Overhead electrical grids 6-20 kV partition

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Abstract. The paper analyzes the technical principles of construction and the typical structure of overhead electric grids 6-20 kV. Reliability calculations were performed for 18 segments of 6-10 kV electrical grids of one of the largest electric grid companies in the European part of the country. Shown, when assessing the reliability of overhead electric grids, it is permissible to take into account only reliability parameters of electric transmission lines. It is permissible to neglect failures of other grid elements in a first approximation (power transformers, circuit breaker e.t.c.)

1 Problem description

In publications [1, 2], the authors analyzed failure outage statistics in 6–10 kV overhead electric grids of one of the largest electric grid companies in the European part of the country to clarify the reliability characteristics of grid elements.

Thus, the failure intensity for uninsulated overhead lines (OHL) is $\omega_{\text{OHL}} = 2.3$ 1/(year per 100 km) and for covered OHL $\omega_{\text{coverOHL}} = 0.31$ 1/(year 100 km). A noticeable decrease in the failure intensity of covered overhead lines is partially offset by an increase in the mean restoration time for them, which is approximately two times higher than for uninsulated OHL. Therefore, the multiplication ωT_r is the expected average annual outage of line: $2.3 \cdot 2.04 = 4.7$ (hrs per 100 km) for uninsulated OHL and $0.31 \cdot 4.38 = 1.36$ (hrs per 100 km) for covered OHL, i.e. from these positions covered OHL $4.7/1.36 \approx 3.5$ times have more favorable characteristic.

Reliability characteristics were also obtained for power transformers 10(6)/0.4 kV, low-oil and vacuum circuit breaker cells and other grid elements (disconnectors, measuring transformers, etc.). Failure intensity obtained for uninsulated and covered OHL and these values differed by more an order of magnitude from previously known values, published 30–40 years ago: 10–20–25 1/(year per 100 km) and even more [3, 4]. Note that the technical principles of medium voltage networks were justified using those overestimated failure intensity - see, for example, [5].

Earlier in document [6] reliability characteristic of power supply for consumers were established. For consumers of the 2nd category in [6], the standard failure intensity (power outages up to four hours) was approximately 2.3 1/year and for consumers of the 3rd category with a duration of power outages up to 24 hours - 3.0 1/year.

Based on these characteristics, the basic technical principles of 6-20 kV overhead grids and the

installation site of sectional devices were formed. According to [6], the total length of the line section (including branches) should not exceed 12 km and be limited to an automatic switching device; also sectionalizers should be installed on branches longer than 2.5 km. Modern regulatory documents [7] partially repeat the previously developed technical principles. For example, if a branch length from overhead feeder line is more than 1.5 km, then installation of a switching apparatus is required. Document [7] also describes the installation requirements of sectionalizers and automatic switching device using vacuum circuit breakers in the overhead feeder line.

Therefore, the authors set themselves the task of justifying the preferred structure of 6-10 kV overhead grids, taking into account the reliability characteristics obtained in the present time interval.

2 Typical configuration of an overhead electrical grids of 6-10 kV

As it is known, a typical configuration of an overhead electrical grid of 6-10 kV (Fig. 1) is a loop circuit with branches. The grid powered from two geographically remote substations of 35...220/10(6) kV, also the network is partitioned by sectional devices (reclosers).

Line branches with transformer substations 10(6)/0.4 kV are connected to the main feeder line using disconnector or recloser installed on the branch (recloser is installed on branches longer than 1.5 km). The grid is partitioned by automatic switching device at the point of current separation with the ability to automatic transfer switch. And this is done not to improve reliability, but to reduce power and electricity losses.

In accordance with [8], the system average interruption frequency index (SAIFI) for consumers is defined as $\text{SAIFI} = (\sum N_i) / N_t$, where $\sum N_i$ – total number of customer experienced interruption, N_t – total number

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of customers served, I – number of failure outage for the period under review. However, if there is one partition point in the grid, any failure in line section from substation to sectional device (including branches from main feeder line) will lead to a power outage for all consumers in this section of line. Thus, the value of SAIFI and ω in this configuration of electrical grid will be equal to each other.

