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Calculation of Target Reliability SAIDI for Distribution Lines

I. Bandurin
Electricity and Electrical engineering department
Pskov State University
Pskov, Russia
bandurin_ivan@mail.ru

A. Martirosian
Electricity and Electrical engineering department
Pskov State University
Pskov, Russia
nastya_auuu@mail.ru

A. Khaimin
Electricity and Electrical engineering department
Pskov State University
Pskov, Russia
akhaimin@mail.ru

***Abstract*—in modern distribution lines reliability indicators are attached great importance. In regulations of the Russian Federation indicated the reliability indicators, which must be counted by Grid Company. SAIDI is one of them. In this article you can see the author's calculation of reliability indicator SAIDI for the distribution lines. Also there are an example of this calculation and comparing with the real measure, which we have taken from software complex «Accident».**

Keywords — SAIDI, electricity supply restoring, distribution line, the electrical consumer.

I. Introduction

In the order of the Ministry of Energy of the Russian Federation № 1256 are used two indicators of reliability for the territorial Grid Company. One of them is a system average interruption frequency index (SAIFI) and another one is a customer average interruption duration index (CAIDI). This situation made it necessary to formulate methods of calculating the reliability of the final electrical consumers [1]. In this article the technique of calculating reliability indicator SAIDI.

Overview of Russian and foreign publications [2-9] was showed that the reliability of the SAIDI can only be determined according to the statistical information of exploitation. Thus, you can obtain an assessment of indicators of reliability the line before reconstruction.

During the engineering of the new or the reconstructing distribution line, we should to assess its reliability. Such assessment is required primarily for feasibility study of construction or reconstruction of distribution lines. In this regard, the purpose of this work is to obtain a reliability indicator calculation methodology SAIDI distribution lines in the engineering phase. This confirms the relevance of this article.

II. Materials and methods

SAIDI is the average outage duration for each customer served, and is calculated as:

$$SAIDI = \frac{\sum_{i=1}^{n} T_{sum,i} N_i}{N_T} \text{ [h]}, \tag{1}$$

where $T_{sum,i}$ – the annual outage time for the i-th place, N_i - the number of customers in the i-th place, N_T - the total number of customers served, n – number of plots.

Estimated time to restore electricity consumers of the 1st section and those that cannot be included, when the i-station is damaged is calculated as:

$$t_{REC,i} = t_{beg,i} + t_{search,i} + t_{loc,i} + t_{on,i} + t_{sweap,i} + t_{rep,i}, \tag{2}$$

where $t_{beg,i}$ – the time from the moment of blackout to the search, $t_{search,i}$ – while searching for a damaged, $t_{loc,i}$ – the localization of the damaged, $t_{on,i}$ – time to include those loads that can be included in absence in the schema of the damaged site, $t_{sweap,i}$ – time to crawl the damaged, $t_{rep,i}$ – time to repair the damaged section and incorporate loads of online/offline users to start repairs. The time from the moment of blackout till the beginning of searching is calculated as:

$$t_{beg} = t_{\inf} + t_{waiting} + t_{transport}, \tag{3}$$

where t_{inf} – the time from the moment of blackout to receipt of this, $t_{waiting}$ – operational readiness, $t_{transport}$ – time spending on the move.

Take time from the moment of blackout to the search for damage t_{beg}=1 h.

Take time to repair the damaged section and incorporate loads of online/offline users to top repair *trep=5 h.*

Time to restore electricity other electrical consumers who may be included, if the damage is in the i-th plot is calculated as:

$$t_{rec,i} = t_{beg,i} + t_{search,i} + t_{loc,i} + t_{on,i} = t_{REC,i} - (t_{sweep,i} + t_{rep,i}). \tag{4}$$

Time to sweap the simplest part of electricity transmission line is calculated as:

$$t_{sweap,i} = \frac{L_{i\ i}}{2v} + \frac{L_i - L}{2\alpha v}, \tag{5}$$

where L_i − full length reporting line section; L_{Mi} − the length of the of electricity transmission line; v − average crawl speed; α − coefficient that takes account of the increase in crawl speed lines, when mobile group return from a spur. The simplest part of electricity transmission line is such a part of the line where no switchgear equipment and devices accelerating search of damage.

