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The influence of switching actions with redundant components on the main reliability substations

L Pană[1], F Deliu[1], E Dragomir[1]

[1]"Mircea cel Bătrân" NAVAL ACADEMY, CONSTANȚA

leon.pana@anmb.ro

Abstract. In this paper is presented a substations reliability analysis based upon substation's component outage or failure modes. The switching actions can be modelled in the reliability evaluation indices we used the three-state model of the substation components (for example circuit breaker). The reliability indices are evaluated using the minimal cut-set method for each components of substation.

1. Introduction

The substations represent the basic subsystems of electric power system and is necessary the reliability evaluation and modeling of these with a view to establish, later on, a degree of continuity in electric energy supply of load points or customers connected at these electrical stations or substations.

In this paper is presented a new modality concerning at reliability analysis of electrical stations, based on failures mode and manifest these failures components of substations (disconnect switches, circuit breakers, lines, cables, power transformers, etc.) and the influence on which to have this failures (short-circuits, interruptions or opens circuit) about of point in comparison with had reliability analysis and possibility overlapping complementary failures or outages to have a results at supplying interruption of one load point.

The reliability analysis of substations has in comparison with of voltage presence on one departure of substation and is evaluated quantitative through numerical reliability index [1,2,4].

2. Contingencies due to substations-originated outages

The role of substations in observed system failures strongly supports the need to recognize the outages of system components because of substation-originated failures. Component performance statistics show that more than 45 percent of disturbances in transmission system are caused by substation-originated failures [3,7,14]. A substation-originated event is the outage of any number of system generators, lines, transformers and load points caused by a failure inside a substation (switching or terminal station).

The probabilities associated with contingencies due to substation failures can be quite high compared to the corresponding probabilities associated with independent overlapping outages. It is therefore not practical to consider independent higher-level contingencies on the one hand and to ignore contingencies, which are substation-originated on the other hand. The effect is sufficiently dominant in most cases, so their inclusion diminishes the need to consider independent higher-order contingencies.

The first improvement on previously developed methods and techniques is to include both normally open and normally closed disconnecting switches and circuit breakers in the analysis. To illustrate the impact of incorporating normally opens and normally closed switching equipment, in final of this paper, consider as case studies the single-line diagram of a typical substation configuration.

The states or events for normal components of substation are:

- operate successfully
- suffers a short-circuit
- suffers an open-circuit
- out for maintenance

For circuit breakers this becomes more complicated.

For example, in the case of normally-closed breaker, can be identify the following operational states and failure states:

- operate successfully in its closed state
- open successfully on command
- fails to open on command
- open without command
- suffer a short-circuit in the busbar side
- suffer a short-circuit in the line side
- out for maintenance.

In the second case, for a normally-open breaker, can be identify the following operational states and failure states:

- closes successfully on demand
- fails to close on demand
- closes without demand
- suffer a short-circuit on the busbar side
- suffer a short-circuit on the line side
- out for maintenance.

