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POWER QUALITY IMPROVEMENT USING AUTOMATION SYSTEMS IN ELECTRICAL DISTRIBUTION NETWORKS

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This paper deals with a case study on the implementation of an automation in the existing medium voltage network of an electricity distribution operator, aiming to reduce the values of SAIDI / SAIFI power quality indicators. A comparative analysis (with and without automation - medium voltage power line) is conducted, the objective being to design a functional model for existing distribution networks.

Keywords: distribution networks, SAIDI/SAIFI quality indicators, electrical network automation, optimization model, smart grids

1. Introduction

The paper presents a modern work system in Romania, using the SCADA application, which results in increasing the efficiency of action time in the process of dispatching electricity networks, but also improving the level of safety in electricity distribution. The current trends of knowledge as accurate as possible and in the shortest possible time of the general state, respectively of the events that occur in an electrical network, involve the use of the latest technologies in the field of informatics and telecommunications [1-3].

The development of computing techniques, of methods specific to operational research, the emergence of new technologies in the development of application packages, has produced important changes in the management of technological processes [4, 5]. The trend of implementing new methods for managing power systems, contributes to a safer operation from a technical point of view, but also economically efficient [6]. The operational management of the power systems is a necessity, and the main objective is to supply consumers with safe conditions of operation, quality, economy and continuity. The activity of the dispatchers within SEN is vital from the point of view of ensuring continuity in the supply of electricity to consumers, respecting the conditions of safety, quality and economy.

Statistics have shown that much of the damage due to staff fault was caused by well-trained staff theoretically and experienced in operation, and in such cases artificial intelligence becomes a real decision support and assistance for the dispatcher, avoiding some errors which may occur in the activity of operational management.

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In order to correctly reflect the continuity in the electricity supply of the consumers, but also the quality of the distributed electricity, the performance indicators require a strict monitoring of all the interruptions, regardless of their character (planned / unplanned interruption), of their duration, of the causes that lead to interruption, but also of the number of affected consumers and of the interrupted electric power [7, 8]. The automation of medium voltage power lines aims to increase safety in the supply of electricity to consumers, improve distribution networks performance indicators and increase the power quality [9, 10].

Distribution automation consists in the installation of specialized equipment provided with the possibility of remote control, in a centralized computer system for monitoring, control and data acquisition (SCADA) [11]. By mounting this specialized device (automatic reclosers), the medium voltage power line is divided into several network areas, and through a programmable logic controller, it communicates via GPRS with each recloser. In the event of a fault in any of the network areas of the medium voltage line (defect detected by the reclosers' own protections), it will be isolated by means of reclosers, and the logic controller will restore the power supply to consumers from the second source, the unaffected network area, which leads to increased security in the supply of electricity to consumers.

2. The evolution of the performance indicators in the distribution network

The continuity of consumers' electricity supply results from the behavior of the entire energy system, which must ensure consumer demand and an appropriate response to the dynamic processes that occur when the system moves from one state to another. System indicators can be deduced using consumer data and load data collected by electricity companies. Most of the interruptions are unpredictable, unplanned events, caused by defects of the system components, lightning strikes in power plants, unauthorized interventions (destruction), incorrect maneuvers in the system.

Usually, the interruptions in the power supply are determined by the appearance of some defects in the electrical network, isolated by the action of the circuit breakers controlled by the protection system, but also by other causes. Currently, the distribution operator (OD) places great emphasis on evaluating the performance indicators of the electricity distribution service. Table 1 presents figures regarding the SAIDI indicator in the interval 2015-2020, and in Fig. 1 the graphical representation from which results annually a decrease of the interruption time in the OD network (number of consumers 1,420,000)

Table 1

SAIDI indicator within the OD network (interval 2015-2020)

