INFLUENCE ANALYSIS OF NEUTRAL TREATMENT METHODS ON THE PERFOMANCE INDICATORS FOR AN ELECTRICAL ENERGY DISTRIBUTION SERVICE

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Abstract – The paper proposes to present the way through which the neutral treatment method influences the performance indicators of an electrical energy distribution service. In the paper are presented both the calculation methods for all indicators as well as their evolution using as reference two different electric stations pertaining to Distribuție Energie Oltenia (DEO), stations which during 2017 have had their neutral treatment method changed. The indicators regarding the quality of the transport and distribution service, as well as the quality of the electric energy distributed through the electrical transport network (RET) and the electrical distribution network (RED) represent an essential factor in the substantiation of the technical and economic elements related to the execution/ modernization of the electric networks and influence greatly the economic efficiency of the users' activity. In the category of users of the electric networks are included the consumers of electric energy, the distribution operator, the producers and other network operators connected to the networks of the national electrical system (SEN).

Keywords: electric station, neuter treatment, performance indicators

1. INTRODUCTION

National energetic system **- SEN** comprises all the installations for the production, transport, distribution and supply of electric energy in Romania, regardless of the manager of the respective installation, are interconnected among them and have a joint and continuous regime of production and use of electric energy.

The distribution of the electric energy is done through electric lines with voltage values ranging between 0,4 and 110kV.

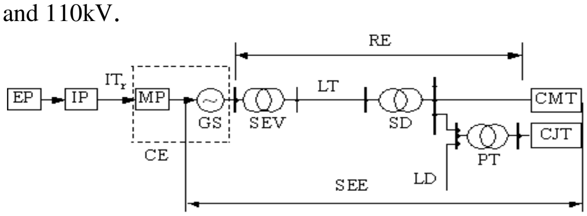

Fig. 1. Graphic representation of SEN

where**: SEN** – national energetic system; **EP** – primary energy; **IP** – primary installation; **ITr** – transport installation ; **MP** – primary machine; **GS** – synchronous generator; **CE** – electric plant; **SEV** – evacuation station; **LT** – transport line; **SD** – distribution station; **LD** - distribution line; **PT** – transformer station; **CMT** – medium voltage consumer; **CMJ –** low voltage consumer [1].

The distribution operator has the obligation to ensure continuity of supply of electric energy in accordance with the performance levels set by the performance standard for the electric energy distribution service [2], [3]. The operator needs to take all measures in order to continuously supply electric energy, reduce the duration of the interruptions and schedule them on dates and at hours which affect as few as possible users.

The electric energy distribution companies have an important role in ensuring the reliability of supply with electric energy, the safety of the employees working in the electric stations and of the persons using electric energy and in ensuring an adequate energy price for the final users.

Through the development strategy, CEZ Distribuție / Distribuție Energie Oltenia SA propose to improve the safety level in the distribution of electric energy, to reduce energy losses and to limit accidents of electric nature.

The activities of the distribution service include operation, maintenance and development of the electric systems, with the purpose of distributing electric energy from producers to users, while complying with the safety conditions during operation of electric installations, safety during functioning, ensuring the quality parameters and reducing maintenance costs.

Currently in CEZ Distribuție / Distribuție Energie Oltenia SA there are several methods for neutral treatment which have been implemented over the years as follows: - neutral treatment with extinguishing coil, with automatic or manual adjustment, with/without additional resistors installed in the secondary power in the extinguishing coil; - neutral treatment with resistor, respectively resistor associated with shunt circuit breaker which was not functional but has now been reactivated; - mixed treatment; - insulated neutral. These treatment systems are dedicated to a certain network configuration and present advantages and disadvantages, which requires their continuous improvement [4], [5].

The phenomena which manifest in the distribution installations directly influence the main quality parameters of the electric energy supplied to the users and especially, the parameter which characterizes the continuity of supply of electric energy.

Neutral treatment in the electric networks represents one of the factors of which depends the safety of electric energy supply to the users.

