Technical efficiency of the shunt breaker in the exploitation of distribution networks

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***Abstract*—Through this paper the authors aim to demonstrate that in mixed networks (overhead + underground) as the share of underground distribution lines increases compared to the overhead lines, the technical efficiency related to "suppression" transient single-phase defects decreases, having at their disposal a database of events resulting from the operation of distribution networks with the neutral treated by a resistor associated with a shunt breaker. Moreover, one of the criteria underlying the choice of the method of treating the 20 kV neutral with a resistor associated with a shunt breaker, for a given medium voltage distribution network, is represented by the weight between the overhead lines and the underground network.**

***Keywords*—shunt breaker, distribution network, technical efficiency, resistor, neutral treatment.**

I. Introduction

The way in which the neutral of the electricity distribution networks is connected to the ground is of particular importance in terms of equipment damage due to overcurrent that occur as a result of faults, providing security for the operating specialized personnel considering the touch and step voltages, and last but not least, providing conditions for greater continuity in the supply of electricity to all the network users [1], [2].

Treating the neutral with a resistor associated with a shunt breaker does not require special devices for compensating the active component of the fault current, representing one of the advantages of this method, compared to the method of treating the neutral with the suppression coil, in which to compensate the active component of the current through the fault site, other devices are needed, especially in addition to the suppression coil - which compensates only the reactive component of the current [2], [3].

On the other hand, other important criteria in choosing how to treat the neutral of the distribution network, obtained artificially or using the accessible neutral of the power transformer, are given by the level of transient overvoltage at single-phase faults, especially at intermittent single-phase faults, respectively insurance of an absolute selectivity of the protective devices [2], [4], and methods of treating the neutral through a resistor associated with a shunt breaker, in addition to the fact that it guarantees a small current at the location of the defect, it also ensures a selective action of the protections, respectively a transient regime that stabilizes very quickly due to the firm connection to earth through the shunt of the same faulty phase.

Considering that the local distribution company - Energy Distribution Oltenia - DEO has in operation since 2017 the method of treating the neutral with a resistor associated with a shunt breaker in the 110/20 kV Poiana Lacului Station, and this has proven its technical efficiency in operation [5], starting with the year 2022 this method was also extended to the Pitesti Nord 110/20 kV Power Station.

The regional power distribution operator delivers power energy for 7 counties in the Oltenia region, being committed to supplying all of its over 1,400,000 clients with high-quality electricity (over 3.5 million people) [2].

The working principle of the resistor treatment method associated with the shunt breaker is shown in Fig. 1. consists in shunting the fault that appeared at point Y in the network by closing pole P1 of the IS breaker for a certain predetermined time interval, thus ensuring a current path with a lower impedance in parallel with the one containing the fault. The reduction of the current through the fault site leads to the self-suppression of the electric arc, and the re-ignition of the arc is no longer possible due to the low voltage between the fault point Y and the ground [6], [7], [8].

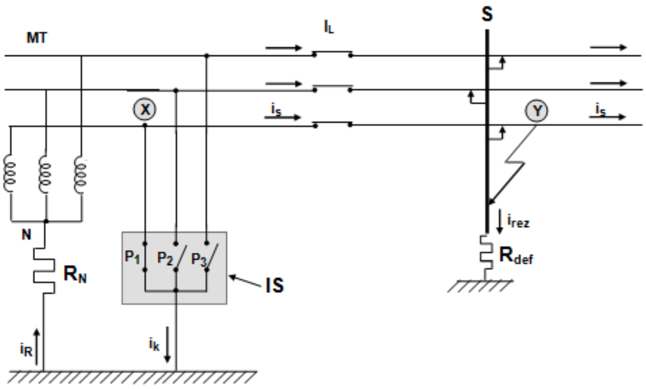

Fig. 1. Operation scheme for shunt breaker IS, [6],[7].

where: IS-shunt breaker; I_L-line breaker; R_N- resistor on network neutral; R_{def} - fault / defect resistance; i_k - current through the shunt breaker; i_{rez} - residual fault current; i_s - load

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current; i_R - current through the neutral point; S - pillar of the line; X - mounting point shunt breaker (on station bus bars); Y - point of the fault/defect.

The Poiana Lacului 110/20 kV station feeds a 20 kV overhead lines distribution network with a length of 274.91 km, which represents 96.3% of the total network, and the remaining 10.6 km (3.7%) is the underground network.

