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Selection of schemes of switchgears for new 110 kV substations

Aleksandrs Ļvovs[1], Armands Staltmanis[2]
[1] Riga Technical University (Riga, Latvia), [2] JSC "Sadales tīkls", (Distribution system operator, Latvia)
aleksandrs.lvovs@inbox.lv, armands.staltmanis@rtu.lv

***Abstract*-Rapid growth of Latvian economy before crisis resulted in rapid growth of electricity demand and reliability requirements are also increased. It's well known that object's influence on reliability of power supply increases growing nearer to power producing centre. This article gives analysis of reliability of switchgears for 110kV substations.**

INTRODUCTION

Power supply network of city is developing during city's growth. Developing of power supply network should be realized according to some grid developing principles. Otherwise it won't be possible to create reliable and economical network in the future. Creating the main lines of developing of network it is important to look to the future and create such a network that will be able to handle increasing power transfer through it from power plants to consumers.

In the states with a developed industry an electric power supply is of vital importance. Losses, which create large power supply interruptions, are so considerable, that, taking into account the technical and pertaining to national economy considerations, is necessary to attain high reliability level for a power supply.

A special attention must be turned to enterprises in the level of the incorporated work to feel sure that they are complemented with enterprises in all network voltage levels maximal diminishing consumers supply interruptions, in such kind diminishing also payments for undelivered electric power. In itself it is clear that spacious enterprises do not provide an absolute reliability in the provision of power supply.

110kV substations are big centres of power supply of cities and reliability of such substations` switchgears affects reliability of power supply of large consumer's amount.

In this article we will analyze reliability of some 110kV switchgears in order to bring out the optimal switchgear for substations.

I. REVIEW OF POWER SUPPLY NETWORKS OF SOME CITIES

Reviewing power supply schemes of some cities, such a Stockholm, Berlin, Moscow, Vilnius, Tallinn and Riga, we can see that high voltage transmission lines round the cities have a ring structure. There are diagonal interconnections between substations in the cities, too. In Vilnius and Tallinn power supply network created using two-chain power transmission lines. Such a structure of scheme is needed to ensure high level of reliability of power supply because there is only one nominal voltage high voltage ring around the city. Overhead lines as well as cable lines are used in the cities, but in the future it is planned to create network using cables only. Usually two power transformers are installed at substations in those cities.

Improving existing power supply network different switchgear schemes will be used in the future.

I. CALCULATION OF POWER SUPPLY RELIABILITY FOR 110KV SUBSTATIONS` SWITCHGEARS

To calculate the possibility of a full loss of power supply for 110kV substation (because of damage of 110kV switchgear) some assumptions are used:

1) switching's are made in one hour $\chi = \frac{1*\sum\lambda}{8760}$;
2) one defect can be eliminated in 12 hours $\chi = \frac{12*\sum\lambda}{8760}$;
3) once a year 110kV transformer has maintenance for 8 hours;
4) one time in 25 years transformer has overhaul lasting for two weeks;
5) one time in 4 years for 16 hours 110kV line or 110kV lines connection has maintenance;
6) All 110kV lines are cable (see table II) or overhead (see table III) lines. Each lines length is 50 km;
7) All substations are equipped with identical equipment;
8) Failure rates λ (average annual number of faults for element) for elements are taken from software's LDM-AD`04 database (developed by Institute of Physical Energy of Latvian Academy of Sciences and is used by "Latvenergo" JSC) [1]. For λ values see Table I;
9) All outgoing lines are connected to power supply centres.

TABLE I
FAILURE RATE λ VALUES FORM COMPUTER SOFTWARE LDM-AD`04

Element	Type of element	λ
Line	Overhead line (cable line) – 100km	8.6 (0.86)
Spark-gap	PEXLIM R,Q,P,E	0.0036
Voltage transformer	TFND-110	0.01
Disconnector	HAC-EV	0.0026
Circuit-breaker	LTB420E2	0.04
Busbar	Latvenergo	0.01
Transformer	Sum of transformer's, spark-gaps and multi-purpose transformer parameters	0.024