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In the absence of data exploitation on annual downtime of consumers in the distribution lines, index SAIDI is calculated as:

$$SAIDI = \frac{\sum_{i=1}^{n} N_{off,i} t_{est.rec,i} N_i}{N_T} \text{ [h]}, \quad (6)$$

where $t_{est.rec,i}$ – estimated recovery time of electricity consumer in the first place, n – number of plots.

<u>*Calculation of indicator SAIDI before reconstruction*</u>

Find SAIDI for the line in Figure 1.

For this purpose make a table to calculate the amount of failure of the 1st phase. An example of one of such tables I is below.

TABLE I.
CALCULATION OF THE NUMBER OF BLAC KOUTS PLOT № 1

№	**Equipment**	**Number**	**Failure rate, year^{-1}**	**The average number of failures per year**
1	low-oil circuit breaker	1	0.008	0.008
2	Non-isolated overhead line	5.27	0.25	1.3175
3	Transformer station	4	0.03	0.12
4	Disconnector	3	0.01	0.03
Total:				1.48

Example of calculation for 1-line:

$$\lambda_{\Sigma 1} = n_1 \cdot \lambda_1 = 1 \cdot 0.008 = 0.008 \ \frac{\text{failure}}{\text{year}}. \quad (7)$$

We assume that the transformer station has a switch or there is a wireman, who can make a switch. The length of a given line in km. Average crawl speed line installed 4 km/h. Coefficient α is 1,25. The average speed of cars along the lines is 40 km/h. Switching is t_{switch}=3 min.

We divide the original schema on 4 independent sites, that can be accessed using the disconnectors (Figure 1). On the concept will find distance between switching devices (Table II). Find transport time from one switching apparatus to another (Table III).