The 110/20 kV Pitesti Nord power station supplies a 78.74 km overhead 20 kV distribution network, which represents 67.5% of the total network, and the remaining 37.95 km (32.5%) is the underground network. The 20 kV distribution networks from both power transformer stations are located in the area of Arges County, the urban areas and neighboring Pitesti Municipality, so it can be considered that they operate in the same meteorological conditions, and analyzing the accidental events over the same time interval and determining the technical efficiency of the method treatment with a resistor associated with a shunt breaker. A comparison can also be made between the two stations from this point of view.

II. THE EFFICIENCY OF THE TREATMENT METHOD FOR SINGLE-PHASE FAULTS DURING THE EXPLOITATION PERIOD

A. Power transformer station Pitesti Nord - the efficiency of the treatment method for single-phase faults during the exploitation period

Considering that the 110 / 20 kV Pitesti Nord station has the treatment resistor connected to the neutral accessible from the 20 kV side of the transformer with the YNyn connection, a different situation compared to the previous experience gained in the Poiana Lacului Station where the resistor is connected through a neutral coil, new tests were needed regarding the technical efficiency of the treatment solution with a resistor and associated shunt breaker [2].

The 110 / MV power transformer station Pitesti Nord is a power station which has two units of 40 MVA power transformers 110 / MV - with main connection Ynyn -12, with the neutral point treated by a resistor associated with a shunt circuit breaker. The treatment resistor is connected directly to the MV neutral of the power transformer, as it is shown in Fig. 2, [2]. [8].

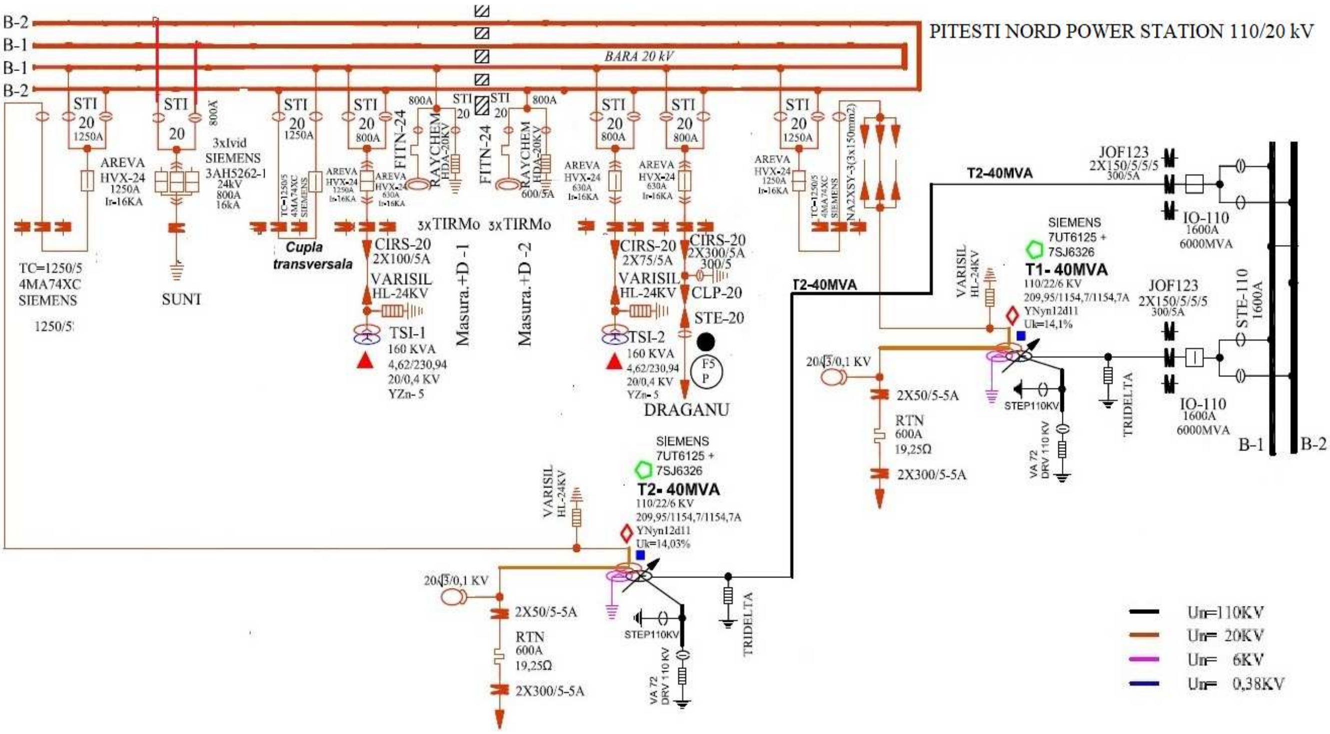

Fig. 2. Pitesti Nord power station 110/20 kV, simplified neutral treatment scheme [8], [12].

