power distribution service, in condition of current operating philosophy for free energy markets that imposed a costs reduction in related to the electricity distribution process [3].

Choosing a solution to treat the neutral of medium voltage (MV) networks is done over a long period of time, involving a large volume of investment and the need to substantiate very carefully the decision taken. The solution adopted at the time of dealing with the neutrality of an electrical network must best meet the requirements and the purpose for which the network is built.

Technological developments associated with a particular way of treating the neutral as well as the evolution and further development of the electrical networks in compliance with the regulations in force may be able to change the terms of the choice at some point. Thus, a solution considered optimal at one point may yield to another's favor, or may be imposed with even greater severity.

Taking into account all these, the neutral treatment system in MV susbstation plays an important role in this electrical distribution networks. For the operators and end users, the major purposes are to provide a safe operating environment for personnel and continuity of supply, and to avoid damages to the equipments [4].

Events occurring as a result of temporary or permanent faults can be costly in terms of network availability, equipment costs and compromised safety. Interruption of power supply in electricity, valuable damage to equipment at the fault event point, premature ageing of equipment at other points on the system and a heightened safety risk to personnel are all possible consequences of all these fault situations.

According to the actual IEC standards [5] (for insulation coordination) the main particularities associated to each neutral grounding arrangement are defined as following:

• Isolated neutral system - at the beginning all MV networks were isolated because conditions for arc self-extinction were fulfilled. Therefore networks could be operated during a fault without additional risk for people and utility. Internal overvoltages in such systems can be up to 2.7Un [6].

• Low-ohm grounding of neutral point - people's and utilities' safety was the reason of letting go isolated neutral and shifting to low-ohm grounding. It manifests itself in having a ground fault current which has a dominant resistive component [7]:

$$3I_R>I_C \tag{1}$$

It affects lower internal overvoltages and intermittent can't even happen. Overvoltages rise up to 1.9Un. The utility equipment such as interrupters and relay protection reacts reliable on mainly resistive ground fault current. In a contrary to isolated neutral systems, network with low-ohm grounding can't be operated while having a fault.

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• Partial compensation grounding of neutral point - resistor and reactor connected in parallel create a partial compensation grounding system.
Advantage of using this grounding is the reduction of a ground fault current with compensating capacitive current. Overvoltages seem to be small too.
Without lots of network changes it looks like a good way of grounding. Disadvantages of this solution lay in the reactor's inability to adjust its inductance to the network's capacitance.
• Resonant grounding (Arc suppression coil) - Arc suppression coil with automatic adjustment of inductance is used in the resonant grounding systems. The biggest advantage of this type of grounding is the improvement of SAIDI and SAIFI indexes without bringing people and utilities in danger.
Overvoltages go up to 2.5Un and intermittent voltages don't exist [6].

2 Project Bridge Grant between UCV / DEO

Evaluation and experimental tests for analyzing the state of the art concerning the neutral system treatment were performed in Stoina, an Energy Distribution Oltenia (DEO) transformation substation 110/20 kV with neutral system treated via a resistor, within a UCV/DEO project - *Bridge Grant* - Knowledge Transfer.

One of the University of Craiova (UCV) / INCESA (Research Hub of Applied Sciences, University of Craiova) projects financed by national grants and based on a partnership with the regional power distribution company –Energy Distribution Oltenia – is called "Intelligent solutions for neutral grounding in 110/MV distribution substations for increasing of the energy efficiency, personnel security and reliability of power users' supply" [8], has as one of the main objectives analysis of the methods for neutral treatment and its implications concerning safe operating environment for the network / personnel and continuity of the power supply.

Knowledge transfer known in literature as the movement of know-how or technical knowledge from one organization to another, is considered to be one of the most important components of the strategic plan of the UCV / INCESA research institute - a young organization; it already counts an important number of collaborations with the local and regional business environment [9],[10].

Research Hub for Applied Sciences is intended to be an inspiring co-working space for driving effective innovation for the benefit of ever wider communities. Times have changed, people have changed … we need to harmoniously meet the expectations of cutting-edge researchers, entrepreneurs and strategic business and socio-cultural partners in a most active and interactive way. INCESA is a hub, framing mindsets, incubating innovative ideas and intensifying and amplifying outcomes for all the intended destinations [10].