Continuity indicator	**OD year 2015**	**OD year 2016**	**OD year 2017**	**OD year 2018**	**OD year 2019**	**OD year 2020**
SAIDI planned Urban (minutes /year)	67,05	70,4	68,06	71,98	75,93	84.89
SAIDI planned Rural (minutes /year)	348,06	301,38	293,72	258,53	285,02	238.43
SAIDI unplanned Urban (minutes /year)	186,72	159,73	143,53	132,05	106,2	93.86
SAIDI unplanned Rural (minutes /year)	554,69	468,85	429,3	373,62	284,46	218.31

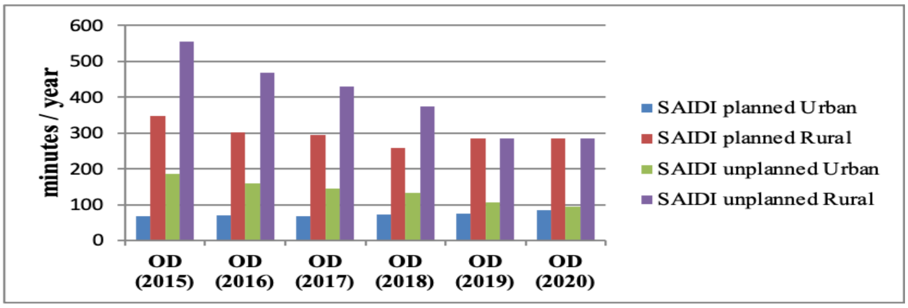

Fig. 1. SAIDI planned and unplanned in urban and rural areas (2015-2020)

The new regulations regarding the performance standard for the electricity distribution service approved, but also the higher requirements from the consumer regarding the quality of electricity, oblige the distribution operators to implement new automations in the electricity network. MT with self-healing power.

In order to calculate the SAIDI and SAIFI quality indicators for the Medium Voltage Overhead Power Line - 20kV (A) - (B) in table 2 were presented information about consumers that are fed to the same feeder that represents the “system”, details on the date of incidents, break duration due to power outage, the number of low and medium voltage consumers.

Following the centralization of the events in the MT network (medium voltage) analyzed, for a number of 73965 consumers interrupted in year 2, the values of SAIDI and SAIFI indicators from table 3 resulted, and for the 57713 consumers interrupted in year 3, those from table 4.

The positive results presented in Figs. 2 and 3, regarding the decrease of the interruption duration and of the interruption frequency for the analyzed medium voltage overhead power line, in the 3 years, are due to:

- replacement of the connecting clamps at the level of the cords in the weak points;
- deforestation in areas with vegetation;
- technical revisions to switching equipment;

- partial replacement of the insulation;
- installation of new remote controlled equipment;
- climatic factors (which differ annually and cannot be influenced);

Table 2

Details regarding the interruptions in the analyzed network year 1

Break time (Hours)	**No. of cons. JT residential**	**No. of cons. MT residential**	**Discontinued consumers**	**No. of cons. R x D JT (H)**	**No. of cons. R x D MT (H)**	**Total interruption duration (RxD JT) + (RxD MT) (H)**
2	1675	1	1676	1880.90	0.82	1881.72
0.92	4532	5	4537	4169.44	4.6	4174.04
3.49	4532	5	4537	15816.68	17.45	15834.13
21.3	4532	5	4537	83366.25	94.65	83460.90
1.6	4532	5	4537	7251.20	8	7259.20
15.41	4534	6	4540	5287.94	21.21	5309.15
8.5	3419	2	3421	26330.08	15.36	26345.44
1.15	4534	6	4540	5214.10	6.9	5221.00
3.75	4534	6	4540	13145.84	18.19	13164.03
0.74	4534	6	4540	3355.16	4.44	3359.60
5.69	1865	1	1866	10611.85	5.69	10617.54
0.78	4534	6	4540	3536.52	4.68	3541.20
3.97	4534	6	4540	17999.98	23.82	18023.80
5.5	4534	6	4540	15153.56	19.08	15172.64
2.5	4534	6	4540	3449.32	6.3	3455.62
3.4	1595	1	1596	2747.00	1.4	2748.40
8.32	4534	6	4540	20534.88	25.92	20560.80
22.34	3656	1	3657	43596.44	10.54	43606.98
1.53	4534	6	4540	6937.02	9.18	6946.20
3.21	4534	6	4540	14554.14	19.26	14573.40
2.21	4534	6	4540	10020.14	13.26	10033.40
3.38	4534	6	4540	15324.92	20.28	15345.20
0.28	4534	6	4540	1269.52	1.68	1271.20
2.08	4534	6	4540	5702.34	11.47	5713.81
8.9	3656	1	3657	9788.05	1.85	9789.90
8.58	3672	1	3673	13674.47	2.87	13677.34
0.52	3419	1	3420	1777.88	0.52	1778.40
5	4534	6	4540	19134.26	25.32	19159.58
1.92	4534	6	4540	8705.28	11.52	8716.80
		Total=	118294		Total=	390741.42