It was defined the technical efficiency of the resistor treatment method associated with a shunt breaker as the percentage ratio between the number of single-phase faults that are self - suppression as a result of connecting the shunt breaker and the number of faults that should self- suppression.

All unplanned (accidental) interruptions in the distribution operator's network are recorded in a database that is created with the help of an IT application called SAP (System Analysis Program Development). Using certain information processing techniques, all unplanned power interruptions, protections that have operated and faulty elements in the network are obtained from SAP in an editable and accessible format. In Table II and in Table III, the relevant information for the study of the technical efficiency was selected.

The analysis period of unplanned interruptions from the two networks is defined in the range: 01.05.2023 – 10.03.2024, and, in the category of unplanned interruptions necessary to determine the technical efficiency, only those due to single-phase faults were considered, namely:

- unplanned interruptions due to permanent single-phase defects (eg: insulation damage related to one phase, etc.) whose interruption duration is t > = 3 sec.
- unplanned interruptions due to transient single-phase faults whose interruption duration is t>= 3 sec, and re-energizing the installation is done by manual connection.
- unplanned interruptions due to transient single-phase faults whose interruption duration is t< 3 sec (transient

interruptions), and re-energizing the installation is done by automatic reconnection of the installation as a result of the operation of the automatic reconnection automation.

A selection from the database with unplanned interruptions related to the network fed from Pitesti Nord Power Station is presented in Table II.

As specified in the Performance Standard for the electricity distribution service, the unplanned interruption is the interruption of the electricity supply to the users of the distribution network of which they were not notified in advance, and is due to incidents that occurred accidentally in the installation, or disconnections to prevent incidents [9]. The same Standard also categorizes the type of interruptions into:

- transient interruptions (t<= 3 sec).
- short interruptions (3 sec < t <= 3 min).
- long interruptions (t>3 min).

In order to define the technical efficiency of the resistor treatment method associated with the shunt breaker, the following specific notations are made:

- ET - the technical efficiency of the treatment method with a resistor associated with a shunt breaker.
- Nt - the total number of single-phase faults in the analyzed network.
- N1 - the number of permanent single-phase faults.
- N2 - the number of transient single-phase faults for which the installation is re-energized by manual reconnection.
- N3 - the number of transient single-phase faults in which the installation is re-energized by automatic reconnection.
- T_shunt_ connected – the time that the shunt breaker is connected and the network fault sounds - implemented in the connection/disconnection logic of the numerical protection relay related to the shunt.

The counting of the total number of single-phase faults occurring in the distribution network is done software, through a logic implemented in the protection relay related to the 20 kV Shunt cell in both power transformer stations, a Siemens 7SJ82 type relay [10].

Using these notations, the technical efficiency is given by the relation:

$$ET = \frac{Nt-(N1+N2+N3)}{Nt-N1} x100\ [\%] \tag{1}$$

The values are presented in Table I for all three phases.

TABLE I. TECHNICAL EFFICIENCY SHUNT BREAKER - PITESTI NORD 110/20 KV POWER STATION - MIXED 20 KV NETWORK (OVERHEAD - 67.5%)

I shunt counter index					Total number of shunt breaker actuations **(from the counter of the protection relay made by the single-phase fault identification logic) [Nt]**	The number of power interruptions with duration t>= 3 sec due to grounding - **with PERMANENT DEFECT** (from SAP) **[N1]**	The number of power interruptions with duration t>= 3 sec due to groundings - **with TRANSIENT DEFECT** (from SAP) **[N2]**	The number of power interruptions with duration t< 3 sec due to grounding - **no. Successful automatic reconnections** (from SAP) **[N3]**	The number of earthings **"turned off" by I_shunt**	Number of groundings **"off" by I_shunt T_shunt_connected=0.5 s ET [%]**
Index reading date	Phase R	Phase S	Phase T	Total						
01.05.2023 hour 00:00	84	94	52	230	229	0	73	28	128	55.90
10.03.2024 hour 24:00	172	183	104	459						