A. Outage probability calculation for switchgear shown on Fig. 1.

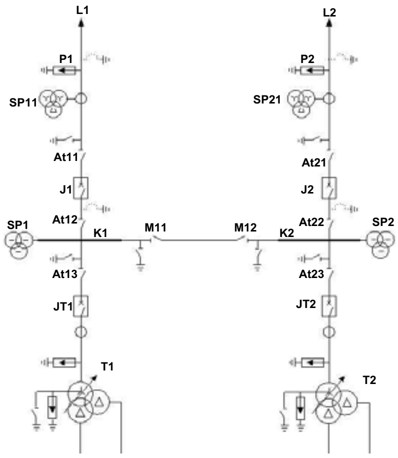

Fig. 1. Substation with one busbar (two sections) without switched busbar circuit-breaker (two 110kV lines)

Forced outage probability of switchgear can be calculated using equation (1).

$$\chi_1 = \frac{12*12}{8760*8760} *[(\lambda_{L1}+\lambda_{P1}+\lambda_{SP11}+\lambda_{At11}+\lambda_{J1}+\lambda_{At12}+\lambda_{SP1}+\lambda_{K1}+$$
$$+\lambda_{At13}+\lambda_{M11}+\lambda_{JT1}+\lambda_{T1})*(\lambda_{L2}+\lambda_{P2}+\lambda_{SP21}+\lambda_{At21}+\lambda_{J2}+\lambda_{At22}+\lambda_{SP2}+$$
$$+\lambda_{K2}+\lambda_{At23}+\lambda_{M12}+\lambda_{JT2}+\lambda_{T2})] + \{1\}$$
$$+\frac{1}{8760}$$
$$*[(\lambda_{J1}+\lambda_{At12}+\lambda_{SP1}+\lambda_{K1}+\lambda_{At13}+\lambda_{JT1}+\lambda_{M11}+\lambda_{M12}+\lambda_{J2}+\lambda_{At22}+$$
$$+\lambda_{SP2}+\lambda_{K2}+\lambda_{At23}+\lambda_{JT2}) + (\frac{12*12}{8760*8760} *(\lambda_{T1}*\lambda_{JT1\ non.op.}))+ ($$
$$\frac{12*12}{8760*8760} *(\lambda_{T2}*\lambda_{JT2\ non.op.})) + (\frac{12*12}{8760*8760} *$$
$$* (\lambda_{L1}+\lambda_{P1}+\lambda_{SP11}+\lambda_{At11}) *\lambda_{J1\ non.op.}) + (\frac{12*12}{8760*8760} *$$
$$(\lambda_{L2}+\lambda_{P2}+\lambda_{SP21}+\lambda_{At21}) *\lambda_{J2\ non.op.})] + \{2\}$$
$$+ (\chi_{L1maint.} + \chi_{L1conn.maint.})* \frac{12}{8760} *(\lambda_{L2}+\lambda_{P2}+\lambda_{SP21}+\lambda_{At21}+\lambda_{J2}+$$
$$\lambda_{At22}+\lambda_{SP2}+\lambda_{K2}+\lambda_{At23}+\lambda_{M12}) + \{3\}$$
$$+ \chi_{K1maint.} \frac{12}{8760} *(\lambda_{L2}+\lambda_{P2}+\lambda_{SP21}+\lambda_{At21}+\lambda_{J2}+\lambda_{At22}+\lambda_{SP2}+\lambda_{K2}+$$
$$+\lambda_{At23} +\lambda_{M12}+\lambda_{JT2}+\lambda_{T2}) + \{4\}$$
$$+ \chi_{T1maint.} * \frac{12}{8760} *(\lambda_{At22}+\lambda_{SP2}+\lambda_{K2}+\lambda_{At23}+\lambda_{M12}+\lambda_{JT2}+\lambda_{T2}) + \{5\}$$
$$+ (\chi_{L2maint.}+ \chi_{L2conn.maint.})* \frac{12}{8760} *(\lambda_{L1}+\lambda_{P1}+\lambda_{SP11}+\lambda_{At11}+\lambda_{J1}+$$
$$+\lambda_{At12}+\lambda_{SP1}+\lambda_{K1} +\lambda_{At13}+\lambda_{M11}) + \{6\}$$
$$+ \chi_{K2maint.} * \frac{12}{8760} *(\lambda_{L1}+\lambda_{P1}+\lambda_{SP11}+\lambda_{At11}+\lambda_{J1}+\lambda_{At12}+\lambda_{SP1}+\lambda_{K1}+$$
$$+\lambda_{At13}+\lambda_{M11}+\lambda_{JT1}+\lambda_{T1}) + \{7\}$$
$$+ \chi_{T2maint.}* \frac{12}{8760} *(\lambda_{At12}+\lambda_{SP1}+\lambda_{K1}+\lambda_{At13}+\lambda_{M11}+\lambda_{JT1}+\lambda_{T1})\ \{8\}$$

(1)

Where {1….8} describes outage probability of switchgear shown on Fig.1.

