AUTOMATION OF ELECTRICAL DISTRIBUTION NETWORKS FOR MINIMIZING UNPLANNED INTERRUPTIONS AND IMPROVING POWER QUALITY

AUTOMATIZAREA REȚELELOR ELECTRICE DE DISTRIBUȚIE PENTRU MINIMIZAREA ÎNTRERUPERILOR NEPLANIFICATE ȘI CREȘTEREA CALITĂȚII ENERGIEI ELECTRICE

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Abstract: *The paper addresses one of the major challenges faced by electricity distribution operators, namely maintaining compliance with industry regulations that impose increasingly stringent requirements on performance indicators. To determine these indicators, the distribution operator (DO) records all unplanned long-duration outages in the network, which are then used to develop plans and strategies to minimize such interruptions. For this purpose, new solutions for automating medium-voltage overhead distribution networks have been identified, with the use of remotely controlled equipment becoming an increasingly attractive option for electricity distribution network operators. The paper analyses the impact of installing remotely controlled equipment on the continuity of electricity supply to users for the years 2022 and 2023 for a medium-voltage electrical line. To this end, performance indicators such as SAIFI – the System Average Interruption Frequency Index, and SAIDI – the System Average Interruption Duration Index for planned or unplanned outages, were calculated in accordance with performance standards. The*

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results demonstrated that integrating these devices into the distribution network has a significant impact on improving the performance of electricity distribution networks, reducing the amount of energy not delivered to consumers, and enhancing performance indicators.

Keywords: power quality; SAIDI; SAIFI; remotely controlled disconnectors; reclosers.

Rezumat: *Lucrarea abordează una dintre provocările majore cu care se confruntă operatorii de distribuție a energiei electrice, anume menținerea aliniamentului cu reglementările din domeniu, care impun cerințe tot mai restrictive privind indicatorii de performanță. Pentru determinarea acestor indicatori, operatorul de distribuție (OD) înregistrează toate întreruperile neplanificate de lungă durată din rețea, pe baza cărora se elaborează ulterior planuri și strategii de minimizare a acestora. În acest scop, s-au identificat soluţii noi pentru automatizarea reţelei de distribuţie aeriană de medie tensiune, utilizarea echipamentelor telecomandate devenind o opțiune tot mai atractivă pentru operatorii rețelelor electrice de distribuție. În cadrul lucrarii s-a analizat influența montării echipamentelor telecomandate asupra continuitații alimentării cu energie electrică a utilizatorilor pentru anii 2022 și 2023 pentru o linie electrică de medie tensiune. În acest scop, conform standardului de performanță, s-au calculat indicatorii de performanță SAIFI – frecvența medie de întreruperi și SAIDI - durata medie de întreruperi planificate sau neplanificate a rețelei. Rezultatele au demonstrat faptul că integrarea acestor echipamente în rețeaua electrică de distribuție au impact semnificativ asupra creșterii performanțelor rețelelor electrice de distribuție, a reducerii cantitații de energie nelivrată consumatorilor și a îmbunătățirii indicatorilor de performanță.*

Cuvinte cheie: calitatea energiei; SAIDI; SAIFI; separatoare telecomandate; reclosere.

1. Introduction

Reclosers and remote-controlled disconnectors serve distinct functions in medium voltage networks, where reclosers ensure automatic fault interruption and reclosing to improve service continuity, while disconnectors enable remote isolation and sectionalizing without interrupting fault current. Indicators related to the power quality of the distribution networks represent a key benchmark in establishing the technical and economic elements for the construction or modernization of electrical networks and significantly influence the economic efficiency of user activities. The analysis was conducted based on the performance indicators defined in the "Performance Standard for the Electricity Distribution Operators," approved by ANRE

Order no. 11/2016, with subsequent amendments and additions [1]. In accordance with the provisions of this standard, the quality of the electricity distribution service provided by the licensed distribution operator was analysed. Essentially, performance indicators quantify the quality of the distribution service provided by the distribution operator and refer to [2], [3]:

- continuity of supply;
- technical quality of electricity;
- commercial quality of the distribution service.