Fig.1. Typical configuration of an overhead electrical grid

Table 1 shows examples of reported data on SAIFI values in EU countries [9] (excluding exceptional events - natural disasters, major system power outage,

Table 1. SAIFI reporting data for EU medium voltage electrical grids

Country	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Germany	0,43	0,31	0,30	0,27	0,24	0,29	0,25	0,46	0,33	0,78	0,49
Greece	–	–	–	–	–	–	1,65	1,50	1,60	1,44	1,42
Denmark	–	–	–	–	0,30	0,27	0,30	0,24	0,23	0,26	0,27
Ireland	–	–	–	–	–	–	–	–	–	0,90	0,80
Italy	1,87	1,71	1,58	1,61	1,47	1,37	1,38	1,28	1,27	1,41	1,20
Latvia	–	–	–	–	–	–	–	2,45	2,12	1,88	2,00
Lithuania	0,51	0,81	0,68	0,52	0,51	0,64	0,63	0,58	0,52	0,48	0,51
Luxembourg	–	–	–	–	–	–	–	0,27	0,22	0,22	0,15
Netherlands	–	–	–	–	–	–	–	0,20	0,20	0,18	0,17
Norway	–	–	–	–	–	–	1,58	2,30	1,59	1,43	1,27
Portugal	2,66	1,98	2,28	2,68	3,02	1,88	1,57	1,70	1,84	1,64	1,68
Romania	–	–	–	–	–	–	–	6,29	4,80	5,16	6,10
Slovenia	–	–	1,80	1,50	1,40	1,63	2,16	1,59	1,89	1,45	1,21
Czech	–	–	1,45	1,82	1,95	1,93	1,87	1,78	1,78	1,57	1,50
Switzerland	–	–	–	–	0,17	0,20	0,22	0,19	0,14	0,17	0,12
Sweden	–	–	–	–	–	–	0,94	1,03	1,02	0,90	0,99

Table 2 shows the parameters of grid segments. Notations defined in the table. 2: $P_{\max}$ and $P_{\min}$ - the largest load of a winter and summer day according to the measurement results; l_{sum} - the total line length of the segment; l_{feeder} - the length of feeder line section between substations, excluding branches; σ_{load} - load density; n_s - the number of substations 10(6)/0.4 kV in a grid segment.

Data analysis of table 2 allows us to establish some statistical regularities in the grid construction. For example, the length of the feeder lines between substations varies in a narrow range from 12.9 to 41.3 km with an average value of 28 km, which indicates a

etc.). These values should be treated with some caution; in different countries, SAIFI calculations use a non-uniform set of source data. Another example is the 2006 summary report [10] for US regions showing SAIFI values of 1.13–1.59 1/year.

3 Reliability calculations

Reliability calculations were performed based on that integrated parameters of 6–10 kV grids obtained in [11]. In [11] were analyzed 18 regions of one of the largest electric grid companies in the European part of the country. Among them were fragments, both adjacent to a big city, and 100-150 km distant from it, where predominantly installed single-transformer substations of pole-mounted type ($S_{\text{rated}}=160\div250$ kV·A) and kiosk type ($S_{\text{rated}}=400\div1000$ kV·A) were installed. The load density was determined from the assumption that transformer substations 10/0.4 kV covers an area with a radius of not more than 0.5 km. In fact, the entire overhead system is made from a wire with a cross section of 70-mm², with the exception of two fragments, where cross section of 120-mm² wire was partially used on the feeder line.

relatively uniform distribution of the substations in the area. The load density varies over a wide range from 8.2 to 157.3 kW/km² (average value of 76.1 kW/km²), i.e. more than an order of magnitude. Moreover, the range of average distances between transformer substations varies from 0.76 to 2.33 km with a total average of 1.14 km, which indicates a relatively uniform distribution of transformer substations across the area. Note that the installed power of the transformer substation 10(6)/0.4 kV is 2–9 times (average value 3.6) higher than the actual maximum load, which is somewhat irrational and requires additional research.

Table 2. Integral parameters of electrical grid segments

Segment number	$P_{\max}/P_{\min}$ kW/kW	l_{sum} km	l_{feeder} km	σ_{load} кВт/км ²	n_s ea
1	3138/1642	40,7	19,8	129,1	48
2	4751/3168	52,4	19,4	154,3	64
3	7358/5816	74,1	32,6	154,3	87
4	3609/1929	70,1	21,0	83,2	71
5	6646/6072	87,6	43,0	157,3	110
6	1781/989	46,9	12,9	57,3	54
7	1840/844	42,5	22,5	45,5	44
8	2486/1244	36,2	22,0	66,8	38
9	2992/1673	62,4	35,8	55,0	47
10	3101/2436	75,7	38,3	45,1	67
11	2716/1338	26,5	13,8	110,4	20
12	2818/1934	54,3	29,6	72,3	60
13	1640/1102	64,6	31,0	39,8	57
14	1193/618	61,8	41,3	24,8	46
15	956/349	50,0	30,9	26,3	33
16	297/78	35,0	30,5	8,2	15
17	3023/1872	42,3	20,3	117,6	56
18	1484/796	107,0	38,5	21,7	68
Average	2879/1833	57,2	28,0	76,1	54

Based on grid configuration and data from table 2 the reliability characteristics of grid segments were calculated in table 3 using the reliability characteristics of:

Only uninsulated OHL (covered OHL);

Uninsulated OHL (covered OHL) and all other elements of the grid.