{1} – describes outage probability that is caused by fault of one element clashing with another element's fault. At least one element should restore its capability;

{2} – describes outage probability that is caused by fault of one element or fault of one element clashing with another element's fault. Switching's should be made.

{3} – describes outage probability that is caused by fault of one element clashing with line's L1 or its connection maintenance;

{4} – describes outage probability that is caused by fault of one element clashing with busbar section's K1 maintenance;

{5} – describes outage probability that is caused by fault of one element clashing with transformer's T1 maintenance;

{6} – describes outage probability that is caused by fault of one element clashing with line's L2 or its connection maintenance;

{7} – describes outage probability that is caused by fault of one element clashing with busbar section's K2 maintenance;

{8} – describes outage probability that is caused by fault of one element clashing with transformer's T2 maintenance.

B. Outage probability calculation for switchgear shown on Fig.2.

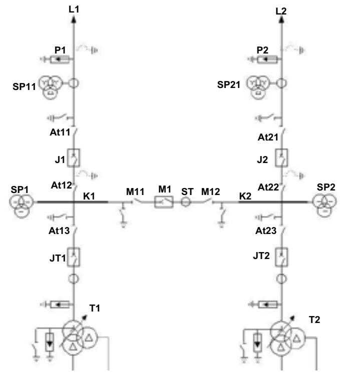

Fig. 2. Substation with one busbar (two sections) with switched busbar circuit-breaker (two 110kV lines)

Forced outage probability of switchgear can be calculated using equation (2).

$$\chi_2 = \frac{12*12}{8760*8760} *[(\lambda_{L1}+\lambda_{P1}+\lambda_{SP11}+\lambda_{At11}+\lambda_{J1}+\lambda_{At12}+\lambda_{SP1}+\lambda_{K1}+$$
$$+\lambda_{At13}+\lambda_{M11})*$$
$$*(\lambda_{L2}+\lambda_{P2}+\lambda_{SP21}+\lambda_{At21}+\lambda_{J2}+\lambda_{At22}+\lambda_{SP2}+\lambda_{K2}+\lambda_{At23}+\lambda_{M12})+$$
$$+(\lambda_{JT1}+\lambda_{T1})*(\lambda_{At22}+\lambda_{SP2}+\lambda_{K2}+\lambda_{At23}+ +\lambda_{M12}+\lambda_{JT2}+\lambda_{T2})+$$
$$+(\lambda_{JT2}+\lambda_{T2})*(\lambda_{At12}+\lambda_{SP1}+\lambda_{K1}+\lambda_{At13}+\lambda_{M11})] + \{1\}$$
$$+ \frac{1}{8760} * [\lambda_{M1} + (\frac{12*12}{8760*8760} *\lambda_{M1\ non.op.} * (\lambda_{J1}+\lambda_{At12}+\lambda_{SP1}+\lambda_{K1}+$$
$$+\lambda_{At13}+\lambda_{JT1}+\lambda_{M11}+ \lambda_{M12}+\lambda_{J2}+\lambda_{At22}+\lambda_{SP2}+ \lambda_{K2}+\lambda_{At23}+\lambda_{JT2})]+ \{2\}$$
$$+ (\chi_{L1maint.} + \chi_{L1cann.maint.}) * \frac{12}{8760} *(\lambda_{L2}+\lambda_{P2}+\lambda_{SP21}+\lambda_{At21}+\lambda_{J2}+$$
$$+\lambda_{At22}+\lambda_{SP2}+\lambda_{K2}+\lambda_{At23}+\lambda_{M12}) + \{3\}$$
$$+ \chi_{K1maint.} * \frac{12}{8760} *(\lambda_{L2}+\lambda_{P2}+\lambda_{SP21}+\lambda_{At21}+\lambda_{J2}+\lambda_{At22}+\lambda_{SP2}+\lambda_{K2}+$$
$$+\lambda_{At23}+\lambda_{M12}+\lambda_{JT2}+\lambda_{T2})+ \{4\}$$
$$+ \chi_{T1maint.} * \frac{12}{8760} *(\lambda_{At22}+\lambda_{SP2}+\lambda_{K2}+\lambda_{At23}+\lambda_{M12}+\lambda_{JT2}+\lambda_{T2}) + \{5\}$$
$$+ (\chi_{L2maint.} + \chi_{L2conn.maint.}) * \frac{12}{8760} *(\lambda_{L1}+\lambda_{P1}+\lambda_{SP11}+\lambda_{At11}+\lambda_{J1}+$$
$$+\lambda_{At12}+\lambda_{SP1}+\lambda_{K1}+\lambda_{At13}+\lambda_{M11}) + \{6\}$$