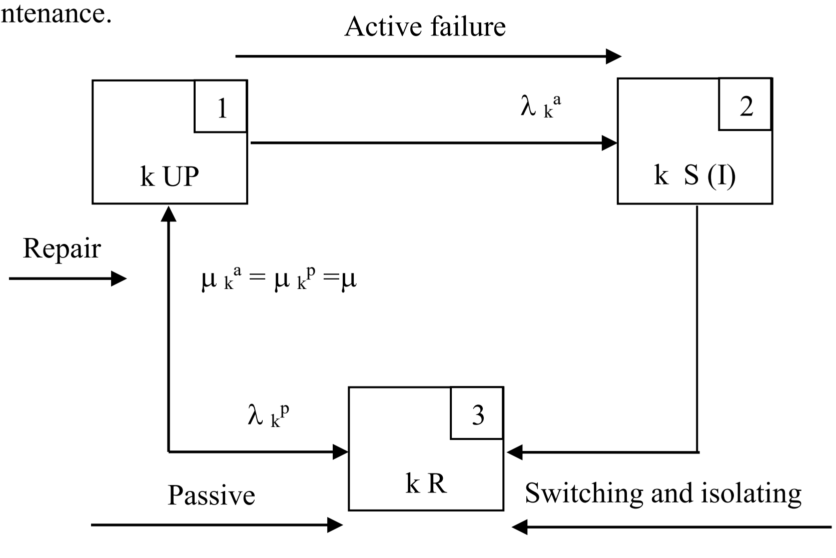


Figure 1 Three-state failure model of substation components

In the models previously used [5, 6, 13], active and passive failure modes of substation components have been modeled together by using the three-state model, shown in figure 1. The three states are the state before a fault (U), the state after a fault but before isolation (S) and the state after isolation but before repair (R). Switching actions with redundant components after the occurrence of a passive failure are not considered in these models.

Therefore, the three-state model cannot be used in reliability evaluation studies of substation components with redundant components that are associated with normally open disconnecting switches and circuit breakers. One of the assumptions in the models previously developed [1,16,17] was that all circuit breakers and disconnecting switches are normally closed. It should be clear that more detailed simulation algorithms are necessary to be able to model switching operations with redundant components.

A second improvement on existing methods is to consider failures of transmission or distribution lines or cables in combination with stuck circuit breakers as well. From experience it is well known that circuit-failure rates are usually greater than the failure rates of substation components.

Therefore, it is not nor consistent to simulate active failures of substation components in combination with a stuck circuit breaker and to ignore the influence of active failures of circuits which directly connected to the substation in combination with a stuck circuit breaker.

Therefore, this paper presents extensions to current techniques. A set of enhanced simulation algorithms is described in detail in this section. From these algorithms, the resulting contingencies can be determined i.e., which generators, circuits and/or load points connected to the substation are out of service due to the substation event.

The substation components assumed to fail are [12,15,18]: circuit breakers (B), transformers (T) and busbar sections (S). Although more components can fail inside a substation, such as metering transformers, grounding equipment and disconnecting switches, these are neglected. However, the failure modes of these components can be incorporated in the failure modes of busbar section or circuit breakers.

As in the foregoing section, several assumptions are adopted in the development of the algorithms. These assumptions are:

- any substation component is repairable or replaceable
- the average duration to repair or to replace a substation component is much smaller than its average operating duration
- the average switching duration of a substation component is smaller than its average repair or replacement duration
- overlapping failure events of three or more substation components are neglected
- all analyses are performed for time-independent component reliability indices
- circuit breakers actively failing cannot clear their own failures
- circuit breakers can operate due to failures in either direction when they are not is a stuck condition

The types of failures, which can occur in a substation and may cause substation-originated outages, are:

- passive failures
- active failures
- stuck circuit breaker conditions
- second-order overlapping substation outages

Outages that are due to events/outages in a transmission substation often led to the outage of more than one transmission line at the same time.

- busbar failures
- short-circuit faults in circuit breaker
- stuck-circuit breaker conditions
- system protection failures

3. Passive failures of equipment substations

Passive failure events are all component failures that do not cause operation of the protection. These failure events include open-circuit failures and inadvertent operations of circuit breakers. Service is restored by a repairing or replacing the failed component or by undertaking switching actions in the substations. It is assumed that passive failure events only occur on circuit breakers. Certain passive failures can result in contingencies, which cannot be reduced by performing switching actions with substation components. In figure 2 is represented the state-space diagram with characterized the passive failures for substations components.

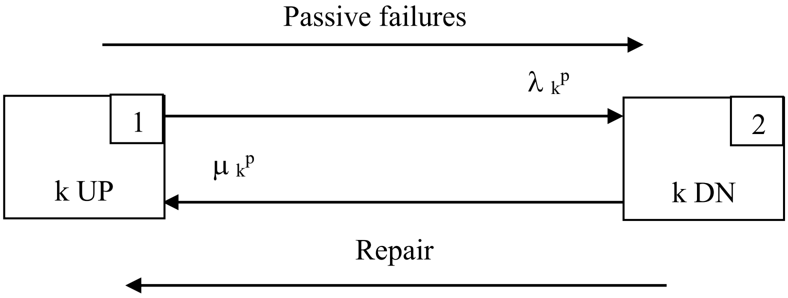


Figure 2 State-space diagram what characterized the passive failures of substations components
UP - working state; DN - failed state