From the point of view of the position of the neutral to the earth the following types of networks can be distinguished [5]:

- network with insulated neutral – neutral does not have any deliberate link to the earth, with the exception of those done by metering, signaling and protection devices, which have a very high impedance;
- compensated network – neutral is bound to the ground through coils which have a reactance of such a value, which in case of a defect between a phase of the network and the ground, the inductive current circulating between the defect area and the coil is subtantially compensating the capacitive component of the deffect current; for the networks which are correctly compensated through the extinguishing coil, the resultant current n the defect area is limited so that the earthing electric arc is extinguished spontaneously;
- network with earthed neutral – directly through resistor or sufficiently small reactance coil.

The schematic diagram of neutral treatment is shown below in figure 2 [6].

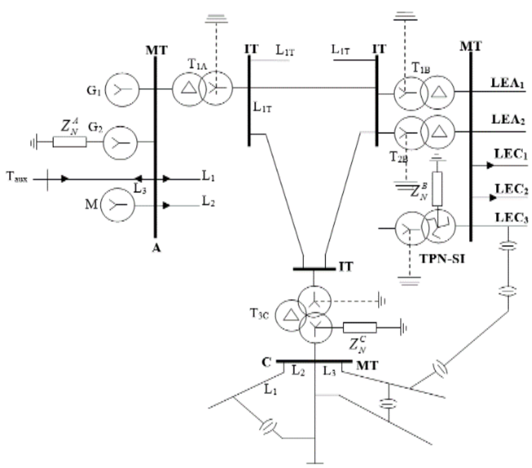

Fig. 2. Schematic diagram of neutral treatment

2. PERFORMANCE INDICATORS RELATED TO THE CONTINUITY OF ELECTRIC ENERGY DISTRIBUTION SERVICE

The performance indicators related to the continuity of the distribution service refers to the interruptions in electric energy supply of the users connected to the network (electric distribution network) [2], [3]. Depending on the duration interruptions are classified in:

- transient interruptions: with durations of maximum 1 second;
- short interruptions: lasting from 1 second to 3 minutes;
- long interruptions: longer than 3 minutes.

For every interruption are recorded:

- the voltage at which the interruption occurred;
- the planned or unplanned (for the calculation of the continuity indicators), respectively the announced or unannounced character of the interruption (for the recording of the interruption);
- the cause of the interruption;
- the date, time and minute of the start, respectively the end of the interruption;
- the total duration of the interruption;
- the electrical power interrupted (last power measured before interruption), or estimated electricity calculated as non-delivered to users / not produced in the plant due to the interruption.

Each event in the RED, which has the effect of long-term interruption of the users' power supply, is presented individually in the annual activity report of the DO (the distribution operator).

The distribution operator records and calculates annually the following data on the continuity of electricity supply for users in the activity area [2], [3]:

a) Energy not supplied to the users/not produced in the plants due to long term interruptions - ENS (Energy Not Supplied) is calculated with the relationship:

$$ENS = \sum_{i=1}^{n} \left(P_i \cdot \frac{D_i}{60} \right) \quad [MWh] \tag{1}$$

where: n – represents total number of long term interruptions; P_i – represents electrical power interrupted at interruption i (last power measured before interruption) (MW); D_i – represents duration of the interruption i (minutes).

b) Average Interruption Time – AIT (Average Interruption Time) is the average equivalent period of long-term interruptions, expressed in minutes per year, and is determined by the relationship:

$$AIT = 8760 \cdot 60 \cdot \frac{ENS}{AD} \left[\frac{min}{an} \right] \tag{2}$$

where: ENS - energy not supplied to the users/not produced in the plants due to long term interruptions (MWh); AD – represents annual demand of electric energy (Annual Demand), exclusively losses of active electric energy in ETN and EDN, including export (MWh).

c) SAIFI (System Average Interruption Frequency Index) – the average frequency of network interruptions (system) for a user is the average number of interruptions supported by users connected to the DO network. The indicator is calculated by dividing the total number of interrupted users who have experienced an interruption of more than 3 minutes to the total number of users supplied

$$SAIFI = \frac{\sum_{i=1}^{n} N_i}{N_t} \tag{3}$$

where: N_i - the number of users interrupted over 3 minutes at interruption i; N_t – total number of users supplied.