$$+ \chi_{K2maint.} * \frac{12}{8760} *(\lambda_{L1}+\lambda_{P1}+\lambda_{SP11}+\lambda_{At11}+\lambda_{J1}+\lambda_{At12}+\lambda_{SP1}+\lambda_{K1}+\lambda_{At13}+\lambda_{M11}+\lambda_{JT1}+\lambda_{T1}) + \{7\}$$
$$+ \chi_{T2maint.} * \frac{12}{8760} *(\lambda_{At12}+\lambda_{SP1}+\lambda_{K1}+\lambda_{At13}+\lambda_{M11}+\lambda_{JT1}+\lambda_{T1})\ \{8\} \quad (2)$$

Where {1….8} describes outage probability of switchgear shown on Fig.2. (See explanations for equation (1)).

C. Outage probability calculation for switchgear shown on Fig.3.

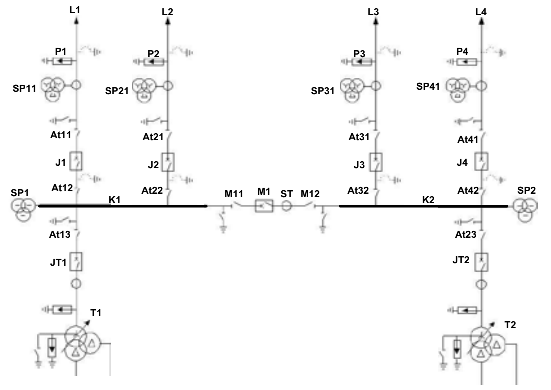

Fig. 3. Substation with one busbar (two sections) with switched busbar circuit-breaker (four 110kV lines)

Forced outage probability of switchgear can be calculated using equation (3). To simplify calculations equation (3) doesn't include such elements, that practically don't affect result, because their values are numerically less then other elements` values more then 3 powers. Such elements are possibility of coincident of faults in all 4 lines or their connections, or maintenance of one line clashing with fault of all other lines, or switched busbar circuit-breaker M1 non operating clashing with fault on busbars.

$$\chi_3 = \frac{12*12}{8760*8760} *[(\lambda_{SP1}+\lambda_{K1}+\lambda_{M11}+\lambda_{At22}+\lambda_{At12}+\lambda_{At13}+\lambda_{JT1}+\lambda_{T1})*$$
$$*(\lambda_{SP2}+\lambda_{K2}+\lambda_{M12}+\lambda_{At32}+\lambda_{At42}+\lambda_{At23}+\lambda_{JT2}+\lambda_{T2})] + \{1\}$$
$$+ \frac{1}{8760} * \lambda_{M1} + \{2\}$$
$$+ \chi_{K1maint.} * [\frac{12*12}{8760*8760} * (\lambda_{L3}+\lambda_{P3}+\lambda_{SP31}+\lambda_{At31}+\lambda_{J3})*$$
$$*(\lambda_{L4}+\lambda_{P4}+\lambda_{SP41}+\lambda_{At41}+\lambda_{J4}) + \frac{12}{8760} * (\lambda_{At32}+\lambda_{At42}+\lambda_{M12}+$$
$$+\lambda_{SP2}+\lambda_{K2}+\lambda_{T2}+\lambda_{JT2}+\lambda_{At23})] + \{3\}$$
$$+ \chi_{T1maint} * \frac{12}{8760} * (\lambda_{SP2}+\lambda_{K2}+\lambda_{At23}+\lambda_{At32}+\lambda_{At42}+\lambda_{M12}+$$
$$+\lambda_{JT2}+\lambda_{T2}) + \{4\}$$
$$+ \chi_{K2maint} * [\frac{12*12}{8760*8760} *(\lambda_{L1}+\lambda_{P1}+\lambda_{SP11}+\lambda_{At11}+\lambda_{J1}) *$$
$$*(\lambda_{L2}+\lambda_{P2}+\lambda_{SP21}+\lambda_{At21}+\lambda_{J2}) + \frac{12}{8760} * (\lambda_{At12}+\lambda_{At13}+$$
$$+\lambda_{JT1}+\lambda_{At22}+\lambda_{M11}+\lambda_{SP1}+\lambda_{K1}+\lambda_{T1})] + \{5\}$$
$$+ \chi_{T2maint.} * \frac{12}{8760} * (\lambda_{At12}+\lambda_{SP1}+\lambda_{K1}+\lambda_{At13}+\lambda_{M11}+$$
$$+\lambda_{JT1}+\lambda_{T1}+\lambda_{At22})\ \{6\} \quad (3)$$

