



The impact of selected variants of remote control on power supply reliability indexes of distribution networks

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Received: 17 March 2021 / Accepted: 20 August 2021 / Published online: 31 August 2021
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Abstract

Ensuring reliability and continuity of energy supply is the main goal of local governments and distribution companies. The continuity of energy supply means capability of a power grid to supply agreed amount of energy, of specific quality, without power cuts. The expectations concerning the quality of supplied energy and ensuring its continuity are constantly growing, and any power cuts have significant impact on comfort of life and manufacturing and service sector. To increase reliability of energy supply and improve condition of a power grid in the distribution companies, the works are conducted to increase power supply reliability indexes. The main goal of this publication is to present a problem of discontinuity of energy supply and actions aiming at improvement of power supply reliability indexes. An analysis of discontinuity of energy supply presented in the article is based on data obtained from a selected department of a distribution company. Based on actual data, the impact of location of remote-controlled controllers on the value of SAIDI and SAIFI was presented. Four variants of remote control on the sequence of a medium-voltage cable line were analysed.

Keywords Distribution company · Department of distribution company · Power supply reliability indexes · SAIDI · SAIFI · Remote control

1 Introduction

Increased requirements of the consumers within the scope of reliability of power supply with constant growth of energy demand, high level of interferences and growing number of connected sources of distributed energy, including prosumers, cause that effective supervision-control of work of distribution networks is difficult and requires to implement new

technological solutions. Provision of better working conditions of the distribution networks is an important problem, and its solution requires verification of solutions applied nowadays, among others, within the scope of control [1, 4].

The improvement of reliability of supplying energy to the consumers requires to reduce duration of stoppages in the medium-voltage distribution networks. The complexity of these networks lies in the fact that one line may supply the large number of medium-voltage/low-voltage transformer stations, which makes it difficult to quickly locate a failure. Effective and quick location of network interferences with the use of remote-controlled switching automation allows to improve the functioning of energy distribution systems [17, 18]. Broadly defined telemechanization of switching processes contributes to effective reduction of duration of location of damages and change of network configuration, which effectively improves functioning of a medium-voltage network, causing minimization of the number of disconnected consumers [7, 16].

The distribution companies, installing devices of remote automation, analyse the variants of controlling the connectors and impact of these locations on SAIDI and SAIFI [2, 8, 14]. The goal of conducted analyses and simulations is

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usually to determine the number of disconnected consumers deprived of the possibility of remote connection. Another variant considered by the distribution companies is determination of the number of the consumers connected remotely within less than 3 min.

The authors of this publication presented the issue of discontinuity of energy supply and types of methods applied by selected distribution company to improve power supply reliability indexes. Based on assumed linear sequence consisting of 18 medium-voltage/low-voltage stations, an analysis of four variants of the possibility of remote control of cut-off switches was conducted, and impact of these actions on SIADI and SAIFI was assessed.

2 The methods and actions taken to improve power supply reliability indexes in the distribution networks of a selected department of distribution company

The main priority of the power industry is to ensure continuity of electricity and thermal energy supplies to the consumers. Therefore, the goal of taken actions is to maintain high level of reliability of manufacturing infrastructure along with transmission and distribution networks. Investment growth in this area results in development of generation assets and networks along with distribution infrastructure [9, 10, 15]. The key element of ensuring continuity of supplies and improvement of power supply reliability indexes is actions that include:

- Conducting regular maintenance works
- Conducting various modernizations
- Making large investments
- Implementation of new technical standards
- Cooperation with other operators
- Raising skills and qualifications of the employees.

The expenditure on the investments of the five largest distribution networks in the medium-voltage and low-voltage networks in 2019 was PLN 6526,6 million, and the sum of expenditure on the innovations was PLN 136,7 million [20]. Whereas resources allotted to reconstruction modernization and strengthening of resistance of medium-voltage and low-voltage networks to atmospheric phenomena constituted in the years 2014–2017 nearly 40% of total expenditure of the operators of a distribution system on the investments [6]. The goal of these investments made by the department of a distribution company is, above all, to improve conditions of supply and quality of supplied energy. In addition, modernization and expansion of infrastructure allow the companies to increase energy safety in the provinces and provide power for

new investors, supporting the development of the regions. One of the priority actions taken in recent years was replacement of old overhead lines with new cable lines. As a result, at the end of 2019, total length of medium-voltage cable lines was 83,586 km, and low-voltage lines without connections were 154,513 km [20]. Despite considerable increase in length of cable lines, it will take Polish electrical power engineering at least 10 years to achieve EU average of share of cable lines in the distribution networks. Another investment is development of smart grids. The main actions in this direction are focussed on automation of the distribution networks having large impact on reduction of power cuts. The investments within this scope include installation of remote-controlled connectors in the medium-voltage overhead lines and transformer stations, as well as modernization of plant controllers and concentrators. The functions of FDIR automation (Fault Detection Isolation Restoration) are also implemented in the selected medium-voltage sequences [3, 5, 11, 19, 21].