In terms of their effect on electricity system users, performance indicators can be broadly divided into two categories: general indicators - which provide an overview of the activity carried out by the OD and secondary indicators - (voltage sags, swells, harmonics, or interruptions) play a crucial role in diagnosing, understanding, and managing power quality (PQ) issues. In their case it is not possible to guarantee values for each individual consumer; guaranteed performance indicators, for which minimum levels are set to be respected in each individual case. The performance standard does not apply, where appropriate, in situations of force majeure or abnormal operation caused by (electricity) producers, other (transport or distribution) operators or consumers. In this context, the paper proposes an incipient analysis of the necessity of integrating reclosers and remotely controlled disconnectors into an electrical distribution network to minimize the SAIFI and SAIDI performance indicators.

The paper is further structured as follows: the status of the issue addressed in chapter 2, the next two chapters analyse the automation systems of electrical distribution networks, respectively the automation process of remotely controlled disconnectors. Finally, a case study is carried out to validate the influence of the installation of remote-controlled disconnectors on the increase of the performance of the electrical distribution network.

2. Problem statement

In the context of the modernization of electricity grids, the use of disconnectors plays a crucial role in power management and infrastructure protection. Classic disconnectors are used to insulate network sections during maintenance, repair work or to isolate faulty network sections in the event of damage. Although they are simple and relatively inexpensive, their use has certain limitations in terms of network performance [4]. They are operated manually and require the physical intervention of the work operative team to open or close the circuit. This involves moving personnel to the equipment site, which can be time-consuming, especially in bad weather conditions or in hard-to-reach locations. The long response time and the need for manual intervention negatively affect performance indicators such as SAIDI and SAIFI, leading to longer and more frequent outages.

In the literature, this problem is studied at length. For example, in [5] an optimization model is proposed to maximize the profit of the DSO based on minimizing the costs due to the reconnection of faulty circuits and the replacement of the circuits, and in [6] a model is proposed for the installation of the reclosers in key points of the radial electrical distribution networks but to maximize the profit of the DSO. In fact, some authors have focused studies on identifying the optimal number and location of remotely controlled reclosers (RTCs) in [5] and remotely controlled disconnectors (RCDs) in [7] to achieve greater reliability with minimal costs. The automation of the distribution network and the improvement of operational efficiency is proposed in [8], and a methodology for optimizing the location of the RTC in the distribution networks to minimize the SAIDI or SAIFI indicators is proposed in [9]. Following the analysis of the influence of RTC and RCD at the level of the analysed electricity distribution network, the next step is to propose an algorithm to optimize their location to streamline the operation and minimize the impact brought to consumers by scheduled or unscheduled interruptions.

3. Electrical Distribution Network Automation Systems

Distribution Automation Systems (DAS) can be succinctly defined as the totality of primary, secondary and telecommunications equipment integrated into a coherent system for identifying and selectively isolating faults in distribution networks.

The purpose of DAS is:

- To increase the performance of electrical distribution networks;
- To reduce the amount of undelivered energy to consumers;
- To decrease operational costs (maintenance, equipment replacement, fault identification and clearance).

DAS implementations across Europe follow different approaches, specifically:

- The use of remotely controlled disconnectors;
- The use of reclosers.

Remote-controlled disconnectors are a key innovation in the management and operation of modern power grids. These advanced devices allow remote monitoring and control, offering numerous advantages over conventional disconnectors. They are integrated into SCADA (Supervisory Control and Data Acquisition) systems, allowing dispatchers to control equipment remotely without the need for physical intervention, considerably reducing response times in the event of faults or the need to reconfigure the network. Remotely controlled equipment provides the ability to monitor the network status in real time, promptly detecting any anomalies or faults, and the data collected can be analysed to anticipate problems and optimize network operation.