d) SAIDI (System Average Interruption Duration Index) – index of average duration of interruptions in the network (system) for a user, presents the average interruption time of the users at distribution operator level, calculated as a weighted average, dividing the cumulative duration of long interruptions to the total number of users served by the distribution operator, as follows:

$$SAIDI = \frac{\sum_{i=1}^{n}(N_i \cdot D_i)}{N_t} \left[\frac{min}{an}\right] \quad (4)$$

sau

$$SAIDI = \frac{\sum_{i=1}^{n}\sum_{j=1}^{k_j}(N_{ij} \cdot D_{ij})}{N_t} \left[\frac{min}{an}\right] \quad (5)$$

where: n – total number of long interruptions; k_i – the number of reconnection steps corresponding to the interruption i; N_i – the number of users interrupted over 3 minutes at interruption i; N_{ij} – the number of users interrupted over 3 minutes at stage j of interruption i; P_i – total electrical power interrupted at interruption i, only for HV; D_i – duration (time) of users' interruptions from the moment of loss of voltage until reconnection for interruption i; D_{ij} – duration (time) of users' interruptions from the moment of loss of voltage until reconnection for stage j of interruption i; N_t – total number of users supplied;

e) MAIFI (Momentary Average Interruption Frequency Index) – momentary average interruption frequency index – short-term interruptions – as a ratio between the total number of short-term interrupted users and the total number Nt users supplied in the system analyzed:

$$MAIFI = \frac{\sum_{m=1}^{M} N_m}{N_t} \left[\frac{min}{an}\right] \quad (6)$$

where: M is the total number of short-term interruptions; N_m – the number of users who suffered a short duration (less than 3 minutes), for each interruption m.

SAIFI, SAIDI and MAIFI indicators are usually determined based on automatic records of MV and HV interruptions, and for LV are estimated through calculation. ENS and AIT indicators are calculated only for users connected to HV electrical network.

SAIDI is considered to be a higher order indicator because it represents an average of the interruption time, but it involves recording the duration of each interruption.

3. ANALYSIS OF THE TREATMENT METHOD ON PERFORMANCE INDICATORS – CASE STUDY

Transformer station 110/20kV Stoina, pertaining to distribution operator Distribuție Energie Oltenia, is located in Balosani village, Stejari commune, Gorj County. The 110 kV station was put in function in 1991, it is an exterior type of station, equipped with 3 cells of 110 kV overhead line, 2 transformer cells 110/20 kV and a longitudinal coupling cell with 110 kV separators. The power transformers are T1-110/20 kV-16 MVA and T2-110/20kV-10 MVA. The single line diagram of Stoina station is found in figure 3 [7].

The treatment of the neutral in Stoina station was made through the resistance method, and after the modernization it is done using an extinguishing coil.

The station supplies a number of over 7500 users in the location area.

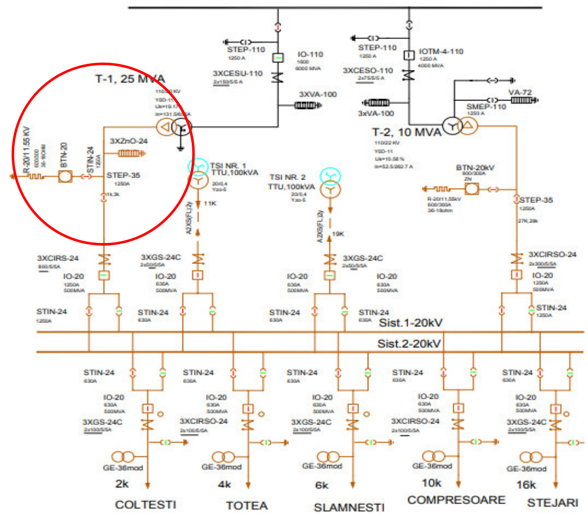

Fig. 3. Stoina single line diagram with neutral treatment through resistor

Station 110/20 kV Poiana Lacului is located in Arges county and was put in function in the years 70', it is not modernized and not included in SCADA, DEO's own command and control system, until end of 2017 when the treatment system was modified.