The probability that such a passive contingency occurs due to a failure of component k, *P(passive contingency due to k),* and the frequency with which it occurs, *P(passive contingency due to k)*, can be approximated by:

$$\text{P(passive contingency due to k)} = \lambda_k^p \cdot r_k = \lambda_k^p \cdot \text{MTTR}_k \tag{1}$$

$$\text{F(passive contingency due to k)} = \lambda_k^p \tag{2}$$

where:

λ_k^p the passive failure rate of component k, in [hr^{-1}]

$\text{MTTR}_k = r_k$ the average repair duration of component k, in [hr]

Other passive failures can result in contingencies, which can be abolished by switching substation components. The probability of being found in such a passive contingency state before switching component k, *P(passive contingency due to k, before switching),* and its frequency of occurrence, *F(passive contingency due to k, before switching),* can then approximated by [11]:

$$\text{P(passive contingency due to k, before switching)} = \lambda_k^p \cdot s_k = \lambda_k^p \cdot \text{MTTS}_k \tag{3}$$

$$\text{P(passive contingency due to k, before switching)} = \lambda_k^p \tag{4}$$

where:

$s_k = \text{MTTS}_k$ the average switching duration of component k, [hr]

The probability, of being found in such a passive contingency state after switching component k, *P(passive contingency due to k, after switching),* and its frequency of occurrence, *F(passive contingency due to k, after switching)*, are given by:

$$\text{P(passive contingency due to k, after switching)} = \lambda_k^p \cdot (r_k - s_k) \tag{5}$$

$$\text{F(passive contingency due to k, after switching)} = \lambda_k^p \tag{6}$$

4. Active failures of equipment substations

Active failures are referred to as all component failures that cause the operation of circuit breakers in the primary protection zone around the failed component and can, therefore, cause those intact components are removed from service. Examples of this failure mode are short-circuit failures of substation components. Service can be restored to the intact parts of the substation after the failed component is isolated. The restoration of the component itself takes places by repair or replacement.

Generally, it takes longer to repair a component than to isolate it or to perform a switching operation. Usually, active failure events cause greater contingencies than passive failure events do.

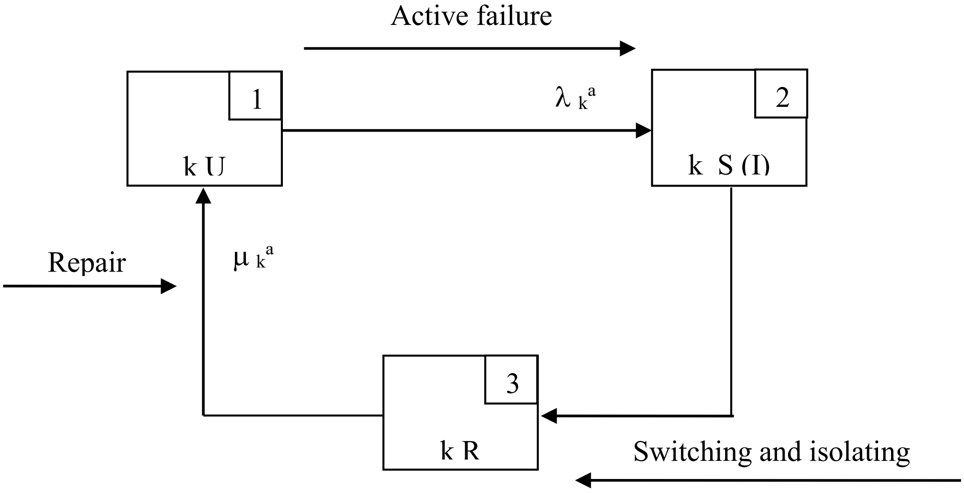


Figure 3 State-space diagram, with three states, which characterized the active failures of substations components
U – the state before a fault; S – the state after a fault but before isolation; R – the state after isolation but before repair

In certain case, active failure can result in contingencies, which cannot be abolished by switching substation components. Therefore, how long such a contingency takes on average is closely associated with the time it generally takes to repair the faulted component.