Consequently, it is developing a management strategy that approaches the knowledge transfer to the industry as a recurrent event.

The regional power distribution operator DEO delivers power energy for 7 counties in the Oltenia region, being committed to supplying all of it's over 1,400,000 clients with high quality electricity (over 3.5 million people).

DEO ensures through its own network (110kV, 20kV, 6kV and 0.4 kV) the power supply of industrial, domestic and service consumers.

The rapid expansion of activities and units, doubled by the permanent objective of network reliability improvement and smart concept implementation shape its policy regarding the staff professional development and expertise.

Following these trends, DEO is perfectly aware of the importance of having highly qualified employees. One of the strategies used is the development and integration to partnerships with the local academic and research environment [4].

3 Fault event analyses

The above mentionated distribution substation 110/20 kV named Stoina, has a solution used for neutral treatment powered by resistor, and is located in Oltenia region - Gorj County. This station consists of a 110 kV bar divided into two sections connected by a longitudinal coupler, being equipped with two power transformers called T1 - 110/20 kV transformer with an apparent power of 16 MVA and a group of Yo D-11 connections; and T2 - 110/20 kV transformer with an apparent power of 10 MVA and a group of Yo D-11 connections.

On medium voltage level, the station is made up of 2 bus bars, the connection between them being realized by a transverse coupling. They feed 5 starting cells named: Coltesti; Totea; Slămneşti; Compresoare; Stejari. The station also has two transformers for internal services with nominal power of 100kVA, Yzo5, $u_{SC}\%$ = 4%, I_{np}/I_{ns}=3A/144,5A and BTN 20 + resistors with nominal voltage of 20 kV/11,55 kV, a current of 600/300A, and a resistance of 38-8 Ohm [3].

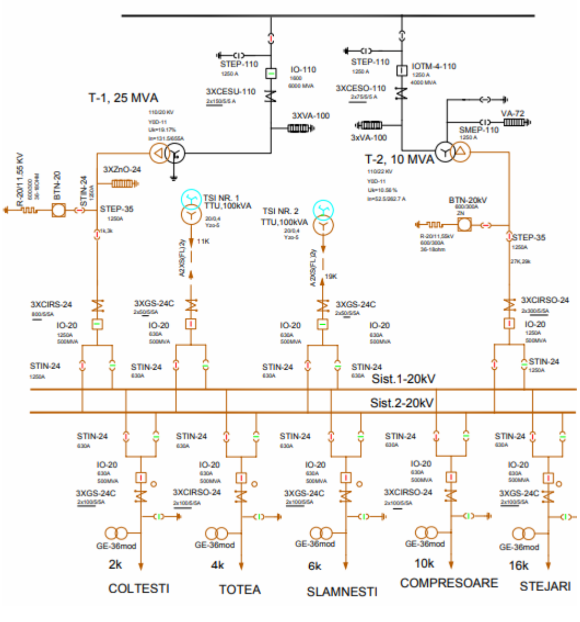


Fig. 1. Simplified monophilic scheme - Stoina substation (R).

The analysis of events in substations with duration of less than 3 minutes and those lasting over 3 minutes separately is of particular interest since it refers to different activities: defects of less than 3 minutes are normal in the energy system and are disconnected by the electrical protection systems by relays.

Failures over 3 minutes are due to internal causes that could have been avoided: rehabilitation of electrical lines, insulation maintenance and equipment, and incorrect correlation of protection systems between the user and the distributor (DEO) [1].

In this respect, analysis based on statistical data can play an important role in improving maintenance management at DEO, highlighting the main causes that affect the power supply service.

Vulnerability is the extent to which a system can be affected by a hazard impact and encompasses all the physical, social, economic, and environmental conditions that increase the susceptibility of the system. Like hazard, vulnerability is an indicator of a future state of a system, defining the level of the (in) ability of the system to cope with the expected stress.