TABLE II.
CALCULATION OF DISTANCES

	D1	D2	D3
Q	0.05	1.56	3.6
D1	-	1.51	3.55
D2	-	-	2.04

TABLE III.
CALCULATION OF THE TRANSPORT TIME

	D1	D2	D3
Q	0.00	0.04	0.09
D1	-	0.04	0.09
D2	-	-	0.05

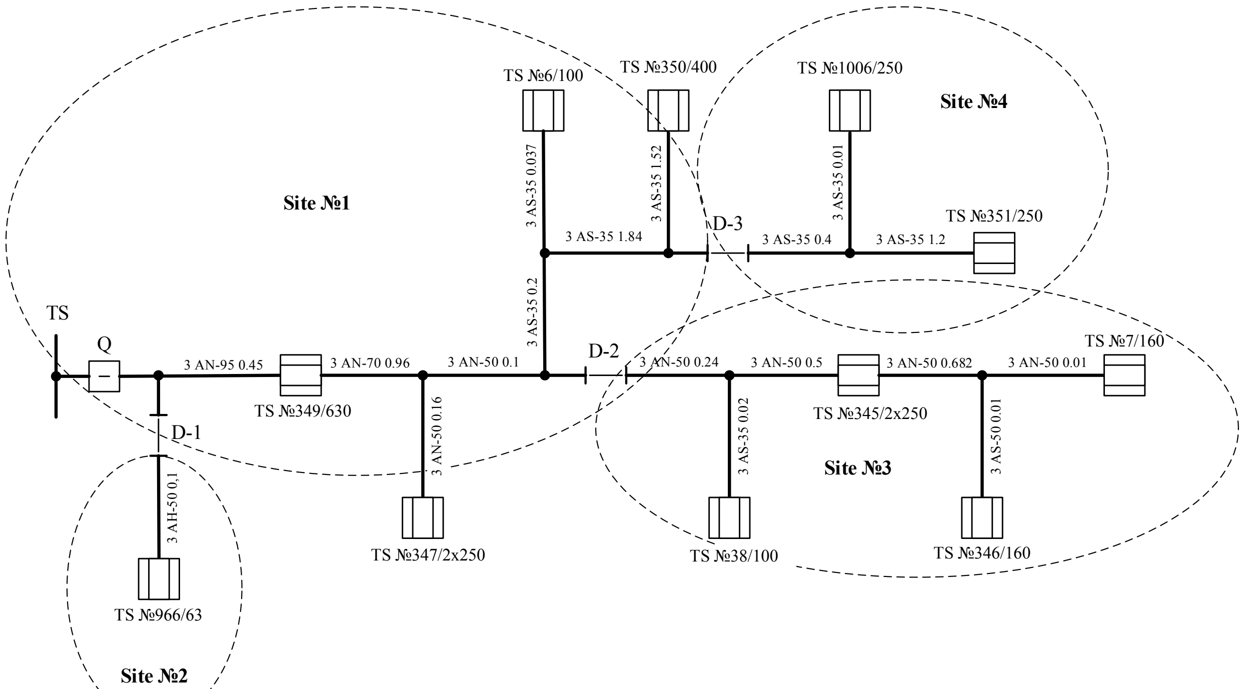

Fig. 1. The scheme of distribution line

Example of calculation of wiremen moving time from Q to D1:

$$t_{transport.D1} = \frac{l_{Q-D1}}{V_{wiremen}} = \frac{0,05}{40} \approx 0 \text{ h}. \quad (8)$$

Time to crawl sites look and bring in table IV.

TABLE I.
CALCULATION OF TIME CRAWLING SITES

№	**L**	**L_m**	**v**	**α**	**t_{swep}**
1	5.27	3.55	4	1.25	0.83
2	0.1	0	4	1.25	0.02
3	1.462	1.422	4	1.25	0.19
4	1.61	1.6	4	1.25	0.20

Example of calculation for 1-St line:

$$t_{sweap1} = \frac{L_1}{2v} + \frac{L_1 - L_{j\,1}}{2\alpha v} = \frac{5,27}{2\cdot 4} + \frac{5,27-3,55}{2\cdot 1,25\cdot 4} = 0,83 \text{ h.} \quad (9)$$

To calculate the time of restoration of power supply in the event of a short circuit on all possible sections of the line, we will draw up a control scheme for the process of restoration of power supply for this line.

In the diagram, the circle marked the detach operation switching apparatus, a square operation switching on. If the circle is marked with a dashed line, it means that the wireman only goes to the switching device, and enable/ disable operation does not produce. The outcome of the incorporation of the switch is marked with an additional rectangle: white-black is enabled-disabled. Duration of operations moving, repair and crawl is shown on the diagram above.

Under the scheme of control (Figure 2) prepare the equation to calculate the recovery time of power supply tвi,j, where i - lot number scheme, j - user number. Let's consider a formula to calculate the recovery time of power supply lines for different sites. Example of calculation for the accident at site 1.

Recovery time for the electricity consumers of the 1-st site of power distribution lines:

$$t_{REC1} = t_Q + t_{Q-D1} + t_{D1-D2} + t_{D2-D3} + 4t_{transport} + t_{sweap1} + t_{rep}. \quad (10)$$

The number of electricity consumers of offline users when an accident on the 1-St station Ncust1=11.