Moreover, the goal of application of new technical standards and modern technologies is to increase energy efficiency. The projects reducing the losses in the transformers are conducted, and special computational algorithms facilitating the process of selection of transformers are developed [4, 12, 13, 22].

Cooperation with other operators means mutual actions aiming at quick repairing of power grids. An expression of this cooperation is agreements signed with a transmission operator and with other operators of distribution systems. Concluded agreements have sanctioned cooperation with other operators of distribution and transmission systems, which is made to remove the effects of extraordinary weather situations such as rainstorms.

Raising skills and qualifications is focussed mainly on the works with voltages. To ensure continuity of energy supply, the networks are usually repaired with connected voltage.

The improvement of reliability indexes consists also of many other factors that distribution companies perceive in the improvement of distribution process. They include changes of structure of management of network traffic, changes of conducted modernizations of a power grid and quality of provided services. One of the significant elements is implementation of a new organization of traffic management services in the companies and reinforcement of the structures of Energy Stations, which makes monitoring of condition of the company's power grid more effective.

3 An analysis of location of remote-controlled connectors illustrated with an example of a medium-voltage cable line in a selected power distribution company.

There are a few power bases of different territorial structures and different distributions of the consumers in urban and rural areas in the considered department of a distribution company. The authors analysed four variants of controlling the connectors and impact of these locations on SAIDI and SAIFI. The indexes were calculated from relations (1) and (2):

$$SAIDI = \frac{\sum U_i N_i}{\sum N_i} \tag{1}$$

where:

N_i —The number of the consumers,

U_i —One-year period of disconnections for the consumer i .

$$SAIFI = \frac{\sum N_i \lambda_i}{\sum N_i} \tag{2}$$

where:

λ_i —The sum of unplanned breaks for the consumer within a year,

N_i —The number of the consumers.

The goal of conducted analyses and simulations was to determine the number of disconnected consumers that were deprived of an option of remote connection. Another variant considered by the authors was determination of the number of the consumers connected remotely within less than 3 min after occurrence of a failure. Index of average duration of long and very long break of SAIDI was determined for six values of reactions of the EET (Energy Emergency Team) to the failures in a linear cable run consisting of 18 medium-voltage/low-voltage stations. It was assumed that intervals of power supply restoration, that is, elimination of interferences by EET will be growing, every 10 min within 10 ÷ 60 min. Total number of consumers in the power base is 456923, whereas the number of all connected consumers in a considered linear sequence is 2984. Topology of analysed medium-voltage sequence of lines is presented in Fig. 1., whereas actual technical data of 18 medium-voltage/low-voltage stations containing names, number of consumers, type of station and power of transformers are presented in Table 1.

Four variants selected for an analysis have the following strategies of simulation of operation of medium-voltage linear sequence:

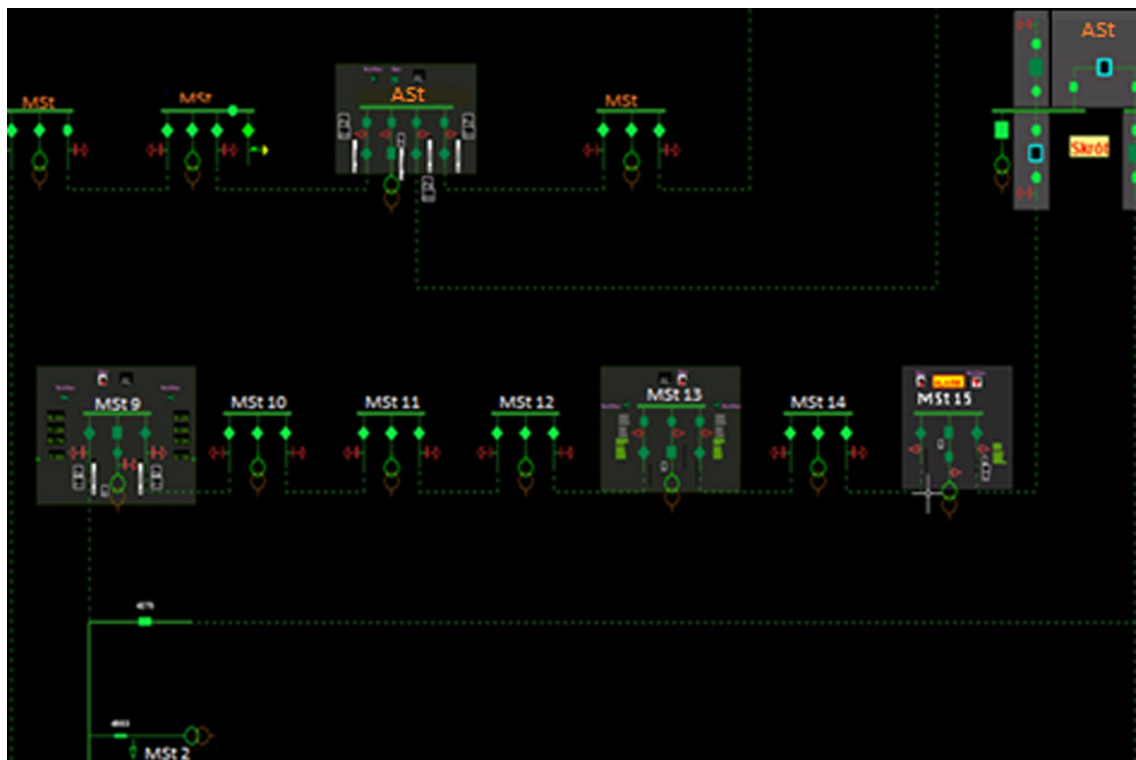


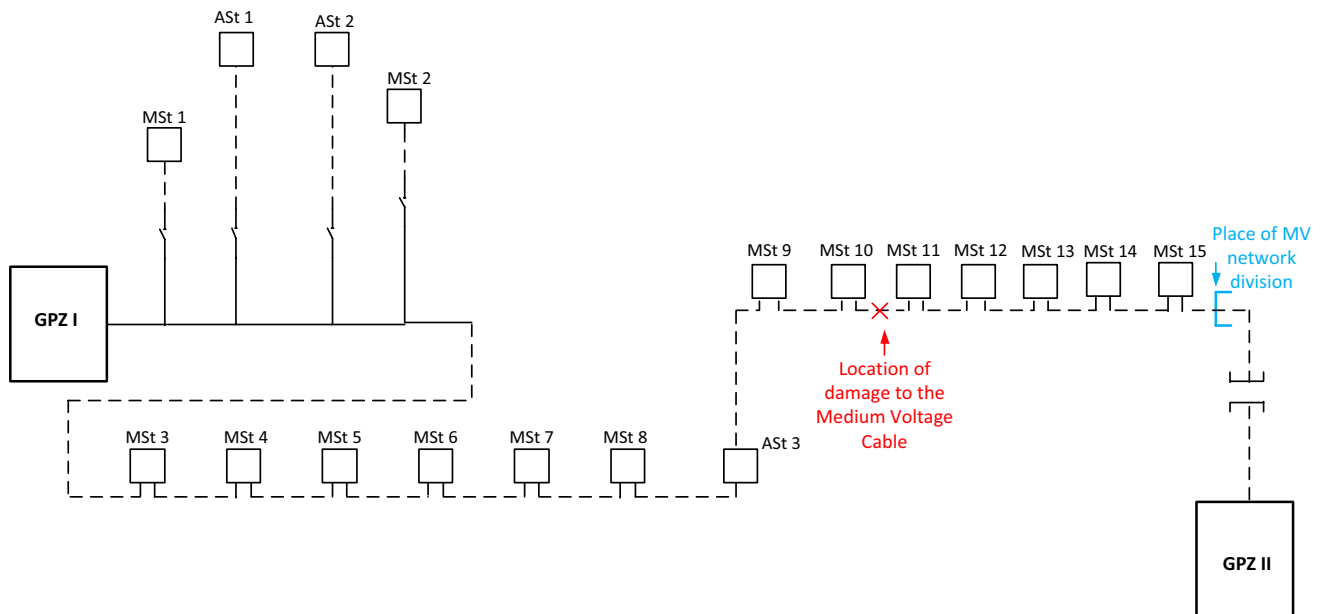
Fig. 1 Topology of line along with medium-voltage/low-voltage stations from SCADA

Table 1 Technical data of 15/0,4 kV medium-voltage station

Station name	Number of consumers supplied from the station	Station type	Station power [kVA]
MSt 15	198	MSTw20/630	400
MSt 14	83	MSTw20/630	400
MSt 13	237	MSTw20/630	400
MSt 12	216	MSTw20/630	400
MSt 11	322	MSTw20/630	400
MSt 10	263	MSTw20/630	400
MSt 9	343	MSTw20/630	630
ASt 3	1	Recipient property	1000
MSt 8	332	MSTw20/630	630
MSt 7	312	MSTt20/630	400
MSt 6	217	MSTw	400
MSt 5	51	MSTw20/630	160
MSt 4	181	MSTw20/630	400
MSt 3	213	MSTw20/630	630
MSt 2	8	STSup 20/400	250
ASt 2	1	Recipient property	1000
ASt 1	1	Recipient property	800
MSt 1	5	STS 20/50	40

3.1 Variant I

In this variant, it was assumed that the whole sequence of a medium-voltage cable line was not equipped with remote-controlled cut-off switches; therefore, there is no possibility of remote switching in the event of a failure and supplying

**Fig. 2** Topology of linear sequence considered for variant I

some consumers. In all fields of the stations that linear sequence consists of, manual cut-off switches were mounted. In order to switch, they require intervention of the Energy Emergency Team. Topology of a cable line along with marked place of permanent network division is presented in Fig. 2. Occurrence of a failure between MSt 10 and MSt 11 was assumed in the variant I. In order to eliminate damaged cable between these stations, cut-off switch in the area of MSt 10 station for a cable towards MSt 11 must be opened, and then, in the area of MSt 11 station, cut-off switch for a cable towards MSt 10 station must be opened and cut-off switch must be closed in the area of MSt 15 station towards the next station supplied from other cable run in order to supply the stations from MSt 15 to MSt 11. Remaining stations, that is, from MSt 1 to MSt 10 will be supplied again by dispatcher who remotely closes a switch in an outgoing bay GPZ I 110/15 kV.