Reclosers are often used as a key component in a smart grid, as they are effectively computer-controlled switchboards that can be remotely operated and interrogated using SCADA or other communications. In overhead networks, most faults are transient, such as lightning strikes, overvoltage, or foreign objects meeting power lines. Approximately 80% of outages can be resolved with a simple closing operation. Reclosers are designed to handle a short trip cycle, with an optional configuration of the number of reclosing attempts before moving to a locked-out stage. The reclosers reduce the duration and frequency of outages by quickly restoring power after transient faults significantly improving the consumer experience, helping to maintain network stability and improving performance indicators.

4. Automation of Remotely Controlled Disconnectors

One of the solutions is the implementation of an automated fault detection and localization system for medium-voltage (MV) distribution networks, aimed at restoring power to consumers. The primary objective of this solution is to reduce the impact on consumers affected by incidents in overhead medium-voltage networks. This approach relies on a logical scheme implemented between remotely controlled reclosers installed on MV overhead lines or the MV breaker in the transformer station and the downstream remotely controlled disconnectors.

The proposed solution consists of a system that commands the independent opening of disconnectors traversed by fault currents during the automatic reclosing cycle (ARC) pause. The logic ensures that once the remotely controlled disconnectors experience fault currents, they are automatically and independently open during the pause of the second ARC cycle. This isolates the fault area and reduces the number of affected consumers. Once the fault is isolated, the upstream recloser (or the breaker in the station) successfully reconnects during the second ARC cycle. As a result, the incident is split into two events: a successful second ARC cycle and an incident on the line section downstream of the remotely controlled s disconnector opened by automation. Since the initial configuration of the RCD did not support direct implementation of this automation, modifications were required for both primary and secondary circuits:

- To verify the presence of fault currents, three current transformers with ratios corresponding to downstream installations were installed at each RCD.
- Challenges arose when it became evident that implementing the automation function would require a numerical relay to be placed in the control cabinet of the RCD. The relay had to be compact due to the limited space in the cabinet and needed to offer a flexible software application for creating the automation logic.

For the disconnectors analysed in this network, the Janitza UMG604 network analyzer was chosen. This device combines the precision of a network analyzer with the programmability of a programmable logic controller (PLC). It is also significantly more cost-effective than a numerical protection relay. The analyzer is capable of measuring or calculating variable electrical quantities such as voltage, current, energy, harmonic components, etc. It includes current and voltage inputs, zero-sequence current measurement, and digital inputs and outputs.

The device is programmed using the GridVis software application via an Ethernet connection. Operational voltage is supplied from the same circuit that powers the RCD control relay, accommodating the additional consumer. The network analyzer identifies fault currents (polyphase, single-phase, or ground faults) that may occur on the MV overhead line and, after a time delay (Δt), sends an opening signal to the RCD actuator. The opening signal is only transmitted if the analyzer has received confirmation that the line is de-energized. For each analyser, protection settings were calculated, considering the settings and time delays of upstream protection devices (reclosers or 20 kV cells in substations). Additionally, the settings were adjusted to account for the capacitive currents of the 20 kV MV overhead lines downstream of the RCD, preventing erroneous RCD openings in the case of single-phase faults elsewhere in the network. The remote transmission of the automation-based opening signal to the disconnector is carried out via a Viola modem using the GSM network. This is the same modem used for the remote operation of the RCD.

5. Study Case

To analyse the impact of integrating remote-controlled equipment into the electrical distribution network, a medium-voltage overhead power line was selected. The continuity of power supply to users, in accordance with the performance standard, was assessed by calculating the SAIDI and SAIFI performance indicators for the years 2021, 2022, and 2023. The analysis focused on two categories of long-term interruptions:

a. Unplanned interruptions caused by the DSO - as unscheduled outages due to failures or incidents under DSO responsibility.
b. Unplanned outages resulting from severe weather critical events.

The separation from planned interruptions is based on event classification in operational logs, notification records, and outage cause coding, being essential for reliability indices, regulatory reporting, and network planning.