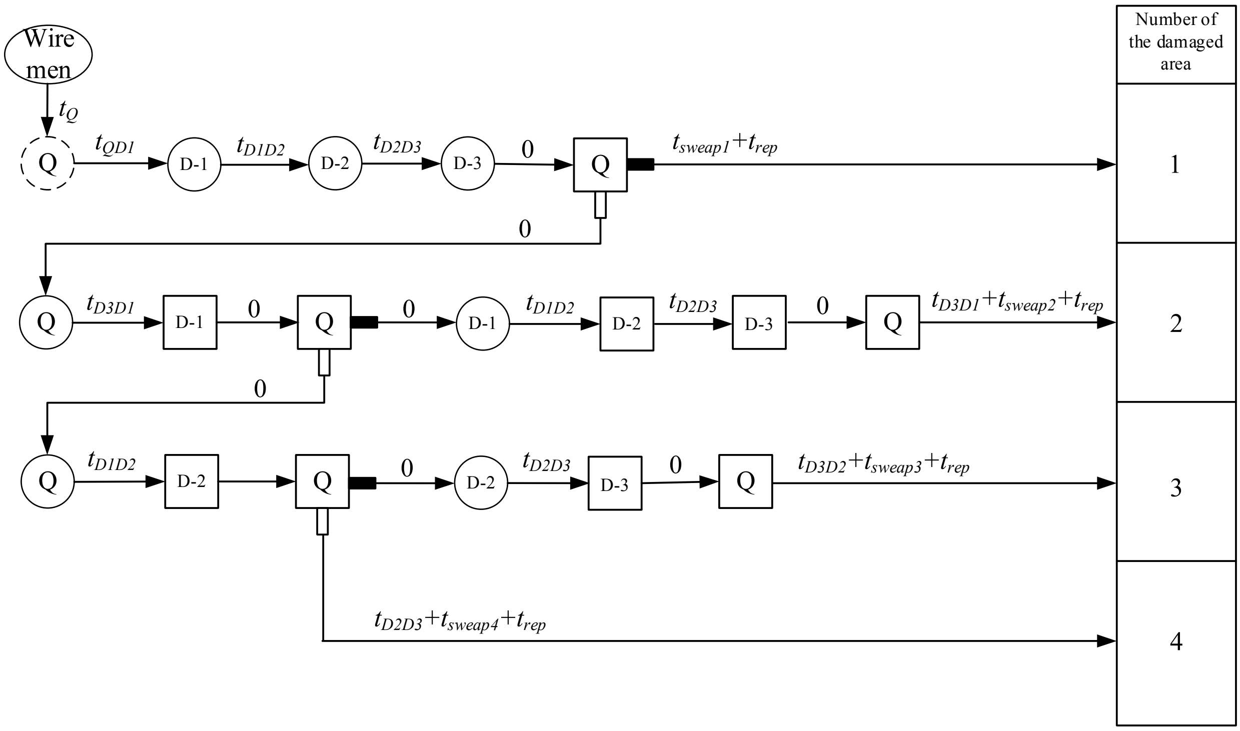

Fig. 2.Control scheme of power supply recovery process in the distribution line before the reconstruction

Find SAIDI for the distribution line before the reconstruction. For this purpose make a table V

TABLE I.
CALCULATION OF SAIDI BEFORE RECONSTRUCTION

№	N_{offi}	$T_{rec.i1}$	$N_{cust.i1}$	$T_{rec.i2}$	$N_{cust.i2}$	*SAIDIi*
1	1.48	7.1	11	0	0	10.54
2	0.1	6.9	1	1.86	10	0.22
3	0.61	7.6	4	1.87	7	2.41
4	0.46	6.9	2	1.67	9	1.20
Total:						14.37

Example of calculation for SAIDI in an accident on 1 site:

$$SAIDI_1 = \frac{N_{off1}\cdot\left(t_{REC1}\cdot N_{cust1} + t_{REC2}\cdot N_{cust2}\right)}{N_{cust}} = \quad (11)$$

$$= \frac{1,48\cdot\left(7,1\cdot 11 + 0\cdot 0\right)}{11} = 10,54 \text{ h.}$$

Thus the SAIDI to reconstruction will be 14.7 h.