The probability of being found in such an active contingency state due to a failure of component k, *P(active contingency due to k),* and its frequency of occurrence, *F(active contingency due to k),* can then be approximated by:

$$\text{P(active contingenc y due to k)} = \lambda_k^a \cdot r_k = \lambda_k^a \cdot \text{MTTR}_k \tag{7}$$

$$\text{F(active contingenc y due to k)} = \lambda_k^a \tag{8}$$

where:

λ_k^a the active failure rate of component k, in [hr^{-1}]

It is also possible that an active failure results in a contingency that can be remedied. In such case two situations arise: a situation before performing switching actions and a situation after performing switching actions.

The probability that the situation before switching occurs, *P(active contingency due to k before switching),* and its frequency of occurrence, *F(active contingency due to k before switching),* can be approximated by:

$$\text{P(active contingenc y due to k before switching)} = \lambda_k^a \cdot s_k = \text{MTTS}_k \tag{9}$$

$$\text{F(active contingenc y due to k before switching)} = \lambda_k^a \tag{10}$$

For the situation after switching, the probability, *P(active contingency due to k after switching),* and its frequency of occurrence, *F(active contingency due to k after switching),* are given by:

$$\mathrm{P(active\ contingenc\ y\ due\ to\ k\ after\ switching)} = \lambda_k^a \cdot (r_k - s_k) \tag{11}$$

$$\mathrm{F(active\ contingenc\ y\ due\ to\ k\ after\ switching)} = \lambda_k^a \tag{12}$$

5. Stuck circuit-breaker conditions

A stuck circuit-breaker condition arises when a circuit breaker or a protective relay is the primary protection zone fails to operate following an active failure event. Back-up or secondary protection must then respond and a larger section of the substation may be disrupted.

The probability that a circuit breaker k is stuck, P_k^{scb}, can be evaluated from a data collection scheme and its given by [8,9,10]:

$$P_k^{scb} = \frac{\text{number of failures to open}}{\text{number of commands to open}} \tag{13}$$

A stuck circuit breaker in general imposes a severe impact on the substation and may cause a higher-order contingency. Therefore, the simulation and analysis of such events are important, although their probability and frequency are usually small.

Therefore, in the situation before switching, the equations for the probability and frequency of this contingency are given by:

$$\mathrm{P(contingency\ due\ to\ k\ and\ circuit\ breaker\ l\ stuck\ before\ switching)} = P_l^{scb} \cdot \lambda_k^a \cdot s_k \tag{14}$$

$$\mathrm{P(contingency\ due\ to\ k\ and\ circuit\ breaker\ l\ stuck\ before\ switching)} = P_l^{scb} \cdot \lambda_k^a \tag{15}$$

After such severe failure events, the operators of the power system should try to restore the substation topology as far as possible. For the new situation after switching, the probability and frequency of this contingency can be evaluated by:

$$\mathrm{P(contingenc\ y\ due\ to\ k\ and\ circuit\ breaker\ l\ stuck\ after\ switching)} = P_l^{scb} \cdot \lambda_k^a \cdot (r_k - s_k) \tag{16}$$

$$\mathrm{F(contingenc\ y\ due\ to\ k\ and\ circuit\ breaker\ l\ stuck\ after\ switching)} = P_l^{scb} \cdot \lambda_k^a \tag{17}$$

If it is impossible to relieve a substation-originated contingency due to the combination of an active failure and a stuck circuit breaker conditions, the probability and frequency of such a long-term contingency are given by:

$$\mathrm{P(contingenc\ y\ due\ to\ k\ and\ circuit\ breaker\ l\ stuck)} = P_l^{scb} \cdot \lambda_k^a \cdot r_k \tag{18}$$

$$\mathrm{F(contingenc\ y\ due\ to\ k\ and\ circuit\ breaker\ l\ stuck)} = P_l^{scb} \cdot \lambda_k^a \tag{19}$$

6. Second-order overlapping substation outages

Second order overlapping substation-originated outages involve the sequential failure of at least two-substation component failure overlapping a scheduled maintenance routine. The condition for this type of fault to occur is that the first component has failed or has been taken out of service for scheduled maintenance.