Table 3

SAIDI/SAIFI values year 2

Name LEA 20kV	Year	SAIFI LEA MT	SAIFI the entire distribution network MT	SAIDI L MT	SAIDI the entire distribution network MT
LEA 20kV (A)-(B)	2	16.29	0.052	2803.140	0.149

Table 4

SAIDI/SAIFI values year 3

Name LEA 20kV	Year	SAIFI LEA MT	SAIFI întreaga RED MT	SAIDI L MT	SAIDI întreaga RED MT
LEA 20kV (A)-(B)	3	12.67	0.041	1239.174	3.975

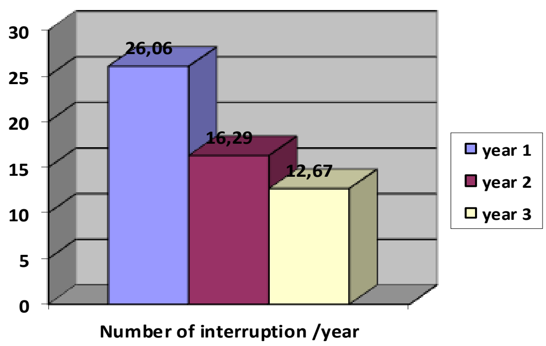

Fig. 2. Evolution over time regarding the reduction of the number of interruption (period 3 years)

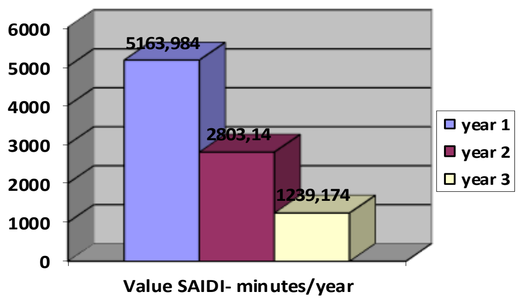

Fig. 3. Evolution of SAIDI on LEA 20kV (A)-(B), (period 3 years).

3.Presentation of the proposed automation system

The medium voltage network (LEA 20kV (A) - (B)) proposed for equipment with the monitoring and control system is supplied from PA 20kV (A), as a basic source, with the possibility of looping with: LEA 20 kV (D) - (B) and 20 kV LEA (A) - (C).

The chosen medium voltage overhead power line (20kV) for which the SAIDI and SAIFI quality indicators have been monitored and recorded has a length of approximately 60km and an Al-Ol conductor of 50/8 mm2 and currently supplies 4558 users.

3.1. Single-wire diagram and automation operating principles (20 kV overhead power line)

On the existing medium voltage overhead power line, in the places indicated on the single-wire diagram, 8 remote-controlled reclosers will be mounted. This led to the appearance of 7 sections of the medium voltage line shown in Fig. 4, each area being bordered both upstream and downstream by an automatic recloser. The choice of the medium voltage line in which the automation is to be performed was based on the following criteria:

- the contribution of the SAIDI index;
- large number of consumers;
- the length of the medium voltage overhead power line;
- hard to reach area for electricians.