The risk is the probable level of losses and damage to the energy system by a particular phenomenon or group of phenomena in a given place and in a certain period. Despite a very precise appearance of the quantitative risk assessment method, there is a great uncertainty in the practical implementation of such a methodology. The level of the risk varies depending on a number of predictable factors.

Vulnerability has been analyzed on the basis of risk and impact concepts. In this sense, evaluation matrices have been defined and proposed according to the number of affected consumers, the duration of the remediation and the probability of occurrence of a defect [1].
Analyzing the statistical data related to the events occurring in the stoma station for a period of about 2 years before 2017 and studying the behavior of the resistor treatment method in the same period [3], it was proposed to modify the neutral treatment solution by switching to the coil treated with the suppression coil, solution implemented since September / October 2017.

To analyze the impact of the treatment solution change, the events were followed and the levels of risk and food continuity indicators were determined over a period of about 9 months - before and after the change of the treatment solution.

3.1. in neutral treatment solution – used until 09.2017

In the period prior to the change of the treatment solution (January - September 2017, approximately 9 months), a total of 123 undesirable events were highlighted: 77 incidents less than 3 minutes, 6 incidents greater than 3 minutes and 40 incidents resolved by protection.

For the proper analysis, only incidents greater than 3 minutes were considered, determining the corresponding risk levels (Figure 2) [11].

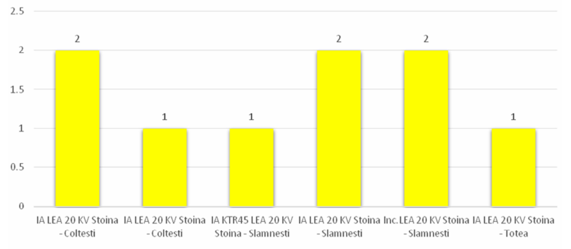


Fig. 2. Risk levels values - Stoina substation - initial neutral treatment solution.

and also calculating the [2] and the continuity indicators in power supply for Stoina electric substation shown graphically (Figure 3).

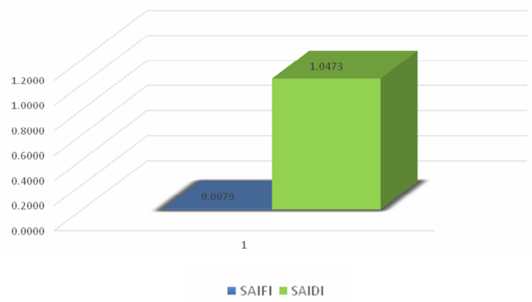


Fig. 3. Continuity indicators in power supply - Stoina substation - initial neutral treatment solution.

The 6 incidents greater than 3 min analyzed were generated from falling trees on line conductors, defects in the outside area or defective equipment - broken / cut off insulator.

3.2. in actual neutral treatment solution – used after 09. 2017

After the implementation of the proposed solution for switching to the suppression coil with the parameters determined according to the analyzed conditions [11], up to now, a total of 46 unwanted events have been highlighted, out of which: 27 incidents less than 3 minutes, 3 incidents greater than 3 minutes and 16 incidents resolved by protection. Evolution of risk levels and continuity indicators for the current situation are presented graphically (Figures 4 and 5).

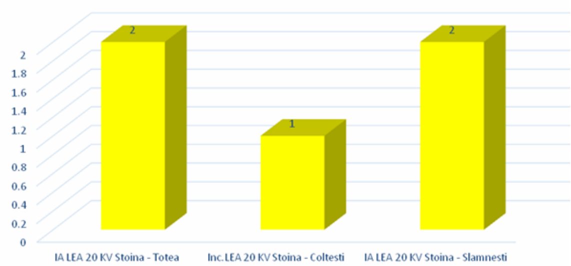


Fig. 4. Risk levels values - Stoina substation - actual neutral treatment solution.

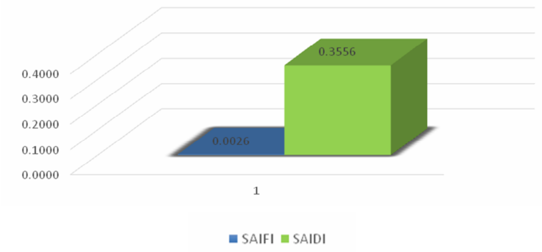


Fig. 5. Continuity indicators in power supply - Stoina substation - actual neutral treatment solution.