The overlapping events usually considered are those involving only two substation components and are referred to as second-order overlapping outages. The probability that higher-order events occur is usually negligible. There are an enormous number of possible combinations of events leading to a second-order-overlapping event. When one tries to split up each contingency into a state before and a state after switching this number is approximately doubled.

Since the situation before switching usually has a short duration compared to the situation after switching, the situations before switching are neglected. In this paper, only contingencies due to second-order overlapping outages for the situation after switching are considered. Therefore, the modelling of switching actions is absent in the algorithms enumerating such overlapping second-order contingencies. Thus, the calculated reliability indices for the considered system will be slightly better than the situations before switching are considered as well.

Can be come into the sight the following failures, in comparison with analysis point:

- active failures or/and total failures of first order
- active failure or/and total failure of second order
- active failure overlapped with stuck circuit breaker

In a total failure, can be used relations for two elements in active reserve, the system success been ensure been ensure of function at one element.

$$\lambda_e = \frac{\lambda_k \lambda_l (\mu_k + \mu_l)}{\mu_k \mu_l + \lambda_k \mu_l + \lambda_l \mu_k} \quad ; \quad \mu_e = \mu_k + \mu_l \tag{20}$$

In case of the second-order active failures, the reliability indices of the system formed by two elements connected in parallel (for example active failure of the first element overlapping a total failure at the second element) can be determined using similar relations to relations (2), but size which intervene has another signification:

$$\lambda_e^a = \frac{\lambda_k^a \lambda_l (\mu_k^a + \mu_l)}{\mu_k^a \mu_l + \lambda_k^a \mu_l + \lambda_l \mu_k^a} \; ; \; \mu_e^a = \mu_k^a + \mu_l \cong \mu_k^a \text{ if } \mu_k^a \geq \mu_l \tag{21}$$

where:

λ_k^a	active failure intensity of the first element, in [hr^{-1}]
$\lambda_l = \lambda_l^a + \lambda_l^p$	total failure intensity, respective the repair intensity of the second element:

$$\mu_l^a = \frac{1}{s_l} \tag{22}$$

s_l	switching time from component l, in [hr^{-1}]
λ_e^a, μ_e^a	equivalent active failure rate and equivalent active repair rate in the case of system formed by two elements connected in parallel, in which the element k suffer an active failure and the element l a total failure.

7. Case study

Consider substation of 110/20 kV, had a simple system bus bar sections, shown as in figure 4. These two bus bar sections are considered through the agency of longitudinal coupling or circuit breakers (10) and an electric power transformer (9). Reliability analyses have in comparison with load point 1 (LD1). The success state is considered the voltage present in the load point 1 (LD1).

The reliability evaluation indices for the substation analyzed has in the following assumptions:

- are considered the three-state failure model for each component of substation (see figure 1)
- circuits breakers actively failing cannot clear own failures
- disconnecting switches from scheme of figure 4 are considered equated in series at lines 1 and 6, respective, at bus bar sections 4 and 8
- takes into account only first and second order failures
- the analysis period is considered one year

The reliability evaluation indices will do used the minimal cut-set method, the total failure and/or active of first order, respective second order failures is overlapping. In table 1 is presented the reliability indices for substation components analyzed. The load point 1 (LD1) is affected by the following failures indicated in table 2.