The line and transformer cells are equipped with separators type STEP 110 kV, I_n=1600 A, switches type IO 110 kV, I_n=1600 A, S_r = 6000 MVA operated with mechanisms type MOP - 1, current measurement transformers type CESU 110 kV 2x300/5/5/5 A for lines and CESU 110 kV de 2x 100/5/5/5 A for transformers.

The single line diagram of Poiana Lacului station is found below in figure 4 [7]. The station supplies a number of over 15000 users in the location area.

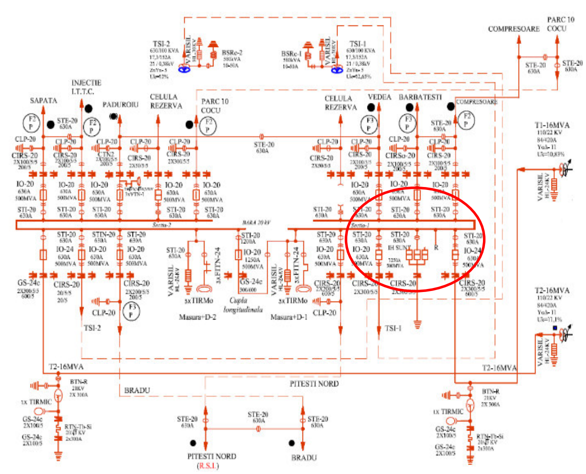

Fig. 4. Poiana Lacului 110/20kV station single line diagram with neutral treatment with extinguishing coil

3.1. Analysis of the behavior of events

The analysis of events in stations with duration of less than 3 minutes and those lasting over 3 minutes separately is of particular interest because it refers to different activities:

- defects under 3 minutes are normal in the power system and are disconnected by the relay electrical protection systems.
- defects over 3 minutes are due to internal causes that could have been avoided: deforesting of electrical lines, insulation and equipment maintenance, and incorrect correlation of protection systems between the user and the distributor.

In this respect, the analysis based on statistical data may have an important role in the improvement of the maintenance management in Distribuție Energie Oltenia (DEO), highlighting the main causes affecting the distribution service [8].

The Vulnerability has been analyzed on the basis of risk and impact concepts. In this respect, evaluation matrices have been defined and proposed according to the number of users affected, the duration of the remediation and the probability of a defect.

The Impact is studied depending on the number of users affected and the remediation time.

(yellow)	Low IMPACT – under 1000 users affected and a remediation period of max 12 hours
(orange)	Medium IMPACT – between 1000 and 5000 users affected and a remediation period between 12hours and 24 hours
(red)	High IMPACT – over 5000 users affected and a remediation period greater than 24 hours

The Probability is defined as a frequency function of the occurrence of a hazard.

(yellow)	Low PROBABILITY: the frequency of occurrence of a hazard is less than 6 in the analyzed range
(orange)	Medium PROBABILITY– the frequency of occurrence of a hazard is greater than 6 but less than or equal to 24 in the analyzed range;
(red)	High PROBABILITY- the frequency of occurrence of a hazard is greater than 24 in the analyzed range.

The level of risk was defined as function of impact and probability.

(yellow)	Low risk level - value interval from 1 ÷ 4
(orange)	Medium risk level - value interval from 5 ÷ 10
(red)	High risk level - value interval from 11 ÷ 30

3.2 Events found subsequent to analysis and monitoring in the 2 stations

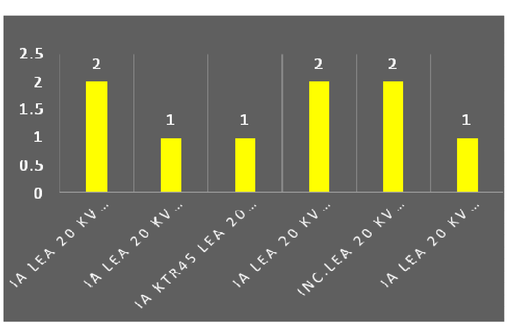

Fig. 5. Risk levels in Stoina station after modification of neutral treatment method

Table 1

Values indicators in Stoina station before the modification of the treatment method	Value
SAIDI	1,68
SAIFI	0,025