Where {1….6} describes outage probability of switchgear shown on Fig.3.

{1} – describes outage probability that is caused by fault of one element clashing with another element's fault. At least one element should restore its capability;

{2} – describes outage probability that is caused by fault of switched busbar circuit-breaker M1;

{3} – describes outage probability that is caused by fault of one element clashing with busbar section's K1 maintenance;

{4} – describes outage probability that is caused by fault of one element clashing with transformer's T1 maintenance;

{5} – describes outage probability that is caused by fault of one element clashing with busbar section's K2 maintenance;

{6} – describes outage probability that is caused by fault of one element clashing with transformer's T2 maintenance.

D. Outage probability calculation for switchgear shown on Fig.4.

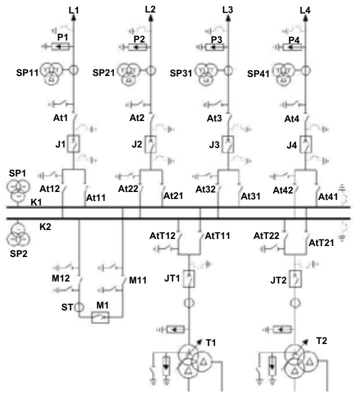

Fig. 4. Substation with two busbars and bus coupler circuit-breaker (four 110kV lines)

Forced outage probability of switchgear can be calculated using equation (4). To simplify calculations equation (4) doesn't include an elements, that practically don't affect result, because their values are numerically less then other elements` values more then 3 powers. Reliability of such 110kV switchgear is depending on busbar`s and directly to busbar connected element's reliability. Making the calculation we consider, that only 2 power transformers are installed at the substation. In case if 3 power transformers will be installed at the substation reliability level will be higher.

$$\chi_4 = \frac{12*12}{8760*8760} *(\lambda_{SP1}+\lambda_{K1}+\lambda_{M11}+\lambda_{At11}+\lambda_{At21}+$$
$$+\lambda_{At31}+\lambda_{At41}+\lambda_{AtT11}+\lambda_{AtT21}+\lambda_{JT1}+\lambda_{T1}) *$$
$$*(\lambda_{SP2}+\lambda_{K2}+\lambda_{M12}+\lambda_{At12}+\lambda_{At22}+\lambda_{At32}+\lambda_{At42}+\lambda_{AtT22}+$$
$$+\lambda_{AtT12}+\lambda_{JT2}+\lambda_{T2}) + \{1\}$$
$$+ \frac{1}{8760} * \lambda_{M1} + \{2\}$$
$$+ \chi_{K1maint/..} * \frac{12}{8760} *(\lambda_{K2}+\lambda_{SP2}+\lambda_{At12}+\lambda_{At22}+\lambda_{At32}+\lambda_{At42}+$$
$$+\lambda_{AtT12}+\lambda_{AtT22}+\lambda_{M12}) + \{3\}$$

$$+ \chi_{T1rem.} * \frac{12}{8760} *(\lambda_{AtT21}+\lambda_{AtT22}+\lambda_{JT2}+\lambda_{T2}) + \{4\}$$
$$+ \chi_{K2rem.} * \frac{12}{8760} *(\lambda_{K1}+\lambda_{SP1}+\lambda_{At11}+\lambda_{At21}+\lambda_{At31}+$$
$$+\lambda_{At41}+\lambda_{AtT11}+\lambda_{AtT21}+\lambda_{M12}) + \{5\}$$
$$+ \chi_{T2rem.} * \frac{12}{8760} *(\lambda_{AtT11}+\lambda_{AtT12}+\lambda_{JT1}+\lambda_{T1}) \{6\} \quad (4)$$

Where {1….6} describes outage probability of switchgear shown on Fig.4.