4 Tests for comparative analysis between the two treatment methods

The comparative analysis between the neutral treated by resistor and the neutral treated by the suppression coil aims at studying the overcurrents on the phase connected to ground, the overvoltages, and the duration of the transient regime after the fault triggering - on the basis of the tests performed in the Stoina station in both situations - net grounding.

At present, the normal scheme for neutral treatment in the 110/20 kV Stoina distribution substation is shown in Figure 7, which shows that the 20 kV network operates with the suppression coil type TRENCH – ENK - 20kV with 50A and 630kVA connected to the system by two TSI transformers of 630kVA - 20/0,4kV type ZnYn-5 (Figure 6).

The coil is EFC 20 automatically adjusted so that any change in the network configuration quickly leads to the adjustment of the corresponding values so that its overcompensation remains always the same.

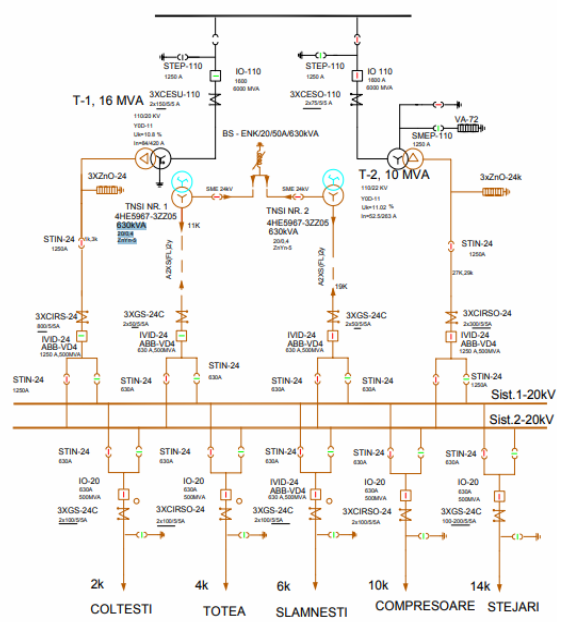


Fig. 6. Simplified monophilic scheme - Stoina substation (SC).

Samples – grounding - were carried out at the terminal block of the second phase belonging to the line LES 20 kV (to the pillar No. 1) by mounting a short-circuit cable with its connection to the pole earth inlet (grounding) [3], [12],[13], [14].

• Currents in effective value during the earth fault through the three phases.

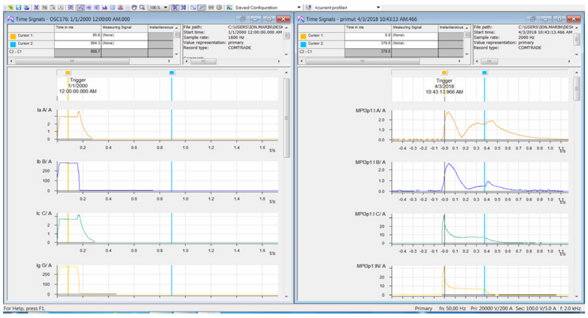
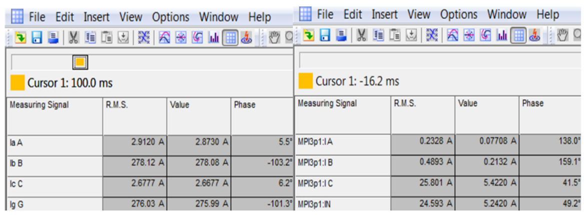


Fig. 7. Phase and homopolar current neutral treated with resistor / neutral treated with coil

For the neutral treated by resistor during grounding, an overcurrent is being recorded from the substation data system on the earthed phase (phase B) of 278.12 A, current who leading to the triggering of the line through the protections (Figure 8 left) [15].