In recent years, remote-controlled reclosers and disconnectors, both automated and non-automated, have been installed within the electrical distribution network to reduce interruption durations and frequencies (Table 1). Must be emphasized that RTC and RDC are essential for reducing long interruptions (> 3 minutes) by [10]: accelerating fault isolation and restoration; enabling remote control and automation and reducing SAIDI, ENS, and operational response time. They transform traditional radial feeders into smart, reconfigurable networks, improving resilience and customer service. Their influence is measurable in every key reliability indicator.

Table 1. **Number of equipment's installed in the network**

Equipment Type	2020	2021	2022	2023
RTC	2	2	7	7
RDC	4	5	7	7
RDC with automation	0	0	2	2

Using the incident database for the analyzed power line from 2021 to 2023, the following metrics were determined: the number of incidents caused by both the Distribution System Operator - DSO and special weather conditions - SWC (Fig. 1), the number of affected consumers experiencing long-term interruptions (>3 minutes) (Fig. 2), the duration of incidents (Fig. 3), and the variation in the cumulative duration of long interruptions (Fig. 4). These data will subsequently be used to calculate the SAIFI and SAIDI performance indicators.

System Average Interruption Frequency Index (SAIFI) – The average frequency of interruptions in the network (system) for a consumer, represents the average number of interruptions incurred by consumers supplied (served) by DSO. It is calculated by dividing the total number of consumers interrupted after 3 minutes by the total number of consumers served:

$$SAIFI = \frac{\sum_{i=1}^{n} N_i}{N_t} \text{ [interruption/year]} \quad (1)$$

In Fig 5. The results of the SAIFI DSO and SWC calculation are represented regarding the consumers of the analyzed power line and in Fig 6. Are represented the results of the SAIFI DSO and SWC calculation based on the consumers number of Iași County.