The calculations of SAIDI for variant I depend on time of reaction on a cable failure, repairing it and power supply restoration by EET. Assumed times of EET reaction are the following: 10, 20, 30, 40, 50, 60 min.

3.2 Variant II

In this variant, installation of remote-controlled cut-off switch was installed in an outgoing bay of MSt 9 station for a cable supplying MSt10 station. Remaining cut-off switches in all stations require manual switches by the Energy Emergency Team. During failure between stations MSt 10 and MSt 11, the whole linear sequence will be disconnected through opening a switch in GPZ I. Meanwhile, a dispatcher

can remotely open a cut-off switch in the area of MSt 9 station for a cable towards MSt 10 station and tentatively connect the line from GPZ I to MSt 9 station. In the event of positive connection, the stations from MSt 10 to MSt 15 will have no voltage. In order to eliminate a damaged cable between MSt 10 and MSt 11 station, cut-off switches must be opened manually in MSt 10 station for a cable towards MSt 11 station and in the area of MSt 11 station for a cable towards MSt 10 station. In MSt 9 station, an attempt to apply voltage can be made in order to supply MSt 10 station through remote closing of a cut-off switch in the area of MSt 9 station for a cable towards MSt 10. Then, cut-off switch must be closed manually in the area of MSt 15 station for a cable towards the next station supplied from different cable runs in order to supply the stations from MSt 15 to MSt 11. Topology of medium-voltage cable line along with a place of installing a remote-controlled cut-off switch in MSt 9 station is presented in Fig. 3.

Performing the sequence of remote switches allows to supply some disconnected consumers from GPZ I to MSt 9 station within up to 3 min. Remaining disconnected consumers from the stations MSt 10 to MSt 15 will be supplied thanks to intervention of the Energy Emergency Team. Six-time variants of repairing a cable are the following: 10, 20, 30, 40, 50, 60 min.

3.3 Variant III

Variant III presents assumptions of installing remote-controlled cut-off switches in MSt 9 station for a cable towards Ast 3 station and in MSt 15 station, for a cable towards.

The next station supplied from different cable lines. In the remaining stations, the cut-off switches require manual switches. The places marked blue in Fig. 4 present installed remote-controlled cut-off switches in the areas of the stations from MSt 9 to MSt 15.

In the event of a failure between the stations MSt 7 and MSt 8, the whole line will be disconnected by short-circuit protection, which will result in opening a switch in GPZ I supplying the whole cable run. A dispatcher can open a remote-controlled cut-off switch in the area of MSt 9 station for a cable towards Ast 3 station and can tentatively connect the line from GPZ I to MSt 9 station. In the event of a negative test, a dispatcher can tentatively connect, closing a remote-controlled cut-off switch in the area of MSt 15 station for a cable towards the next station supplied from GPZ II of a different cable run, which results in applying voltage from MSt 15 to MSt 9, that is, to an opened cut-off switch in MSt 9 station. Above actions should be correlated with the work of the Energy Emergency Team, which in order to eliminate a damaged cable between MSt 7 and MSt 8 station, must manually open a cut-off switch in the area of MSt 7 station for a cable towards MSt 8 station and in MSt 8 station, for a cable towards MSt 7. After elimination of a damaged fragment of a cable between MSt 7 and MSt 8, a dispatcher can remotely close a cut-off switch in the area of MSt 9 station for a cable towards Ast 3 station and apply voltage in Ast 3 and MSt 8 station. The cable run from GPZ I to MSt 7 station can be supplied through remote closing of cut-off switch in the area of 15 kV and applying voltage from GPZ I to MSt 7 station.