Because communication between the new reconnect controller and the self-healing controller will be via GPRS, the restore time can be up to 30 seconds, mainly depending on GPRS communication delays.

The self-healing concept of the network consists of 3 steps:

- the first step is to trigger protection;
- the second step is to isolate the faulty network;
- the third step is to refuel the unaffected areas.

The controller with the self-healing function in the dispatcher center is responsible for all the logic and automatic restoration of the MV network, therefore it needs:

- GPRS communication with the installed lockers;
- IEC 104 communication with 20kV PA (A);
- IEC 104 communication with the SCADA system in the dispatcher center.

It monitors all reconnection controllers and RTUs (Remote Terminal Unit-unit for acquiring data from power and transmission equipment to them, central system commands) installed in 20kV PA (A) and initiates automatic restoration in case of a trip using a recloser or switch in substation (A).

3.2. Logic of self-healing and network restoration:

For all faults (defined trigger events), an automatic restore will be initiated in the automatic mode. The sequences will run automatically, controlled and monitored by the controller with self-healing function, and by command from the dispatcher center you switch to maintenance mode (where automatic restoration will be disabled).

It was assumed that when a permanent fault occurs (short circuit or grounding) on one of the network sections of the 7 proposed, the fault will be detected and eliminated by the own protections of the reclosers (after performing RAR cycles), and through a logic controller programmable that communicates (via GPRS) with each recloser, the fault isolation command will be given and the power supply, from the two sources, of the healthy network areas will be restored.

If the reclosers had not been installed in the studied network, the defect would have led to the final tripping by protection of the circuit breaker in the 20kV (A) PA station or in one of the 110 kV / MT stations (after performing the RAR cycles), fact which would have led to the non-supply of all transformer stations connected to the medium voltage power line - 20kV.

3.3. Principles of automation operation:

1. Any other operative state related to the equipment described in the normal scheme will lead to the automation blocking;

2. The decommissioning / commissioning of the automation will be done by order from the Dispatch Office.

3. There will be 2 groups of settings (set 1 and set 2), set 1 of settings will be active in all relays for the normal operation scheme;

4. For reclosers that change their power supply from Source 1 (PA (A) cell 20kV (B)), or Source 2 (PA (A) cell 20kV (C)) to Source 3 (Station (D) cell 20kV (B)), the automation will switch to set 2 of settings, and the return to set 1 of settings will be done manually from the spot or from the Dispatch Office.

5. After an operation, the automation will be blocked, and the unlocking will be done from the Dispatch Office. When commissioning, the automation will check the correctness of the operating scheme and the sets of adjustments and in case they do not correspond to the initial situation, it will give a message through which it will explicitly signal the discrepancy found. Due to the large number of reclosers, and taking into account that we cannot increase the operating time of the protections in the source cell, non-selective tripping of the protections may occur.