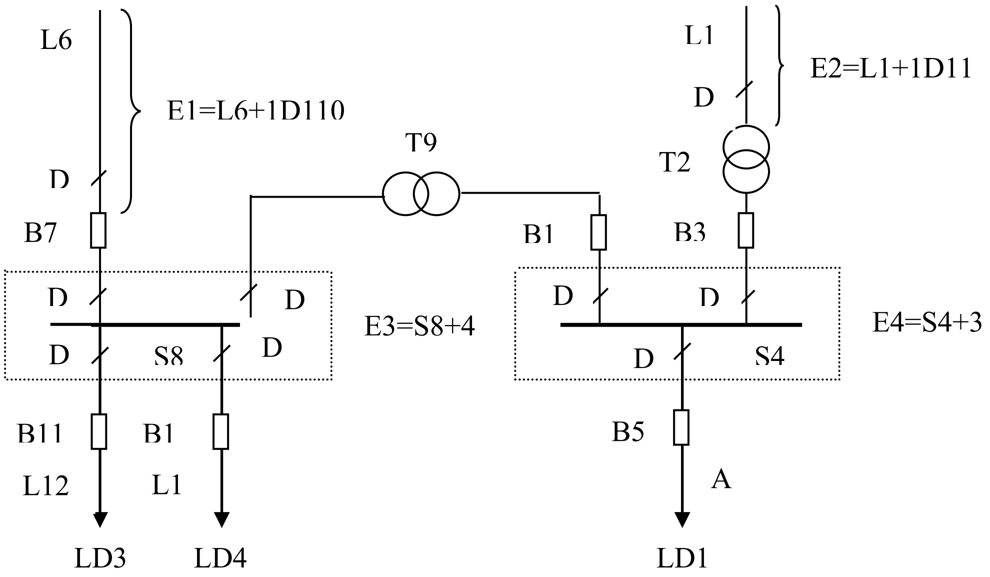
Table 1 Observed and estimated component reliability data, which are used in substation studies

Components	Index	$\lambda_k^t \cdot 10^{-4}[hr^{-1}]$	$\lambda_k^a \cdot 10^{-4}[hr^{-1}]$	$\mu \cdot 10^{-4}[hr^{-1}]$	P_k^{scb}	s_k [h]
Line 110 kV (100 km)	L1, L6, L12, L14	1.47	1.47	613.68	-	1
Power transformer 110/20 kV	T2, T9	0.057	0.057	32.46	-	1
Circuit breaker 110 kV	B7, B11, B13	0.1083	0.0337	183.06	0.080	1
Circuit breaker 20 kV	B3, B5, B10	0.0864	0.0156	205.3	0.080	1
Disconnecting switch 110 kV	D_{110}	0.0044	0.0044	464.48	-	-
Disconnecting switch 20 kV	D_{20}	0.003	0.003	588.34	-	-
Busbar section 110 kV	S8	0.0147	0.0147	198.81	-	1
Busbar section 20 kV	S4	0.0119	0.0119	596.49	-	-
Equivalent element: L6+1D110 L1+1D110	E1, E2	1.4744	1.4744	641.04	-	-
Equivalent element: S8+4D110	E3	0.0323	0.0323	293.63	-	1
Equivalent element: S4+3D20	E4	0.020	0.020	588.23	-	-

Evaluation of these reliability indices has used the minimal cut-set methods of second-order. The essential problem which put is established the following reliability indices: active failure rate of component k (λ_k^a) and the passive failure rate of component k (λ_k^p), those values not been determined, in Romania, for all power system components.

With results, can be calculated the probability of residing in a state in case of electrical station supposed analysis. The probability of occurrence of the UP state (state 1 or operational state, or successful state) and the probability of occurrence of the DN state (state 2 or unsuccessful state) of electric station shows in figure 2, in comparison of point of analysis A, are given by:

$$P_1 = \frac{\mu_A}{\lambda_A + \mu_A} = 0.9995 \ , \ P_2 = \frac{\lambda_A}{\lambda_A + \mu_A} = 0.0005 \tag{23}$$



S : Busbar section
T : Transformer
B : Circuit breaker
D : Disconnecting switch
⁄ : Normally closed
▯ : Normally closed

Figure 4 Single line diagram of substation analyzed

Table 2 Total failure and active failure of first order and second order, reliability indices