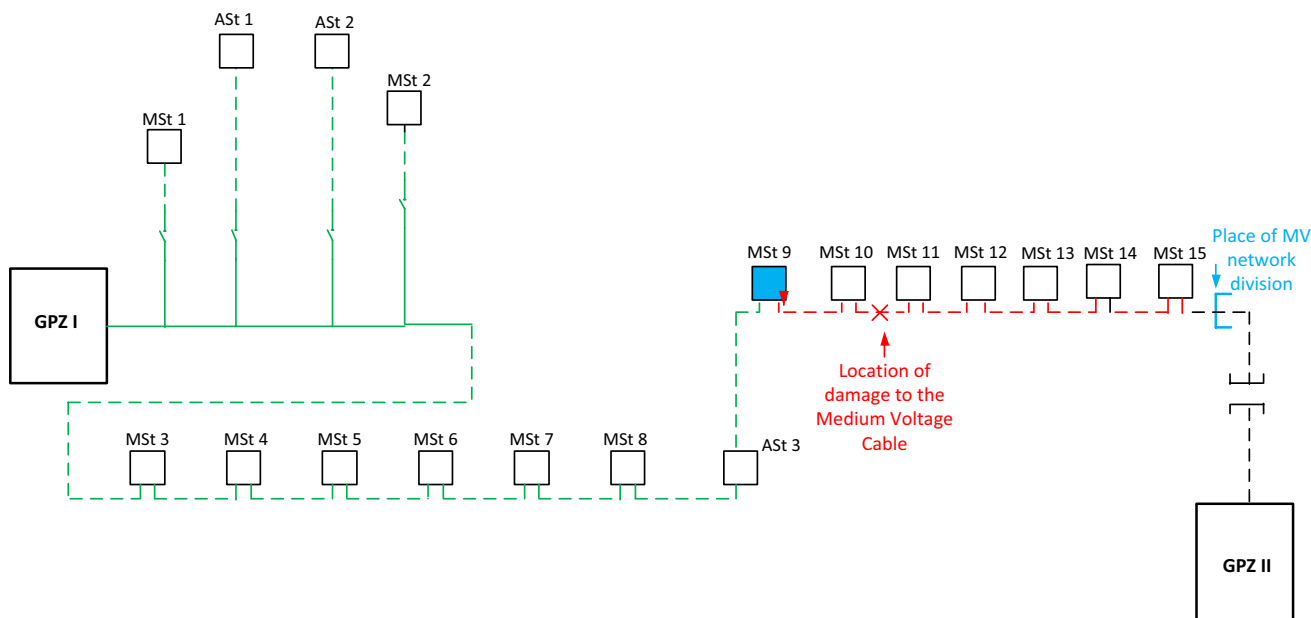


Fig. 3 Topology of linear sequence considered for variant II

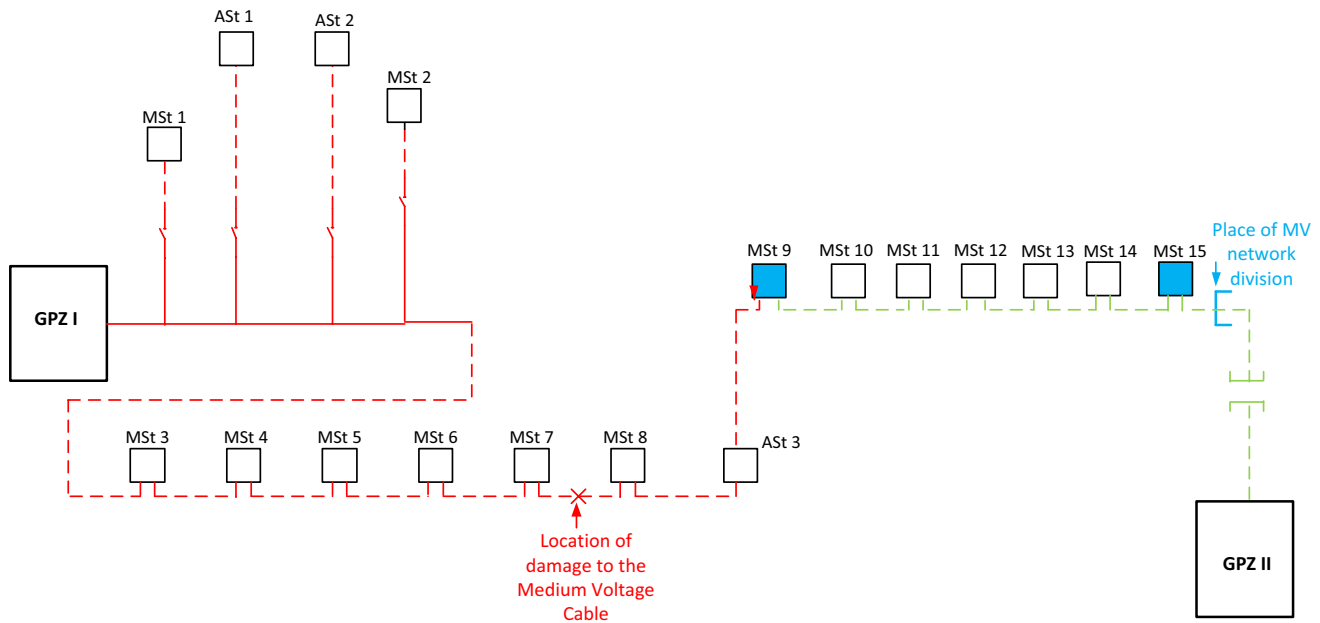


Fig. 4 Topology of linear sequence considered for variant III

Performing the sequence of remote switches allows to supply some disconnected consumers from the second GPZ II to MSt 9 station within up to 3 min. Remaining disconnected consumers from GPZ I to MSt 7 and from MSt 9 station to MSt 8 station will be supplied thanks to an intervention of the Energy Emergency Team. Six-time variants of repairing a cable are the following: 10, 20, 30, 40, 50, 60 min.