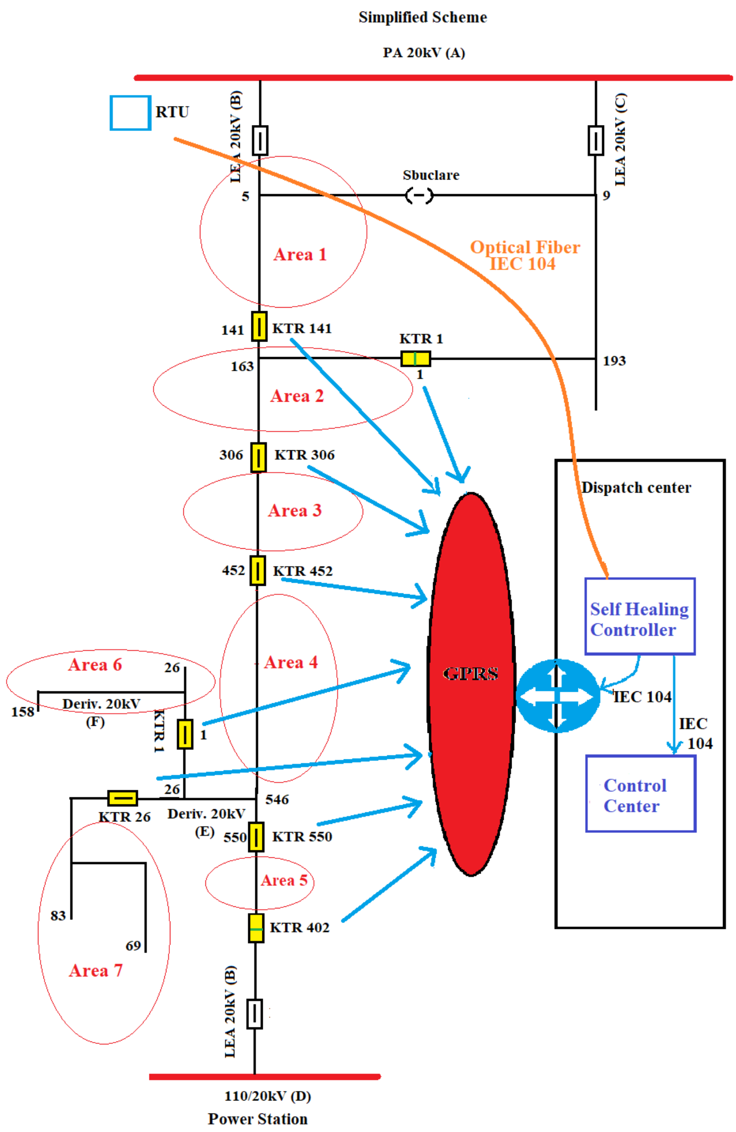

Fig. 4. Scheme with network areas, communication overview

To correct these inconveniences, the logic will reconnect the reclosers closest to the source, then refuel the areas with the possibility of power supply. (the order of non-selective connections will be from the sources to the downstream reclosers). The connection time of the next recloser after receiving the feedback from the upstream one will be longer than the trigger time of the protection with the longest timing (the automation will act after performing the RAR cycles). Any manual actuation of any recloser involved in the automation will lead to the blocking of the automation, and the unlocking will be done by order from the Dispatcher. Any loss of communication with any of the equipment involved in automation will lead to the blocking of the automation, and the unblocking will be done by order from the Dispatch Office.

3.4. Scenario regarding the failures on the area in the analyzed network.

The following have been defined:
- S1, S2, S3 energy sources;
- P01 - 20 kV LEA circuit breaker (A) - (C);
- P03 - 20 kV LEA circuit breaker (A) - (B);
- P02 Recloser KTR 1 (disconnected in normal operation diagram);
- P04 Recloser KTR 141
- P05 Recloser KTR 306
- P06 Recloser KTR 452
- P07 Recloser KTR 550
- P08 Recloser KTR 402 (disconnected in normal operation diagram)
- P09 Recloser KTR 1B - 20kV derivation (F);
- P10 Recloser KTR 26 - 20kV derivation (E);
- T1, T2 - Low voltage transformers (20 / 0.4kV)
- C01 Area that cannot be powered automatically (if P01 triggers, only C01 is unusable).

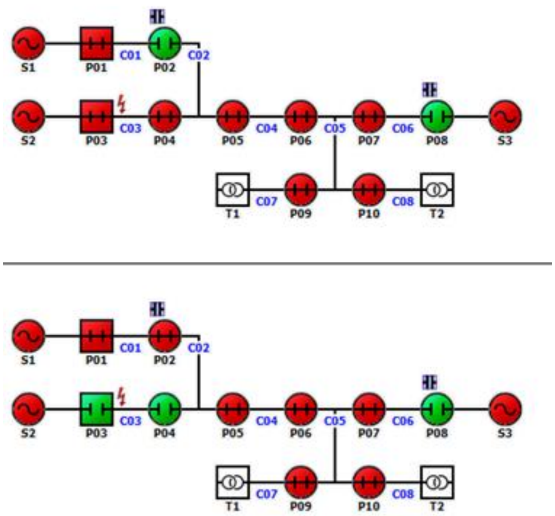

Fig. 5. Fault in zone 1 (C03) and status after restart / power supply, red = connected, green = disconnected.