Index	Element failures	$\lambda \cdot 10^{-4}$ [hr^{-1}]	$\mu \cdot 10^{-4}$ [hr^{-1}]
a) first order of total failure (TF1)			
1	E4	0.020	588.23
2	B5	0.0864	205.3
Total (TF1)		0.1064	236.44
b) second order of total failure (TF2)			
1	E1 and E2	0.00675	1282.08
2	E2 and B7	0.00111	824.1
3	E2 and E3	0.00023	934.67
4	E2 and T9	0.00271	673.5
5	E2 and B10	0.00081	846.34
6	T2 and E1	0.00271	673.5
7	T2 and B7	0.00022	215.52
8	T2 and E3	0.00006	326.09

9	T2 and T9	0.0002	64.92
10	T2 and B10	0.00017	237.76
11	B3 and E1	0.00081	846.34
12	B3 and B7	0.000096	388.36
13	B3 and E3	0.00002	498.93
14	B3 and T9	0.00017	237.76
15	B3 and B10	0.000072	410.6
Total (TFII)		0.016138	748.63
Total (TFI+TFII):		0.122538	258.57
c) first order of active failure (AFI)			
1	B3 AF	0.0156	10000
2	B10 AF	0.0156	10000
3	E2AF+SCB3	0.011795	10000
4	T2AF+SCB3	0.00456	10000
5	B7AF+SCB10	0.00269	10000
6	E3AF+SCB10	0.00258	10000
7	T9AF+SCB10	0.00456	10000
8	B11AF+SCB10	0.00269	10000
9	B13AF+SCB10	0.00269	10000
Total (AFI)		0.16892	10000
d) second order of active failure (AFII)			
1	B11AF+E2	0.00034	10000
2	B11AF+T2	0.000069	10000
3	B11AF+B3	0.000030	10000
4	B13AF+T2	0.000034	10000
5	B13AF+B3	0.0000069	10000
6	B13AF+B3	0.000030	10000
Total (AFII)		0.000878	10000
Total (AF=AFI+AFII)		0.1697	10000
Total (TF+AF)		0.2922	608.75

Tabelul 3 Reliability indices

Type of interuption	TF=TFI+TFII		AF=AFI+AFII		TF+AF		Safety indicators evaluated by component types
	$\lambda_d 10^{-4}$ [hr^{-1}]	$\mu_d 10^{-4}$ [hr^{-1}]	$\lambda_m 10^{-4}$ [hr^{-1}]	$\mu_m 10^{-4}$ [hr^{-1}]	$\lambda_A 10^{-4}$ [hr^{-1}]	$\mu_A 10^{-4}$ [hr^{-1}]	
Long-term	0.12253	258.57					T_A=8760 [hr] α_l=8755.93 [hr] β_l=4.14 [hr] v_l=1072.60 $F_l=0.12x10^{-4}$
Maneuver			0.1697	10000			s_m= 1 [hr] α_m=8759.85 [hr] β_m=0.14 [hr] v_m=1471.70 [interruption/hr] $F_m=0.16x10^{-4}$
Totals					0.2922	608.75	T_A=8760 [hr] P_S=0.9995 P_R=0.0005 α_t=8755.80 [hr] β_t=4.28 [hr] v_t=2544.3 [interruption/hr] $F_t=0.28x10^{-4}$

In table 3, the signification of reliability indices are following:

- α_1 is mean time of supplying (without taking into account time fault)
- β_1 the average power failure time due to power outages
- v_1 the average number of interruptions of duration

$$v_l(T_A) = F_l \cdot T_A \tag{24}$$

where F_e - long term frequency

- α_m total average power time due to maneuver interruptions
- β_m the total average non-feeding time, which takes into account the maneuver interruptions
- v_m the average number of interruptions by manoeuvre

$$v_m(T_A) = F_m \cdot T_A \tag{25}$$

where F_m - frequency of occurrence of interruptions

8. Conclusions

In the case study analyzed above, there is presented a way of analyzing the reliability of the electrical stations, in relation to the presence of the voltage on a departure. The analysis is based on the possible modes of component failure (which are grouped into: passive, active and total defects).