Cursor 1: 100.0 ms

Measuring Signal	R.M.S.	Value	Phase
Ia A	2.9120 A	2.8730 A	5.5°
Ib B	278.12 A	278.08 A	-103.2°
Ic C	2.6777 A	2.6677 A	6.2°
Ig G	276.03 A	275.99 A	-101.3°

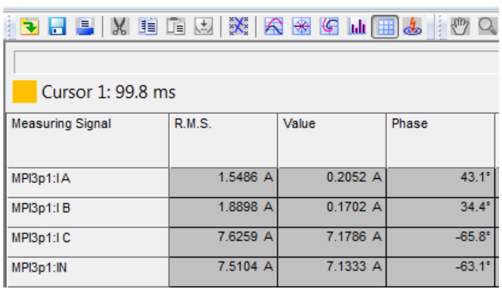
Cursor 1: -16.2 ms

Measuring Signal	R.M.S.	Value	Phase
MPl3p1:A	0.2328 A	0.07708 A	138.0°
MPl3p1:B	0.4893 A	0.2132 A	159.1°
MPl3p1:C	25.801 A	5.4220 A	41.5°
MPl3p1:IN	24.593 A	5.2420 A	49.2°

Fig. 8. Overcurrent on the ground phase neutral treated with resistor / neutral treated with coil

For the neutral treated by the suppression coil, immediately after grounding, an overcurrent of 25,801 A (Figure 8 right) appears on the earth phase (phase C).

The overcurrent is stabilized after approx. 120 ms at the moment of grounding at 7.6 A (Figure 9), if the fault is passing the coil extinguishes the electric arc at the ground.



Cursor 1: 99.8 ms

Measuring Signal	R.M.S.	Value	Phase
MPl3p1:I A	1.5486 A	0.2052 A	43.1°
MPl3p1:I B	1.8898 A	0.1702 A	34.4°
MPl3p1:I C	7.6259 A	7.1786 A	-65.8°
MPl3p1:IN	7.5104 A	7.1333 A	-63.1°

Fig. 9. Current stabilized on the ground phase - neutral treated with coil.

 https://doi.org/10.1051/matecconf/201821002054

• Overvoltages during grounding and after triggering the line.
For the two modes of neutral treatment – with coil and with resistor, variation of phase voltages during grounding (effective values) and phase voltages variation after triggering of the grounding line are shown in figure below.

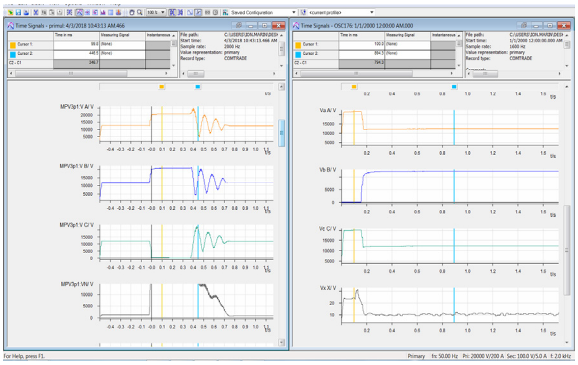


Fig. 10. Phase and homopolar voltages - neutral treated with coil / neutral treated with resistor.

For the neutral treated by resistor, the effective surge voltage during grounding is 21.45 kV (Figure 11 left), and after the grounded line is triggered the duration of the transient regime is very low for about 20 ms and no other overvoltages occur.

For the neutral treated by the suppression coil, during grounding, the effective values of the overvoltages on the all three phases are (Figure 11 right) [15]:

• Phase A - V_A=20.835 kV;

• Phase B - V_B=20.813 kV;

• Phase C (grounded) - V_C= 0.14 kV

Cursor 1: 100.0 ms

Measuring Signal	R.M.S.	Value	Phase
Ia A	2.9120 A	2.8730 A	5.5°
Ib B	278.12 A	278.08 A	-103.2°
Ic C	2.6777 A	2.6677 A	6.2°
Ig G	276.03 A	275.99 A	-101.3°
Va A	21.452 kV	21.438 kV	55.7°
Vb B	0.08029 kV	0.04474 kV	21.4°
Vc C	20.028 kV	20.017 kV	117.5°