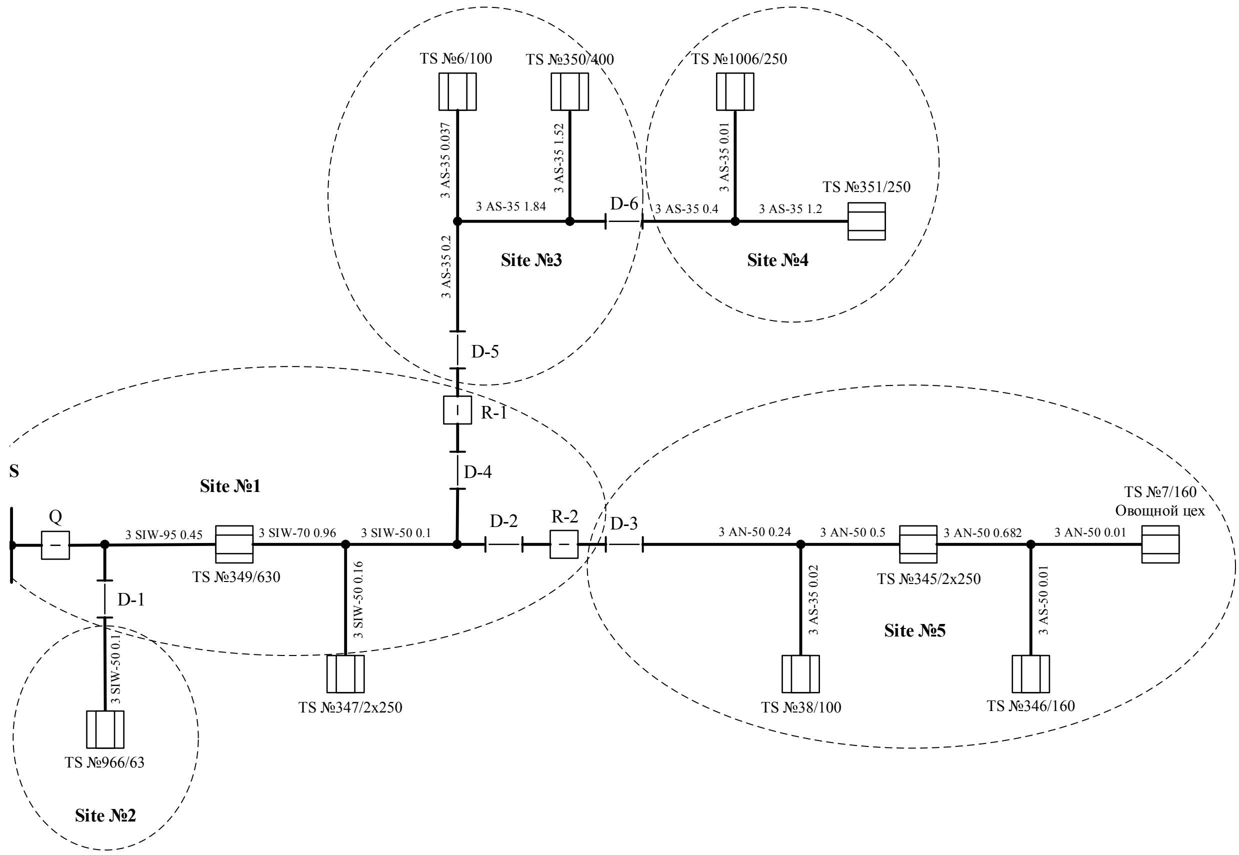

Fig. 1. Distribution Diagram of the line after reconstruction

Calculation of indicator SAIDI after reconstruction we divide the original scheme to 5 independent sites, which can be accessed using the disconnectors (Figure 3). Prepare a table to calculate the amount of bounce of the 1st phase. An example of one of such tables is below.