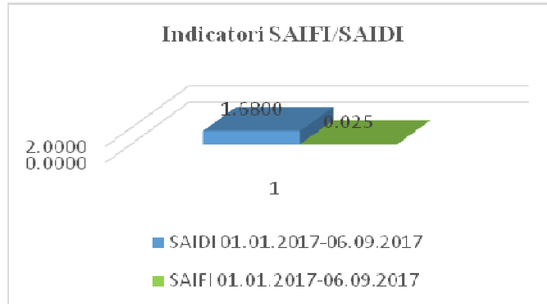

Fig. 6. Graphic indicators in Stoina station before changing the neutral treatment method

Description of the events occurred in Stoina 110 kV/MT station is presented in the table below.

Table 2

Defect exterior area	**1**
Defect consumer	**1**
Passing Defect cleared after maneuvers	**1**
Defect equipment	**1**
Broken/ cut insulator	**2**
Total	**6**

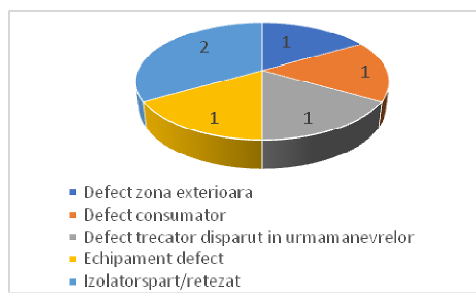

Fig. 7. Graphic events in Stoina station

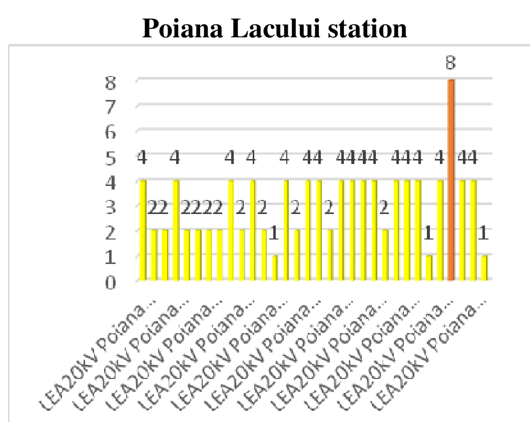

Fig. 8. Risk levels Poiana Lacului station

Tabelul 3

Values indicators in Poiana Lacului station before the modification of the treatment method	Value
SAIFI	0,041
SAIDI	5,88

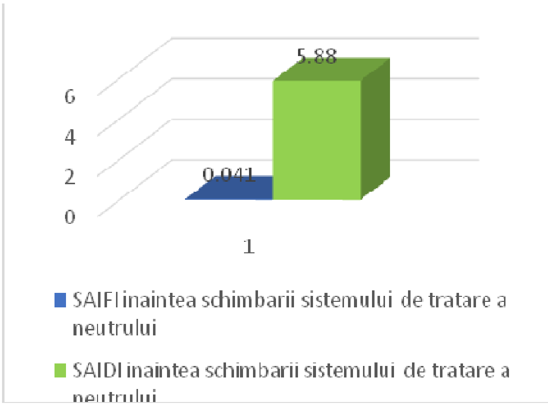

Fig. 9. Graphic indicators in Poiana Lacului station

Description of the events occurred in Poiana Lacului 110 kV/MT station is presented in the table below.

Table 4

Tree fallen on conductors	9
Defect consumer	3
Passing Defect cleared after maneuvers	4
Defect equipment	9
Broken/ cut insulator	7
Total	32

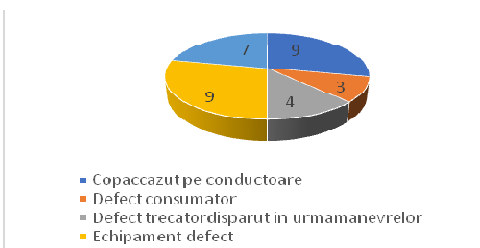

Fig. 10. Graphic events in Poiana Lacului station

Further to the analysis of the results of the study related to the influence of the neutral treatment method on the performance indicators of electrical energy in Stoina and Poiana Lacului stations it was recommended, for their improvement, to change the neutral treatment method as follows:

***Stoina 110/20kV station*:**

Past: treatment of the neutral through resistor ➡
Present: treatment of the neutral through extinguishing coil.