3.4 Variant IV

Variant IV presents the assumptions of installing remote-controlled cut-off switches in MSt 6 in the area for a cable towards MSt 7, and in MSt 11 station, in the area for a cable towards MSt 10. In addition, it was assumed that in the area of MSt 15 station, a remote-controlled cut-off switch will be turned on for a cable towards station supplied from GPZ II of a different cable run applying voltage to MSt 15 to MSt 11. Subsequent actions in the form of manual switches will be taken by the Energy Emergency Team, that is, switches between stations MSt 10 and MSt 7. After eliminating a damaged cable between stations MSt 10 and MSt 9, a dispatcher remotely closes a cut-off switch in the area of MSt 11 to MSt 10 and remotely closes a cut-off switch in the area of MSt 6 for a cable towards MSt 7. It will result in supplying the section of a cable line along with the stations from MSt 7 to MSt 9.

Performing the sequence of remote switches allows to supply some disconnected consumers from GPZ I to MSt 6 station and from GPZ II to MSt 11 station within up to 3 min. Remaining disconnected consumers between MSt 7 and MSt 10 will be supplied thanks to an intervention of the Energy Emergency Team. Six-time variants of repairing a cable are the following: 10, 20, 30, 40, 50, 60 min.

Based on such formulated strategies of control and distribution of connectors, calculations and assessment of the

11 for a cable towards MSt 10, then, open the switch in GPZ I, close the cut-off switch in MSt 6 towards MSt 7 and close again the switch in GPZ I, trying to connect a larger section of a cable line from GPZ I to MSt 10 station. In the event of a negative test, a dispatcher remotely opens a cut-off switch in the area of MSt 6 for a cable towards MSt 7 and connects a switch in the area of GPZ I connecting the section of a cable line to MSt 6. After this operation, a dispatcher remotely opens a cut-off switch in MSt 11 for a cable towards MSt 10, then, closes a cut-off switch in the area of MSt 15 for a cable towards the next station supplied from GPZ II of a different cable run applying voltage to MSt 15 to MSt 11. Subsequent actions in the form of manual switches will be taken by the Energy Emergency Team, that is, switches between stations MSt 10 and MSt 7. After eliminating a damaged cable between stations MSt 10 and MSt 9, a dispatcher remotely closes a cut-off switch in the area of MSt 11 to MSt 10 and remotely closes a cut-off switch in the area of MSt 6 for a cable towards MSt 7. It will result in supplying the section of a cable line along with the stations from MSt 7 to MSt 9.

Based on such formulated strategies of control and distribution of connectors, calculations and assessment of the