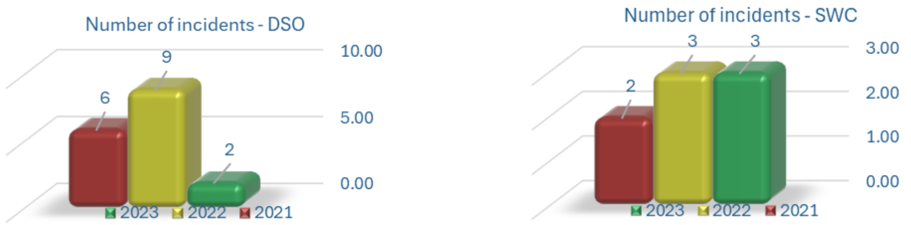

Figure 1. Number of incidents 2021-2023

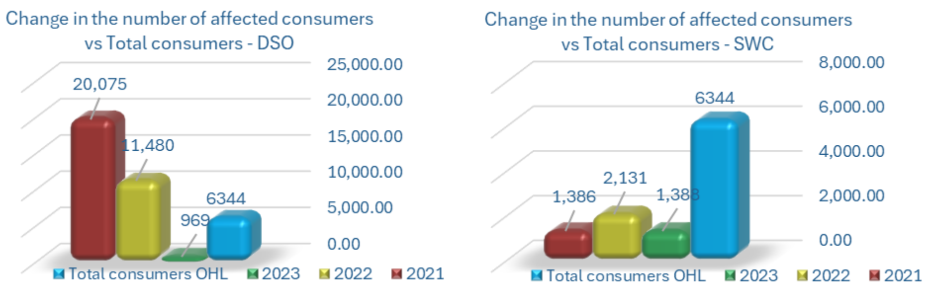

Figure 2. Number of affected consumers vs Total consumers 2021-2023 DSO and SWC

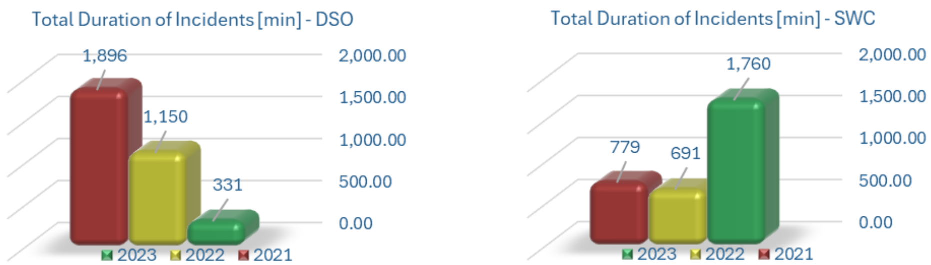

Figure 3. Total Duration of Incidents 2021-2023 DSO and SWC

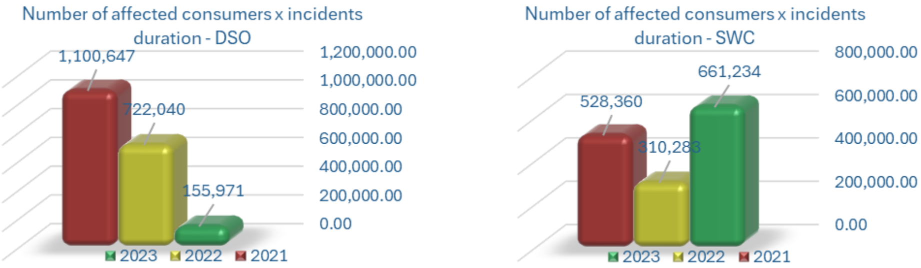

Figure 4. Variation in the cumulative duration of long DSO and SWC interruptions

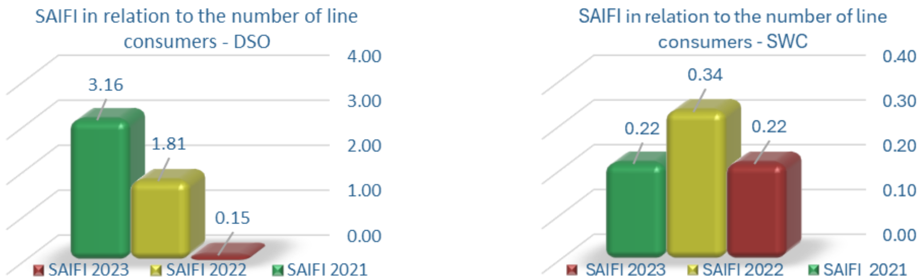

Figure 5. SAIFI DSO and SWC considering the consumers of the line

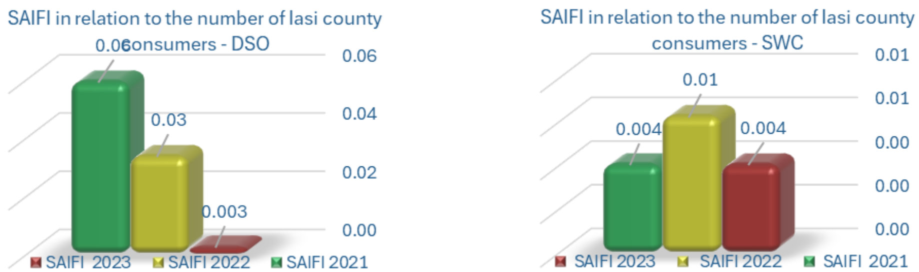

Figure 6. SAIFI DSO and SWC considering the consumers in Iasi County

System Average Interruption Duration Index (SAIDI) – The average duration of interruptions in the network (system) for a consumer, represents the average interruption time of consumers at the DSO level. The indicator is calculated by dividing the cumulative duration of long interruptions by the total number of consumers supplied (served) by the DSO.

$$SAIDI = \frac{\sum_{i=1}^{n} N_i \times D_i}{N_t} \ [min/year] \qquad (2)$$

where: N_i – the number of users interrupted after 3 minutes at interrupt i; D_i – the duration (time) of the interruption of the users from the moment of the disappearance of the voltage until the reconnection for the interruption i; N_t – the total number of users served.

In Fig. 7. the results of the calculation of the SAIDI, DSO and SWC are represented in relation to the number of consumers of the analyzed power line and in Fig. 8. the results of the SAIDI DSO and SWC calculation are represented in relation to the number of consumers in Iasi County.