To take into account the switches that take place in the electrical stations of transformation of the electricity and their effect on the analyzed departure, it is introduced the three-state model for a single component. The switches occur in the calculations by means of the blocking probability. This mode of analysis is faster, compared to the Markov chains method with continuous parameter, because it avoids the multitude of combinations of states.

The safety indicators evaluated are determined on the components:

- safety indicators that refer to interruptions in electrical stations
- indicators that refer to manual maneuver interruptions (without automatic reclosing type) in electrical stations.

The determination of these safety indicators is done using the method of the minimum cuts of maximum order II. A minimal cut is a set of elements whose failure involves the failure (fall) of the system. A minimal cut is a cut that does not contain elements belonging to another cut (the minimum set of elements leading to the system fall). When applying the method it is considered that the system elements are reliably independent. In this case, the scheme of the system can be represented by a set of minimal cuts.

The problem that arises is the establishment of safety indicators: the intensity of the passive defects (λ_k^p) and the intensity of the active defects(λ_a^a), their values not being clarified, in Romania, for all the components related to the surface electricity distribution systems, in time what for the underground mining distribution systems the values of these indicators are totally missing.

Current statistical performance for surface and mining distribution systems will in the future have to include: the average repair time of the system components, the probability of blocking the switches and the intensity of the passive faults of the switches.

The final step is to list all system failures by the probability of occurrence. This will provide a clear picture of scenarios that will cause the most problems. To find the system reliability (or in this case, substation reliability), combine the system failure probabilities and frequencies. Each failure state is an exclusive state, so the probability of occurrence of system failure is the sum of all the failure event probabilities. The product of occurrence of failure event and the duration can be used to determine the probability of the failure state

REFERENCES

[1] McDonald JD 2012 Electrical power substation enginneering, *CRC Press*
[2] Padilla E 2015 Substation automation systems: design and implementation, *Willey*
[3] Shvarisberg B 2016 Fundamentals of modern electrical substations, *Willey*
[4] William PE and Smith H 2018 Electric power system reliability, *Alphagrafics-Roswell GA, September 21*
[5] Brown RE 208 Electric power distribution reliability, *CRC Press, 2 edition, September 9*
[6] CIGRE Green Book 2019 Substation, *Springer, 1 st edition*
[7] Meeuwsen JJ and Kling WI 1997 Substation reliability evaluation including switching actions with redundant components*, IEEE Transaction on Power Delivery*, Vol. PWRD-12, pp. 1472-1479
[8] Endreny J 1978 Reliability modeling in electric power systems, *John Wiley & Sons*, Chichester
[9] Endreny J, Three state models in power system reliability evaluation, *IEEE Trans on Power Apparatus and Systems*, PAS-90, 1971 pp.1909-16
[10]Secui C 1999 *Modelarea şi evaluarea fiabilităţii previzionale a staţiilor electrice,* Rev. Producerea, transportul şi distribuţia energiei electrice şi termice, nr. 11-12,
[11] O'Conner P and Kleyner A 2012 Practical reliability engineering, *5th Edition, Willey, January 30, 2012*
[12]Billinton R, Ringle JR and Wood AJ 2003 Power-system reliability calculation, *MIT Press*
[13] Karki R, Bilinton R and Verma AK 2014 Reliability modelling and analisys of smart power systems - Reliable and susteineable electric power and energy system management, *Springler*
[14] Zhu J 2015 Optimization of power system operation (IEEE press series on power engineering), *Willey*
[15] Liu J, Dong X, Chen X, Tong X, Zhang X and Xu S 2016 Fault location and service restoration for electrical distribution system, *1 st edition, Willey*
[16] Sallaman AA and Malik OMP 2018 Electric distribution system (IEEE press series on power engineering) 2rd edition, Willey -IEEE Press
[17] Blume S, 2016 Electric power system basic for the nonelectric proffesional, *Willey-IEEE Press*
[18] Adibi MM, 2000 Power system restoration: methodologies and implementation strategies, 1 st edition, Willey-IEEE Press