Poiana Lacului 110/20kV station:

Past: treatment of the neutral through extinguishing coil [10] ➡ **Present:** treatment of the neutral through resistor and shunt switch [9].

4.3. Indicators and events in Stoina and Poiana Lacului stations subsequent to modification of the neutral treatment method

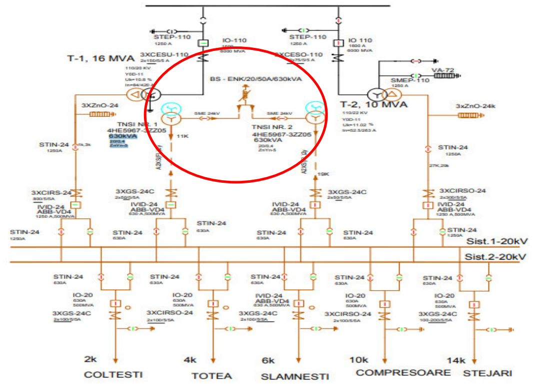

Fig.11. Single line diagram of Stoina station after modification of the neutral treatment method

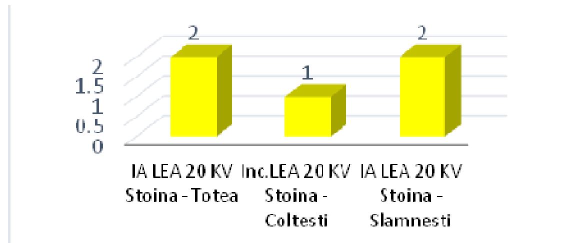

Fig. 12. Risk levels after change of neutral treatment in Stoina station

Table 5

Values indicators in Stoina station after the modification of the treatment system	Value
SAIDI	1,24
SAIFI	0,02

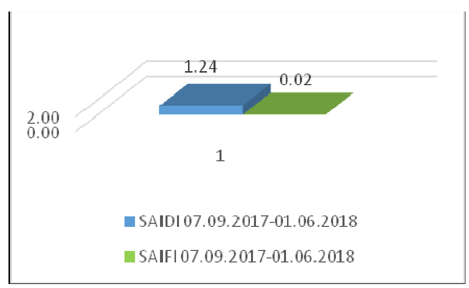

Fig. 13. Graphic indicators Stoina station after modification of the neutral treatment system

Description of the events occured in Stoina 110 kV/MT station is presented in the table below.

Table 6

Tree fallen on conductors	1
Defect consumer	0
Passing Defect cleared after maneuvers	0
Defect exterior area	0
Defect equipment	1
Broken/ cut insulator	1
Total	3

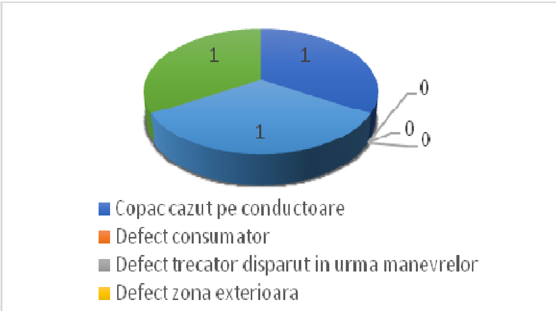

Fig. 14. Description events occurred in Stoina after modification of neutral treatment system

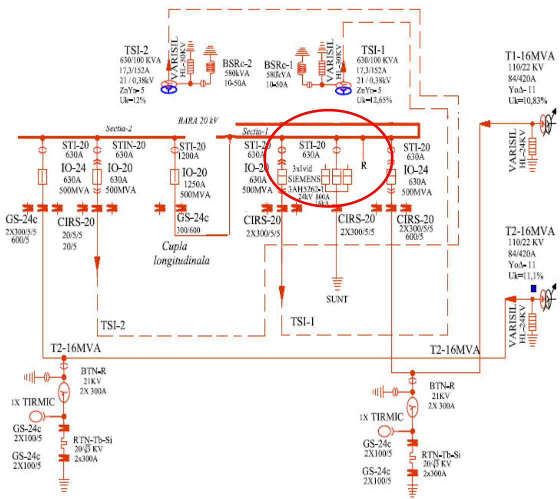

Fig. 15. Single line diagram of Poiana Lacului station after modification of the neutral treatment system