TABLE II. SELECTION FROM THE SAP DATABASE WITH UNPLANNED OUTAGES FROM THE 20 KV ELECTRICAL NETWORK FED FROM THE PITESTI NORD POWER STATION

1) Unplanned interruptions due to transient single-phase faults whose interruption duration is t< 3 sec (transient interruptions), and the resetting of the installation under voltage is done by automatic reconnection of the installation as a result of the operation of the automatic reconnection automation

Notification	Notification data	Description	Functional place	Start failure	Start failure (hour)	Explanations / Description of the disturbance	Type of notification	Type of protection
100006761248	5/22/2023	RAR(+) LEA 20 kV Pitesti Nord-Mioveni	DS-HV-MP021013	5/22/2023	4:05:00 PM	Temporary fault	H4	4
100006767603	5/27/2023	RAR(+) LEA 20 kV Pitesti Nord-Draganu	DS-HV-MP021012	5/27/2023	7:54:00 AM	Temporary fault	H4	4

2) Unplanned interruption due to transient single-phase faults whose interruption duration is t>= 3 sec, and re-energizing the installation is done by manual connection

Notification	Notification data	Description	Functional place	Start failure	End of failure	Start failure (hour)	End of failure (hour)	Duration of the break	Type of notification	Explanations / Description of the disturbance	Type of protection
100006759374	5/20/2023	INC OHL 20 kV Pitesti Nord-Draganu	DS-HV-MP021012	5/20/2023	5/20/2023	1:11:00 PM	1:14:00 PM	0.05	H3	Temporary fault	4

Analyzing the value of the technical efficiency recorded in Table I, it is found that it is low (55.90%), which is due to the rather significant weight of the 20 kV underground network (32.5%).

B. *Poiana Lacului transformer station - the efficiency of the treatment method for single-phase faults during the exploitation period*

The measurements were performed in the 110/20 kV Poiana Lacului substation, a transformer station equipped with two 110/20 kV transformers - 16 MVA, and in the normal operation scheme it has the neutral treated by resistor and shunt breaker. Also, as can be seen in the simplified single-wire electrical diagram of the transformer station shown in Fig.3, the treatment of the neutral can also be performed by the arc suppression coil or with the neutral isolated [11].

The analysis period of unplanned interruptions from the two networks is the same as that considered for Pitesti North Station (see point II, letter A), namely 1.05.23 - 10.03.24, and in the category of unplanned interruptions necessary to determine the technical efficiency only those due to single-phase defects were considered, defined in the same way as in point II, letter A.

A selection from the database for unplanned interruptions related to the network fed from Poiana Lacului Power Station are presented in Table III.