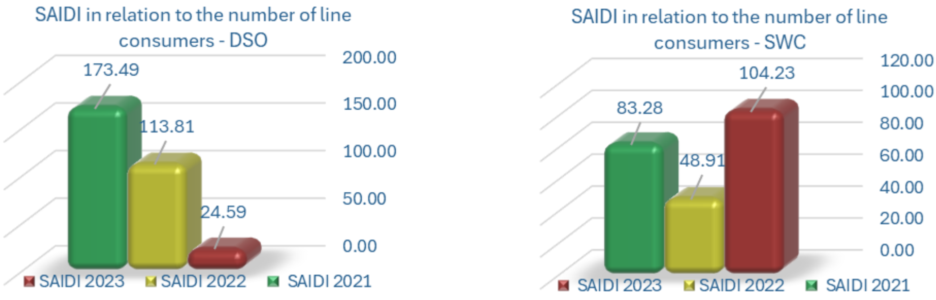

Figure 7. SAIDI DSO and SWC considering the consumers of the line

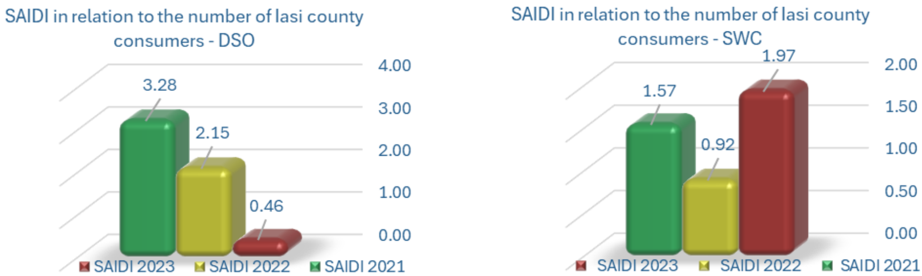

Figure 8. SAIDI DSO and SWC considering the consumers in Iasi county

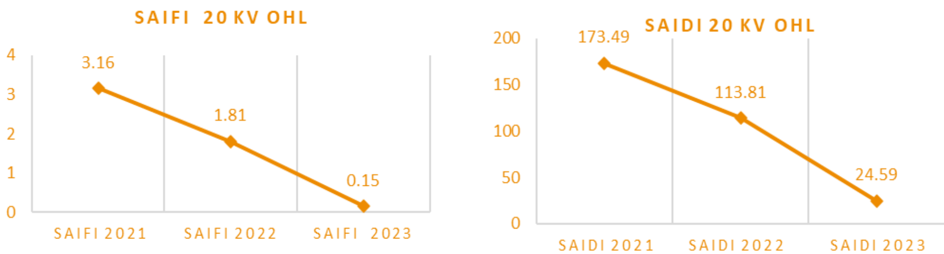

Figure 8. SAIDI and SAIFI results in relation to the number of consumers of the line

For the analysed medium-voltage power line, there is a significant decrease in both the number of affected consumers and the duration of incidents in the period 2021-2023 with the implementation of remote-controlled equipment. If in 2021, 2 RTCs and 4 RCDs were installed at the level of the medium voltage line, in 2023 there were 7 RTCs, 7 RCDs and 2 RCDs with automation, which led to a very high impact on the performance indicators both at the line level and at the county level. In accordance with the problem statement, the SAIFI considering the number of consumers of the line decreased from 3.164 interruptions/year to 1.81 interruptions per year in 2022, reaching 0.15 interruptions/year in 2023 (Fig. 9).

6. Conclusions

With the help of the results obtained regarding the performance indicators calculated using the number of affected consumers, the duration of the incidents, the total number of consumers of the respective line and the number of consumers in Iasi County, it resulted that the values of the performance indicators decrease from one year to another as more remote-controlled equipment is implemented. The installation of remote-controlled equipment has led to a considerable improvement in the performance indicators by significantly reducing the number of manoeuvres necessary to identify defects in the network, quickly isolate them and resupply as many consumers as possible in a short period of time.

R E F E R E N C E S

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