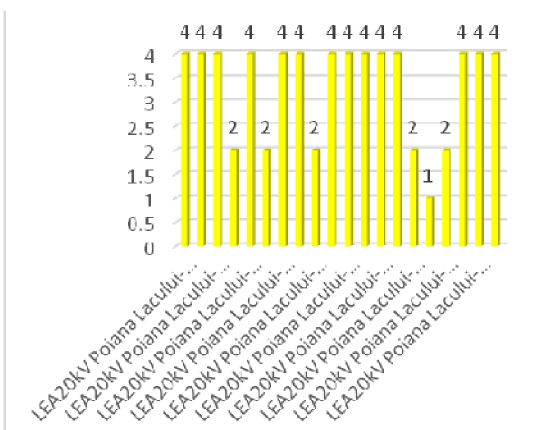

Fig. 16. Poiana Lacului station – risk levels after change of the neutral treatment system

Table 7

Values indicators in Poiana Lacului station after the modification of the treatment system	Value
SAIFI	**0,019**
SAIDI	**2,290**

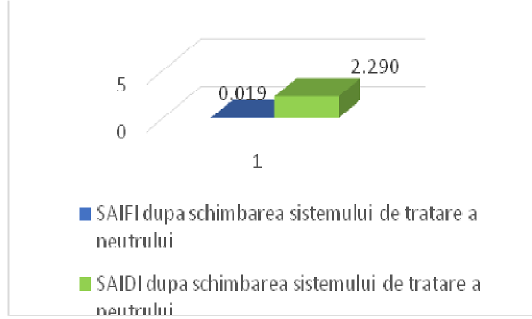

Fig. 17. Graphic indicators in Poiana Lacului station after modification of neutral treatment system

Description of the events occurred in Poiana Lacului 110 kV/MT station is presented in table below.

Table 8

Tree fallen on conductors	5
Defect consumer	1
Passing Defect cleared after maneuvers	3
Defect exterior area	2
Equipment defect	3
Broken/ cut insulator	6
Total incidents	20

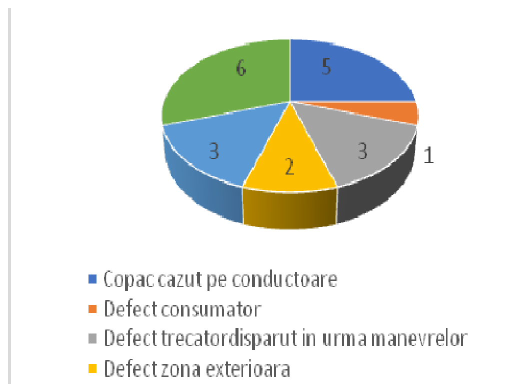

Fig. 18. Description events occurred in Poiana Lacului station after modification of the neutral treatment system

4. CONCLUSIONS

The neutral treatment methods in 110kV/MV transformer stations have a major impact both on the number of events (longer than 3 minutes) as well as on the indicators stipulated in the performance standard of the distribution system for electric energy.

Table 9

Stoina station 01.01.2017-06.09.2017	
Incidents longer than 3 minutes	6
Incidents shorter than 3 minutes	2
RAR (incidents solved by protections)	89
Total	97

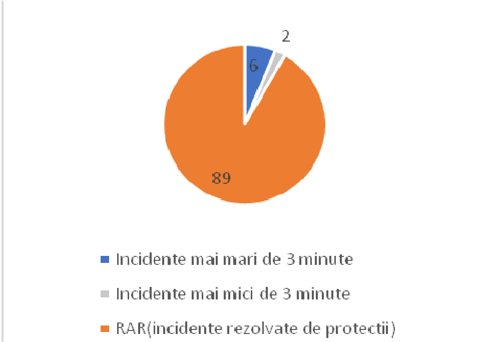

Fig. 19. Events in Stoina station before modification of the neutral treatment system