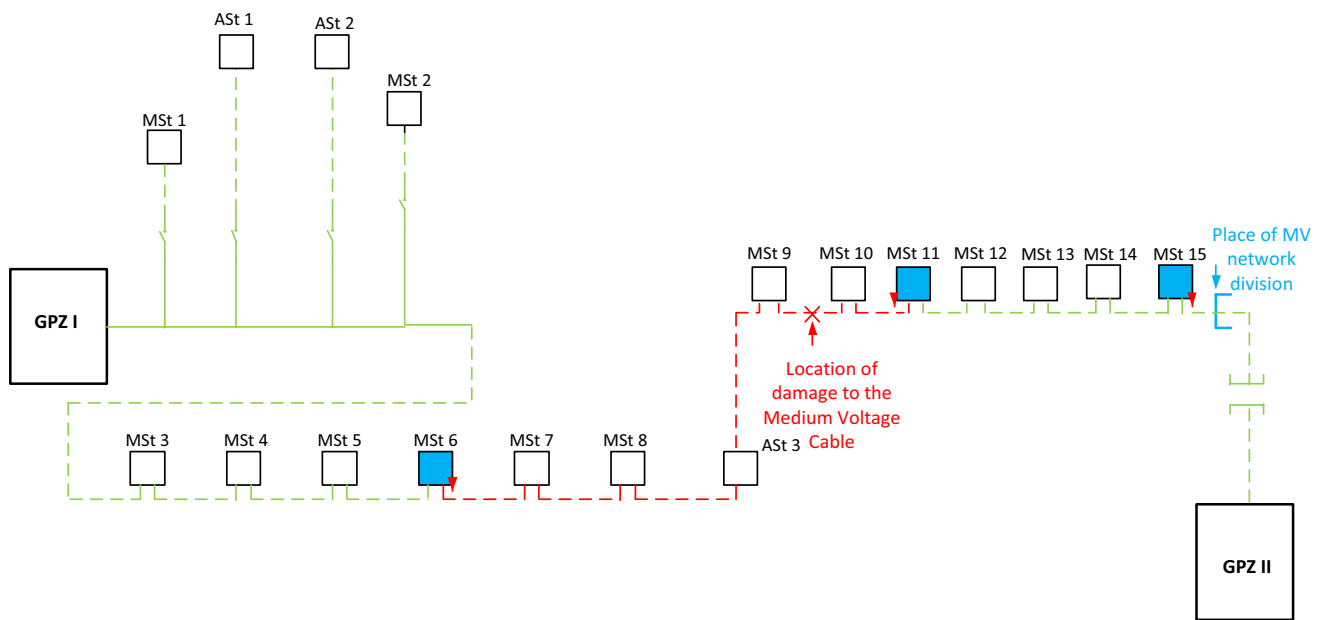


Fig. 5 Topology of linear sequence considered for variant IV

Table 2 Value of SAIDI for variant I

EET reaction time [min]	10	20	30	40	50	60
SAIDI	0.0653	0.1306	0.1959	0.2612	0.3265	0.3918

impact of particular variants on SAIDI and SAIFI were made.

4 An analysis and assessment of the impact of selected variants of location of remote-controlled cut-off switches on SIADI and SAIFI

Particular variants of location of cut-off switches were analysed in order to determine the number of disconnected consumers who, as a result of application of automation of linear sequence, would be connected again within less than 3 min. Based on assumed times of EET reaction, index of average duration of long and very long break of SAIDI was calculated. Index of average system frequency of long and very long breaks of SAIFIs was also calculated.

4.1 SAIDI and SAIFI for variant I

In this variant, disconnection of all consumers in a given sequence of lines, without an option of remote switching, was assumed. Disconnected consumers will be supplied by EET. The number of disconnected consumers in the linear sequence is 2984, whereas calculated SAIDI is presented in

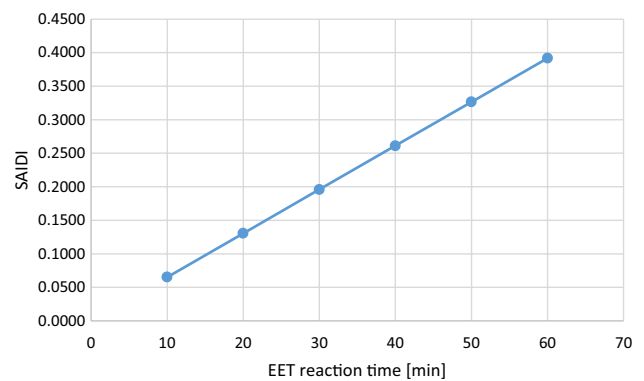


Fig. 6 SAIDI without an option of remote switches of sequence of lines

Table 2. The course of SAIDI depending on ZPE reaction time is presented in Fig. 6

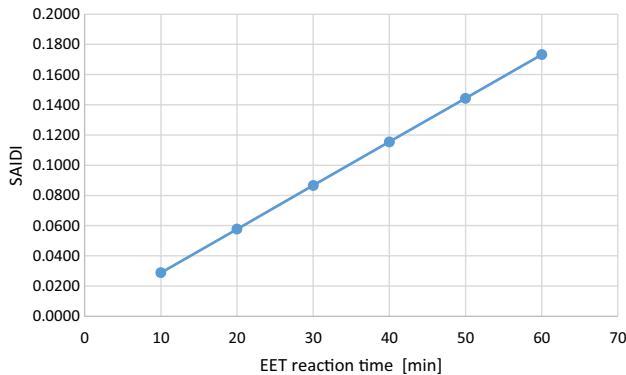
Index of average system frequency of long and very long breaks of SAIFI for 2984 disconnected consumers is 0.0065 min.

4.2 SAIDI and SAIFI for variant II

The location of remote-controlled connector that allows to remotely open a cut-off switch in the area of MSt 9 station for

Table 3 Value of SAIDI for variant II

EET reaction time [min]	10	20	30	40	50	60
SAIDI [-]	0.0289	0.0577	0.0866	0.1155	0.1443	0.1732

**Fig. 7** SAIDI for failure between stations MSt 10 and MSt 11

a cable towards MSt 10 station was assumed. Some consumers will be connected within less than 3 min. Remaining consumers will be connected after manual switches and identification of a damaged cable by the Energy Emergency Team, in various time variants.

Thanks to such strategy, 1665 consumers supplied from GPZ I to MSt 9 station will be connected within less than 3 min. The number of disconnected consumers from MSt 10 to MSt 15 without an option of remote connection for assumed variant is 1319. The calculations of SAIDI for variant II are presented in Table 3. The course of SAIDI depending on EET reaction time is presented in Fig. 7.

Index of average system frequency of long and very long breaks of SAIFI for 1319 disconnected consumers is 0.0029 min.

4.3 SAIDI and SAIFI for variant III

The location of remote-controlled cut-off switches in the area of MSt 9 for a cable towards ASt 3 and in the area of MSt 15 for a cable towards the next station supplied from GPZ II from a different cable line was assumed. It was assumed that failure will occur in a considered cable line between MSt 7 and MSt 8.