TABLE VI

CALCULATION OF THE NUMBER OF BLACKOUTS PLOT

№	Equipment	Number	Failure rate, year^{-1}	The average number of failures per year
1	Macuum load-breaking switch	3	0.004	0.012
2	Overhead line with insulated conductors	1.67	0.08	0.134
3	Transformer station	2	0.03	0.06
4	Disconnector	3	0.01	0.03
Total:				0.236

We did not do the example of calculation here, because they are like a calculating of SAIDI before reconstruction. Time to crawl sites look and bring in table VII.

TABLE VII

CALCULATION OF TIME CRAWLING SITES

№	L	L_m	v	α	t_{swep}
1	1.67	1.51	4	1.25	0.22
2	0.1	0	4	1.25	0.02
3	3.6	2.04	4	1.25	0.61
4	1.61	1.6	4	1.25	0.20
5	1.462	1.432	4	1.25	0.19

Recovery time for calculation of electricity short-circuit in all possible areas lines compose a recovery process for this line (Figure 4).

Control scheme make up the equation to calculate the recovery time of power supply $t_{RECi,j}$. Let's consider a formula to calculate the recovery time of power supply lines for different sites.

The accident at site 1

Recovery time for the electricity consumers of the 1-st site of power distribution lines:

$$t_{REC1} = t_Q + t_{Q-D1} + 2t_{transport} + t_{sweap1} + t_{rec} \quad (12)$$

The number of electricity consumers of offline users when an accident on the 1-St station Ncust1=11.

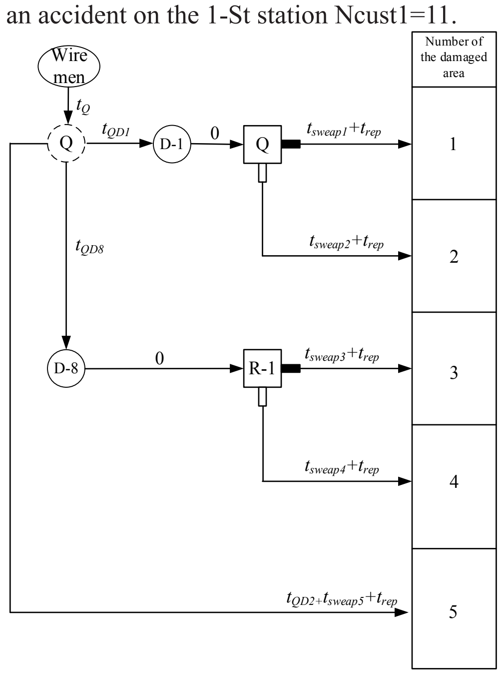

Fig. 2. Recovery process control scheme of power supply in the distribution line after reconstruction

Find index SAIDI for the distribution line after reconstruction. SAIDI after reconstruction will be 6.07 h.

TABLE VIII
CALCULATION OF SAIDI AFTER RECONSTRUCTION

№	N_{offi}	$T_{REC.i1}$	$N_{cust.i1}$	$T_{REC.i2}$	$N_{cust.i2}$	*SAIDIi*
1	0.236	6.32	11	0	0	1.49
2	0.078	6.12	1	1.1	10	0.12
3	0.98	6.8	4	0	0	2.42
4	0.46	6.39	2	1.19	2	0.63
5	0.62	6.23	4	0	0	1.40
Total:						6.07

I. RESULTS AND DISCUSSION

Thus, after the reconstruction of the distribution line, the SAIDI indicator decreased from 14.74 hours to 6.07 hours. As shown by experimental data for the 10 kV distribution line of the Pskov region, the SAIDI indicator is 15.6 hours. The obtained theoretical values of the SAIDI indicator before reconstruction differs from the value obtained according to the operation, no more than 10%. This confirms the right way of calculating the SAIDI indicator.

IV.CONSULTION

The article presents the first developed calculating of SAIDI for distribution lines during the engineering phase. An example of calculating SAIDI for the typical distribution lines before and after reconstruction was present. The developed technique can be used for a feasibility study for the construction of new distribution lines or for the reconstruction of existing ones with the aim of increasing reliability.

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