Tabelul 10

Stoina station 07.09.2017-01.06.2018	
Incidents longer than 3 minutes	3
Incidents shorter than 3 minutes	0
RAR (incidents solved by protections)	13
Total	16

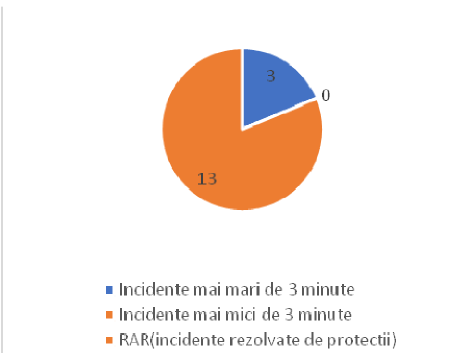

Fig. 20. Events in Stoina station after modification of the neutral treatment system

Table 11

Poiana Lacului station 01.01.2017-20.09.2017	
Incidents longer than 3 minutes	32
Incidents shorter than 3 minutes	63
RAR (incidents solved by protections)	51
Total	146

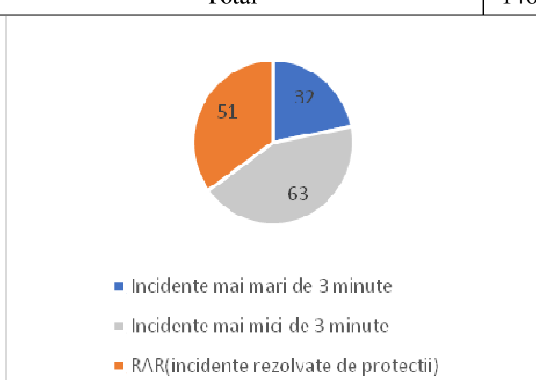

Fig. 21. Events in Poiana Lacului stations before modification of the neutral treatment system

Tabelul 12

Stația Poiana Lacului 21.09.2017-01.06.2018	
Incidents longer than 3 minutes	20
Incidents shorter than 3 minutes	70
RAR (incidents solved by protections)	120
Total	210

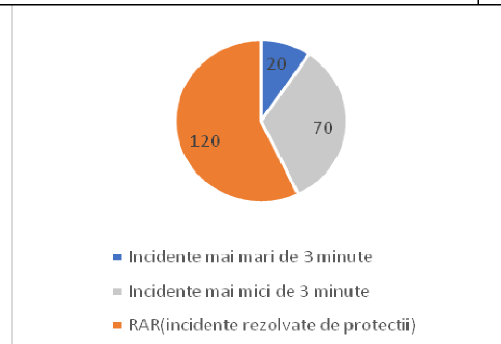

Fig. 22. Events in Stația Poiana Lacului station after modification of the neutral treatment system

Stoina station where the neutral treatment method was changed from neutral treated with resistor to neutral treated with extinguishing coil - the events decreased from 6 to 3 and the indicators improved: – SAIFI from 0,025 to 0,020, and SAIDI from 1,680 to 1,240.

Poiana Lacului station where the neutral treatment method was changed from neutral treated with coil to neutral treated with resistor and shunt – the events decreased from 32 to 20, and the indicators improved – SAIFI from 0,041 to 0,019, and SAIDI from 5,808 to 2,290.

Further to the analysis done in Poiana Lacului station the advantages can be exactly observed in what concerns the performance indicators.

The incidents of the events longer than 3 minutes decrease which means that SAIFI and SAIDI indicators, after the modification of the neutral treatment system, have a lower value, which means fewer interruptions which have a major impact in the value of the compensation payments to the client.

It must be mentioned that from 01.01.2019 the time of restoring supply of electric energy after a planned interruption will be 6 hours in urban areas instead of 8 hours and in rural areas will decrease from 18 hours to 12 hours, which will lead to payments made by the distribution operator in case these intervals are not complied with.

From the point of view of the total number of events, it was not found an improvement for events shorter than 3 minutes and those solved by protections, but these are not regulated by the performance standard for distribution systems.

Stoina station was completely modernized and an improvement at global level can be observed concerning the incidents and events in the transformer station.

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