Cursor 1: 99.8 ms

Measuring Signal	R.M.S.	Value	Phase
MPI3p1:IA	1.5486 A	0.2052 A	43.1°
MPI3p1:I B	1.8898 A	0.1702 A	34.4°
MPI3p1:I C	7.6259 A	7.1786 A	-65.8°
MPI3p1:IN	7.5104 A	7.1333 A	-63.1°
MPV3p1:V A	20.835 kV	20.821 kV	49.0°
MPV3p1:V B	20.813 kV	20.800 kV	-11.2°
MPV3p1:V C	0.1405 kV	0.02301 kV	116.5°
MPV3p1:VN	20.853 kV	20.844 kV	19.0°

Fig. 11. Overvoltages - neutral treated with resistor / neutral treated with coil.

The duration of the transient regime after the triggering of the grounding line is very high compared to the neutral treated by the resistor, namely about 400 ms (20 times higher).

During the transient regime, voltage oscillations occur with the maximum value on the phase A of V_A = 24,883 kV.

Cursor 1: 401.1 ms

Measuring Signal	R.M.S.	Value	Phase
MPI3p1:IA	1.7666 A	0.01776 A	156.2°
MPI3p1:I B	0.8412 A	0.08075 A	170.2°
MPI3p1:I C	5.3758 A	0.3261 A	159.3°
MPI3p1:IN	2.9119 A	0.3958 A	163.5°
MPV3p1:V A	24.883 kV	24.616 kV	78.4°
MPV3p1:V B	14.629 kV	14.184 kV	20.3°
MPV3p1:V C	11.263 kV	10.685 kV	135.1°
MPV3p1:VN	22.916 kV	22.066 kV	73.7°

Fig. 11. Maximum overvoltage values during the transient regime after triggering the grounding line.

The points outlined above lead us to the following conclusions:
• the earth leakage ground for the neutral treated by the resistor is much higher than the neutral treated by the coil, so in the case of the coil some passive defects are extinguished by the coil and the consumers remain fed;
• overvoltages occurring both during and after grounding are higher for the neutral treated by the coil compared to the resistor treated feed;
• the duration of the transient regime after triggering the grounded line is much higher for the neutral treated by the extinguishing coil, so by default there is a much greater probability that the defect will evolve into a double grounding, a defect that can lead to the subsequent triggering of other lines;

5 Conclusions

The modification of the neutral treatment method in the Stoina electric substation was mainly aimed at improving the performance of the distribution service by decreasing the number of events / incidents, which lead directly to obtaining better continuity indicators, provided the standards in force and satisfying the users' requirements.

As a result of those presented above in the paper, the following advantages result from the transition to the neutral treated by the suppression coil:
• The decrease in the total number of events/incidents, but especially those lasting over 3 minutes (to about 50%).
• Maintaining the level of risk at a relatively low value (Yellow 2) being defined as the probable level of losses and damage to the energy system by a particular event / incident or group of events / incidents in a specific place and within a certain period.
• Improvement of SAIFI and SAIDI continuity indicators, with the indication that although the analyzed period is not very long, the improvement trend is certain.
• Any single-phase fault that causes a current of less than 10 A to be grounded will become a passing fault because it will be extinguished by the suppression coil, whereas in the case of a resistor – neutral treated network, the fault will lead to the triggering of the line and the interruption of the consumers power supply.

• In the normal operating mode, for the same neutral displacement voltage, the current flowing through the suppression coil (for the 20 kV artificial neutral treated by the coil) is less than the current flowing through the resistor (for the artificial neutral 20 kV resistor treated), thus the additional losses introduced by the treatment method under normal operating conditions are lower for the neutral treated by the suppression coil.
• Touch and step voltages for the neutral treated by the suppression coil are smaller than those for neutral system treated by resistors.

Acknowledgement

This work was supported by a grant of the Romanian National Authority for Scientific Research and Innovation, CNCS / CCCDI – UEFISCDI, project number PN-III-P2-2.1- BG-2016-0202, within PNCDI III".

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