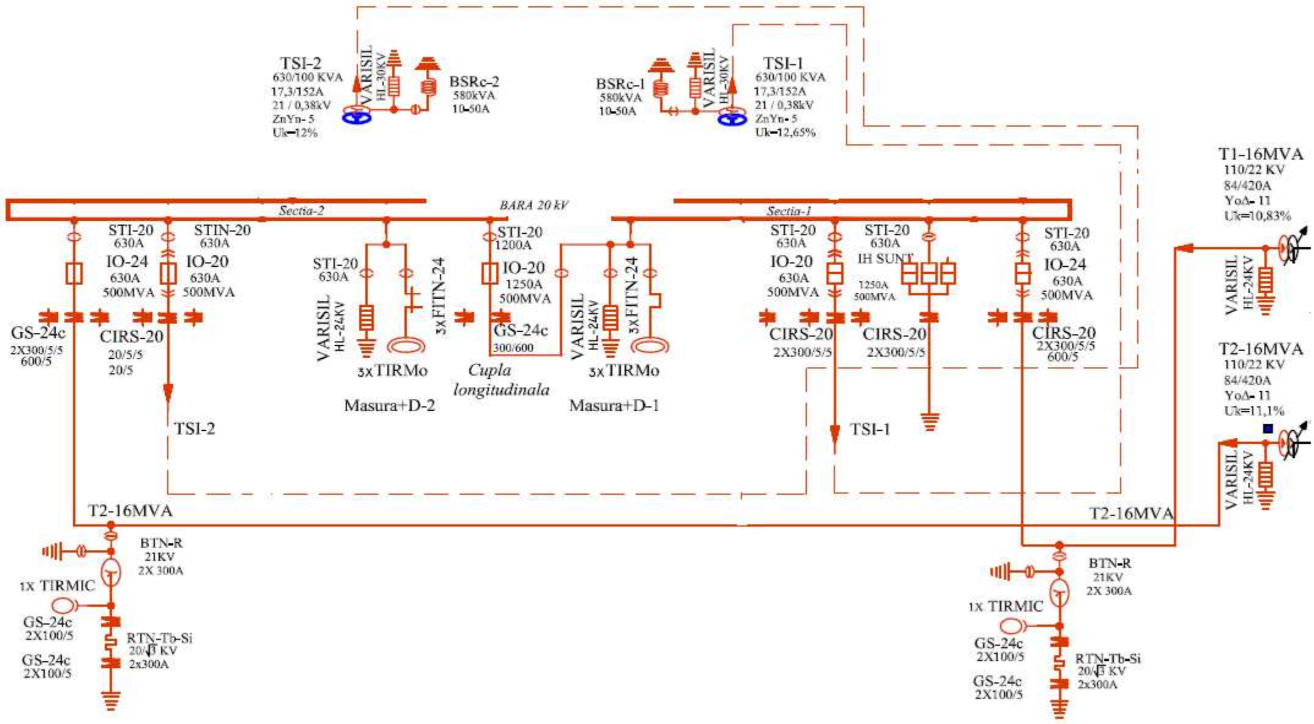

Fig. 3. Poiana Lacului power station 110/20 kV, simplified neutral treatment scheme [12].

TABLE III. SELECTION FROM THE SAP DATABASE WITH UNPLANNED OUTAGES FROM THE 20 KV ELECTRICAL NETWORK FED FROM THE POIANA LACULUI POWER STATION

1) Unplanned interruptions due to transient single-phase faults whose interruption duration is t< 3 sec (transient interruptions), and the resetting of the installation under voltage is done by automatic reconnection of the installation as a result of the operation of the automatic reconnection automation

Notification	Notification data	Description	Functional place	Start failure	Start failure (hour)	Explanations / Description of the disturbance	Type of notification	Type of protection
100006772702	5/31/2023	RAR+OHL20kV Poiana Lacului-Sapata	DS-HV-MP021206	5/31/2023	5:26:00 PM	Temporary fault	H4	4
100006790374	6/18/2023	RAR+OHL20kV Poiana Lacului-Vedea	DS-HV-MP021207	6/18/2023	3:33:00 PM	Temporary fault	H4	4
100006813356	7/2/2023	RAR+OHL20kV Poiana Lacului-Paduroiu	DS-HV-MP021204	7/2/2023	2:52:00 PM	Temporary fault	H4	4

2) Unplanned interruptions due to permanent single-phase faults whose interruption duration is t>= 3 sec

Notification	Notification data	Description	Functional place	Start failure	End of failure	Start failure (hour)	End of failure (hour)	Duration of the break	Type of notification	Explanations / Description of the disturbance	Type of protection
100006775199	6/3/2023	INC OHL20kV Poiana Lacului-Sapata	DS-HV-MP021206	6/3/2023	6/3/2023	6:55:00 AM	8:28:00 AM	1.55	H3	Vegetation in the network between Stp 149-150	4

3) Unplanned interruption due to transient single-phase faults whose interruption duration is t>= 3 sec, and re-energizing the installation is done by manual connection

Notification	Notification data	Description	Functional place	Start failure	End of failure	Start failure (hour)	End of failure (hour)	Duration of the break	Type of notification	Explanations / Description of the disturbance	Type of protection
100006844462	7/21/2023	Inc OHL20kV Poiana Lacului - can be seen - defect disappeared during maneuvers	DS-HV-MP021207	7/21/2023	7/21/2023	12:10:00 AM	2:48:00 AM	2.63	H3	Defect disappeared during maneuvers	4

Using the same notations as those done in chapter II presented above - point A, the technical efficiency is given by the first relation - (1) and has the value clearly presented in Table IV.