Fig. 5 shows the overall diagram with the fault zones in the analyzed network and its condition after power supply.

4. Evaluation of the impact on the SAIDI performance indicator

Table 5 presents the concrete analysis of the incidents that took place on the overhead power line 20 kV PA 20kV (A) - (B) in year 2, without the automation of the 20kV power grid, and in table 6 the reduction of interruption times.

Table 5

Simulation results for medium voltage power line with automation (events recorded in year 2)

Crt. No.	**Defective area (events year 2)**	**No automation overhead power line 20kV**			**With automation overhead power line 20kV**		
		Break time (hours)	No. cons. of discontinued consumers	Total interruption time (hours)	Break time (hour)	No. cons. of discontinued consumers	Total interruption time (hours)
1	Area 2+4+6+7	17,52	4.531	35533	8	4310	34480
2	Area 3	6,99	3.657	25569	4	860	3440
3	Area 2	5,8	4.531	19556	4	650	2600
4	Area 3	4,5	3.657	16461	4	860	3440
5	Passing defect;	3,15	4.531	13343	2	2200	4400
6	Passing defect;	3,73	4.531	12683	2	2200	4400
7	Area 6+7	6,95	1.690	11752	4	620	2480
8	Area 7	8,12	4.531	9196	4	640	2560
9	Passing defect;	2	4.534	9080	1	2200	2200
10	Area 2	17,25	4.531	8922	4	650	2600
11	Area 5	6,56	4.531	8596	4	430	1720
12	Unidentified defect;	1,63	4.531	7395	1	2200	2200
13	Unidentified defect;	1,62	4.531	7350	1	2200	2200
14	Unidentified defect;	2,79	2.586	7215	1	2200	2200
15	Area 1	5,17	4.531	6159	4	220	880
16	Area 2	1,23	3.971	4886	1	650	650
17	Unidentified defect;	0,86	4.534	3904	0,5	2200	1100
18	Area 7	2,12	1.071	2273	2	640	1280
19	Def	0,88	1.438	1266	0,5	700	350

	Unidentified defect;						
20	Area 7	0,67	1.438	964	0,5	640	320

Table 6

SAIDI year 2 - network analyzed with and without automation.

Name	Year studied	SAIDI Initial (min.)	SAIDI automation (min.)	Reduction SAIDI (%)
LEA 20kV (A)-(B)	2	2808.7	999.77	64.4

5. Conclusions

The renewable energy sources generation is heavily based on the uncertain meteorological conditions. The connection of these sources in public networks can determine, in certain periods, supplementary loading of the power systems which can lead to congestions. These ones can reduce the secure operation of the system and can affect the power quality delivered to the customers.

A power quality analysis is conducted on the operation of a real part of the distribution system in normal regime and with automations is conducted. Reliability indices are monitored and compared in both cases resulting in an improvement of the power quality indices in the case of automation systems. The optimization of the activity of the dispatcher can determine flexible system resulting in the increase of the efficiency of the performed activity. This increase in the efficiency of the activity is found in:

- the reduction of the maneuvering times for the admission of the teams to work and for the incident liquidation, by the uniformization of the dispatchers' load, which led, implicitly, to the reduction of the non-delivery times of the electricity (refueling of the consumers);
- efficient use of human resources, resulting in the possibility of adapting to fluctuations in workload, both in normal conditions and in special weather conditions;
- integration in the SCADA system of all remote-controlled equipment allows the reduction of SAIFI / SAIDI continuity indicators in the supply of electricity to consumers;

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