1662 consumers from GPZ II to MSt 9 station will be connected within less than 3 min. Remaining 1322 consumers connected from GPZ I to MSt 7 and from MSt 9 to MSt 8 will be connected by manual switch and identification of a damaged cable by the Energy Emergency Team.

Table 4 Value of SAIDI for variant III

EET reaction time [min]	10	20	30	40	50	60
SAIDI [-]	0.0289	0.0579	0.0868	0.1157	0.1447	0.1736

The calculations of SAIDI for variant III are presented in Table 4. The course of SAIDI depending on EET reaction time is presented in Fig. 8.

Index of average system frequency of long and very long breaks of SAIFI for 1322 disconnected consumers is 0.0029 min.

4.4 SAIDI and SAIFI for variant IV

The remote-controlled cut-off switches in MSt 6 station in the area for a cable towards MSt 7 station, in MSt 11 station and in the area of for a cable direction MSt 10 and MSt 15 were installed. In addition, it was assumed that in the area of MSt 15, a remote-controlled cut-off switch for a cable towards station supplied from GPZ II of a different cable run will be turned on. The occurrence of a failure between stations MSt 9 and MSt 10 was assumed. 1733 consumers from GPZ I to MSt 6 and from GPZ II to MSt 11 station will be connected again within up to 3 min. Remaining 1251 consumers connected from MSt 7 to MSt 10 will be connected by manual switch and identification of a damaged cable by the Energy Emergency Team. The calculations of SAIDI for variant IV are presented in Table 5. The course of SAIDI depending on EET reaction time is presented in Fig. 9.

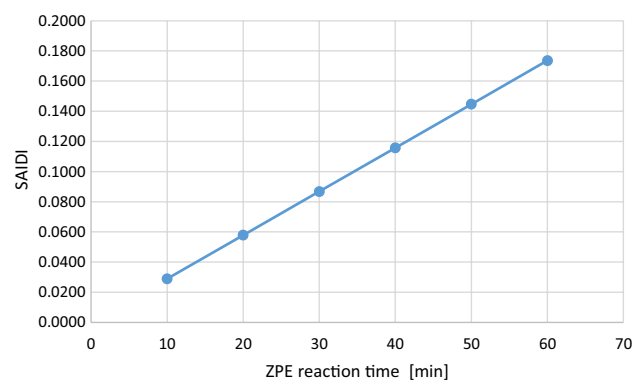
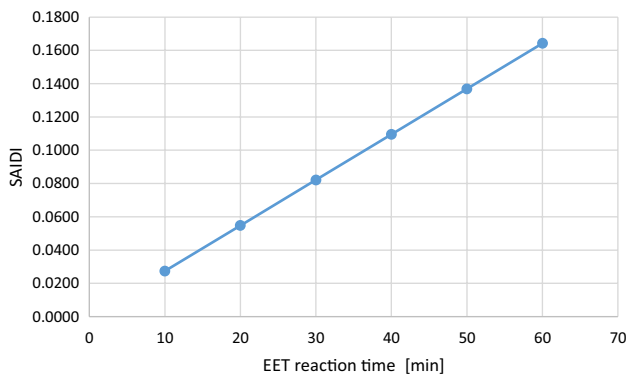
**Fig. 8** SAIDI for failure between stations MSt 7 and MSt 8

Table 5 Value of SAIDI for variant IV

EET reaction time [min]	10	20	30	40	50	60
SAIDI [-]	0.0274	0.0548	0.0821	0.1095	0.1369	0.1643

**Fig. 9** SAIDI for failure between stations MSt 9 and MSt 10

Index of average system frequency of long and very long breaks of SAIFI for 1251 disconnected consumers is 0.0027 min.

5 Conclusions

The issues ensuring continuity of energy supply for consumers connected to a medium-voltage cable line were analysed in the article. The Energy Regulatory Authority, imposing reduction of permissible index values of power cuts, forces the operators of a distribution system to take actions aiming at reduction of duration and number of these breaks.

Based on an example of actual data obtained from a selected department of distribution company, the impact of location of remote-controlled connectors on the value of SAIDI and SAIFI was presented. Presented actions taken in order to ensure continuity of supply are classic examples of an assessment of the impact of installing remote-controlled connectors on functioning of the medium-voltage lines while removing the effects of a failure in the form of reduction of the number of connected consumers. Conducting such analyses by the distribution companies is necessary to determine qualitative reduction of SAIDI and SAIFI.

Conducted analysis confirmed the necessity of further modernizations of medium-voltage network in order to install sufficient number of remotely controlled connections in the distribution infrastructure. Such actions enable to obtain high manoeuvre flexibility without the necessity of extending of an intervention of the Energy Emergency Team. Effective and quick location of network interferences connected with remote-controlled switching automation reduces the time of reaction of power supply restoration

in the sections of a network, having large impact on the functioning of the energy distribution systems. Obtained results for analysed variants confirm the usefulness of taking actions aiming at reduction of duration of unplanned disconnections in the distribution networks.

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