It was considered that a switching device in the middle of a feeder section partitioned the grid segment. Notations defined in the table 3: ω_{OHL} – failure intensity of a grid segment, using the reliability characteristics of only OHL, $\omega_{\text{OHL}\Sigma}$ – same, but using the reliability characteristics of OHL and other grid elements; ω_{coverOHL} , $\omega_{\text{coverOHL}\Sigma}$ – similar parameters for covered OHL.

Table 3 shows that the increase in failure intensity of a grid segment, when taking into account all other grid elements, (i.e., in addition to uninsulated OHL) is about 6% (average values of $\omega_{\text{OHL}}=0.66$ 1/year and $\omega_{\text{OHL}\Sigma}=0.7$ 1/year), which is not important. For covered OHL this increase is much larger - about 30% ($\omega_{\text{coverOHL}}=0.09$ 1/year and $\omega_{\text{coverOHL}\Sigma}=0.13$ 1/year, moreover 27% of this increase is the failure of 10(6)/0.4 kV power transformer. Thus, the value of failure intensity obtained are relatively small. Therefore, in assessing the reliability of medium voltage electrical grids, it is sufficient to take into account the reliability characteristics of only uninsulated OHL (covered OHL) as a first approximation.

Table 3. Reliability characteristics of grid segments

Segment number	ω_{OHL} , 1/year	$\omega_{\text{OHL}\Sigma}$, 1/year	ω_{coverOHL} , 1/year	$\omega_{\text{coverOHL}\Sigma}$, 1/year
1	0,47	0,51	0,06	0,10
2	0,60	0,65	0,08	0,13
3	0,85	0,91	0,11	0,17
4	0,81	0,86	0,11	0,16
5	1,01	1,09	0,14	0,22
6	0,54	0,58	0,07	0,11
7	0,49	0,52	0,07	0,10
8	0,42	0,45	0,06	0,09
9	0,72	0,75	0,10	0,13
10	0,87	0,92	0,12	0,17
11	0,30	0,32	0,04	0,06
12	0,62	0,66	0,08	0,12
13	0,74	0,78	0,10	0,14
14	0,71	0,74	0,10	0,13
15	0,58	0,60	0,08	0,10
16	0,40	0,41	0,05	0,06
17	0,49	0,53	0,07	0,11
18	1,23	1,28	0,17	0,22
Average	0,66	0,70	0,09	0,13

Moreover, power transformers in overhead electric grids 6-10 kV in country are usually protected by base fuses. The above conclusion can be used for electrical grids in which fuses are excluded [12]. This application, in our opinion, is progressive and may be useful in the reconstruction of grids with isolated transformer neutral to a neutral grounded through a low-ohm resistor (see [13]).

It follows from the table 3 that the use of covered OHL significantly increases the reliability of power supply to consumers ($\omega_{\text{coverOHL}}=0.05\text{--}0.17$ 1/year). Taking into account the data of the table 1 it is enough to have only one point, partitioned by an automatic switching device (recloser) at the current separation point (in the typical configuration in Fig. 1). For additional partitioning, for example, when connecting consumers of the 2nd category, for power grid partition it is enough to use disconnectors or load break switches.

A similar approach can be used for uninsulated overhead lines. Here ω_{OHL} varies in the range 0.4–1.23 1/year. This range of reliability characteristics is present in the practice of a number of industrialized countries (see above). For comparison, in existing grid segments 6-10 kV from table 2, the actual number of automatic switching device (reclosers) is in the range of 9–16, which seems redundant.

4 Conclusion

1. When assessing the reliability of overhead electric grids, it is permissible to take into account only reliability parameters of electric transmission lines. It is permissible to neglect failures of other grid elements in a first approximation.

2. The use of covered OHL significantly increases the power supply reliability to consumers. In a typical configuration of the electric grid, it is enough to have one point, partitioned by a switch (recloser) at the point

of current separation. A similar approach can be used with some limitations for uninsulated overhead lines.

3. The previously established regulatory documents and their corresponding requirements for ensuring the reliability of medium voltage grids turned out to be noticeably worse than the obtained modern reliability characteristics from Table 3. The values obtained are comparable with the level of reliability of power supply to consumers in industrialized countries.

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