TABLE IV. TECHNICAL EFFICIENCY SHUNT BREAKER - 110/20 KV POIANA LACULUI POWER STATION - 20 KV NETWORK MAINLY OVERHEAD LINES (96.3%)

I shunt counter index					Total number of shunt breaker actuations **(from the counter of the protection relay made by the single-phase fault identification logic) [Nt]**	The number of power interruptions with duration t>= 3 sec due to grounding - **with PERMANENT DEFECT** (from SAP) **[N1]**	The number of power interruptions with duration t>= 3 sec due to groundings **with TRANSIENT DEFECT** (from SAP) **[N2]**	The number of power interruptions with duration t< 3 sec due to grounding - **no. Successful automatic reconnections** (from SAP) **[N3]**	The number of earthings **"turned off" by I_shunt**	Number of groundings **"off" by I_shunt T_shunt_connected=0 .5 s ET [%]**
Index reading date	Phase R	Phase S	Phase T	Total						
01.05.2023 ora 00:00	26	26	12	64	453	15	25	31	382	87.21
20.08.2023 ora 24:00	178	193	146	517						

Analyzing the result in Table IV, we find that the technical efficiency of the treatment method with a resistor associated with a shunt breaker is 87.21%, much higher than that calculated in the case of the network fed from Pitesti North Station, this is due to the increase the weight of the 20 kV overhead network to the value of 96.3%.

III. CONCLUSIONS

Analyzing the results of the study presented in point II, the following can be found:

- the technical efficiency of the treatment method with a resistor connected to the artificial neutral created by the three-phase neutral coil (BTN-R) and associated with a shunt breaker, the method implemented in the Poiana Lacului 110/20 kV Station is very high, reaching the value of 87.21 %, a fact largely due to the structure of the 20 kV distribution network, mostly overhead lines (96.3%).

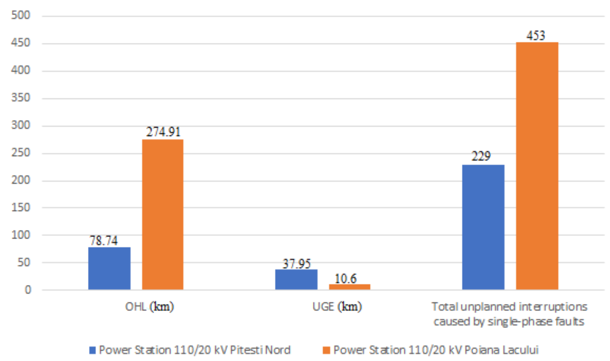

Fig. 4. Poiana Lacului & Pitesti Nord distribution network and unplanned interruptions.

- the technical efficiency of the treatment method with a resistor connected to the accessible 20 kV neutral of the 110/20 kV power transformer and associated with a shunt breaker, the method implemented in the Pitesti Nord 110/20 kV Station is very low, reaching the value of 55.9% , a fact largely due to the structure of the 20 kV mixed distribution network, with a lower share of overhead (67.5%).
- a decrease in the share of the 20 kV overhead network from 96.3% - 274.91 km (Poiana Lacului 110/20 kV Station) to 67.5% - 78.74 km (Pitesti Nord 110/20 kV Station) leads to a decrease in technical efficiency from 87.21 % (Poiana Lacului 110/20 kV Station) to the value of 55.9% (Pitesti Nord 110/20 kV Station) – Fig. 4.
- from the experience accumulated in the operation of the two 20 kV distribution networks and the numerous tests and measurements carried out, it resulted that the technical efficiency of the method of treating the neutral with a resistor associated with a shunt breaker is also influenced by the time that the shunt breaker is connected (the defect), and its value is higher in the case of 20 kV predominantly OHL networks (see"T_shunt _connected" Table II compared to Table IV).

In conclusion, one of the important criteria underlying the choice of the treatment method with a resistor associated with a shunt breaker is the weight of the overhead network compared to the underground network, and for a good technical efficiency of the method, the weight of the overhead network must not fall below 70% of total network.

Also, in order to extend the treatment method with a resistor associated with a shunt breaker to other stations, it is very important to initially carry out an analysis of the technical treatment method in operation for as long a period of time as possible to be compared with the efficiency of the method from an already implemented station. If the technical efficiency of the existing method is lower than that with a resistor associated with a shunt breaker, then it can be decided to use the latter.

The database with power interruptions from the two 20 kV distribution networks contains a large number of records, which is why it was not presented in detail in the paper, but it can be made available for analysis upon request.

Acknowledgment

The work was carried out as part of a collaboration between the Energy Distribution Oltenia DEO and University of Craiova Faculty of Electrical Engineering, a collaboration that started in 2016 in the field of neutral treatment in 110/MV power stations, once the first power station from DEO that uses as a solution to treat the neutral - a resistor associated with a shunt breaker was put back into operation, a method that was also used in the former time but abandoned due to the low performance of the equipment at that time - especially the shunt breaker.

The studies carried out were done by the instrumentality of the modern infrastructures of the DEO stations, as well as the high-performance measuring and recording equipment of the university.

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