{1} – describes outage probability that is caused by fault of one element clashing with another element's fault. At least one element should restore its capability;

{2} – describes outage probability that is caused by fault of bus coupler circuit-breaker M1;

{3} – describes outage probability that is caused by fault of one element clashing with busbar section's K1 maintenance;

{4} – describes outage probability that is caused by fault of one element clashing with transformer's T1 maintenance;

{5} – describes outage probability that is caused by fault of one element clashing with busbar section's K2 maintenance;

{6} – describes outage probability that is caused by fault of one element clashing with transformer's T2 maintenance.

Results of are summarized in Table 2 and Table 3.

Nowadays more popular become Gas Insulated Switchgears (GIS). One of the advantages of such switchgears are compact dimensions, that is very important for city substations. GIS are produced as modules, so it is easy to mount such switchgears. As such switchgears have gas insulation and all components are covered with metal enclosure reliability level of such switchgears should be higher. Unfortunately there is no or very little information about failure rates of such switchgear's elements and that's why it is not possible to make calculations for such type of switchgears.

TABLE II
SUMMARY OF RESULTS (ALL ELECTRIC LINES ARE CABLE LINES)

Number of switchgear	Outage probability, χ	Up state probability	Time of outage state, minutes per year
1	$2,786*10^{-5}$	0,9999721	14,65
2	$7,818*10^{-6}$	0,9999922	4,11
3	$5,316*10^{-6}$	0,9999947	2,79
4	$5,092*10^{-6}$	0,9999949	2,68

TABLE III
SUMMARY OF RESULTS (ALL ELECTRIC LINES ARE OVERHEAD LINES)

Number of switchgear	Outage probability, χ	Up state probability	Time of outage state, minutes per year
1	$7,889*10^{-5}$	0,9999211	41,46
2	$5,884*10^{-5}$	0,9999412	30,93
3	$5,348*10^{-6}$	0,9999947	2,81
4	$5,092*10^{-6}$	0,9999949	2,68

CONCLUSIONS

Analysing results we can see, that the most reliable switchgear, as it was expected, is switchgear with two busbars and bus couples circuit-breaker between busbars, but the worse, from reliability point of view, switchgear is single busbar switchgear with two sections without switched busbar circuit-breaker between sections.

As we can see from Table 2 if network is formed using cable lines outage probability values for all switchgears with circuit-breaker between sections (busbars) are quite similar and are 3.5 to 5.3 times less than for substation without circuit-breaker between sections in the cities. For countryside substations, where 110kV network is formed by overhead lines, it is recommended to use cheaper scheme without circuit-breaker, because, as we can see from Table 3, usage of circuit-breaker in countryside substation doesn't give us result as in cable network situation. If consumers don't need high reliability power supply and their power load is little (for example 6.3 MVA) it would be possible to use cheaper 110kV switchgear scheme – one 110kV transformer and one 110kV transmission line, previously calculating reliability of such switchgear and evaluating expected economical losses. Results have also shown that number of connected 110kV lines, if it is more than 2 lines; don't affect reliability level a lot, if network is formed

Using cable lines, but in case of overhead lines number of connected lines changes result of calculations. Comparing outage probabilities for two busbar switchgear (see Fig.4) with switchgear with one busbar (two sections) (see Fig.3) in spite of network structure – cable or overhead lines, it is clear that such a scheme doesn't give us much better outage probability. Taking into account such scheme's costs, it would be useful to use such switchgear scheme only for 110kV distribution points and for 330/110kV substations. Such scheme can be used for substations where 3 transformers are installed.

Analyzing results we should remember that calculations were made using statistical data of LDM-AD`04 database. To make accurately calculations of outage probability for GIS type switchgears statistical data of new equipment failure rates is needed.

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