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CONTRIBUTIONS TO THE THOROUGHGOING STUDY OF THE POWER DISTRIBUTING STATIONS' RELIABILITY ANALYSES

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***Abstract**: This paper is structured in five parts. In the first part are conjured up the used methods to evaluate the reliability performances of power distributing stations (PDS).*
In the paper are presented the authors proposal, to evaluate the models of some indices which have a plus precision for reliability analyses of PDS. In this sense, it starts with the functions analyses of power equipment in PDS, in the second part of the paper are detailed the stages, the failures modes as well as the transitions viewing the profound the reliability analyses of PDS.
In the third part of the paper are presented the main event, categories which determine the power energy unavailability to consumers and the reliability indices expressions to obtain a detailed simulation of electric equipment. In the fourth part are presented the results of case study, and in the last part are described the authors conclusions from this study.

1. PRELIMINARY

A great variety structure of power substations exists into electric power systems (EPS), other wise considering the operation, they are: electric power substations with injections, connection and distribution.

The analyses of power system reliability suppose to evaluate certain indices, which are included in the following categories [1, 4]: performance (typical to power substations), oriented on consumers, and on load, (typical to supplier - consumer relation). The reliability level is influenced by some factors, as: length of power electric lines, connecting schemas, used maintenance strategies, performances of electric installations, and environmental factors. The impact of these factors is treated in [2]. To estimate the reliability factors of (PDS) are used the following methods with high applicability [1, 2]:

- binomial method;
- reliability level estimate via equivalent diagram (function of structure);
- events and failures trees method;
- minimal cut set method;
- Monte Carlo simulation;

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- Markov chain method with continuous parameter.

Comparing with the usual treating methods of reliability for PDS [1, 2], by using the above enumerated methods, this paper present the authors proposal to estimate models of certain indices which introduces a plus of fidelity in reliability analyses of PDS; all these are made in relation with structures and functions of the equipments (EP) for the (PDS), the failures causes and modes, using an EP stage modeling with a higher emphasis grade.

2. EQUIPMENT RELIABILITY MODELING VIA POWER DISTRIBUTING STATIONS

To profound the reliability analyze of distributing PDS is made basing on the obtained results of certain detailed modeling of EP stages considering the typical events from PDS. Knowing the structure and functions of EP from the PDS [1], EP could be grouped as:

The first group: equipment and installations which doesn't execute maneuver: power transformers and autotransformers, measure transformers, collector bus bars, choke-coils, power lines. In figure 1 are presented the stages which characterizes the equipment from the first group;

Second group: equipment which is supposed to maneuvers as: circuit breakers, disconnectors, fusible.

The significations of parameters (λ, r) are described in [1, 2, 3], which aren't used for MPP and SF stages, because MPP habits as a SC (treated), fusible characterizes EP with failure, resulting reaction of protection.

Consequently, the set of failures stages which characterizes EP from the first group (MD) is:

$$\{MD\} \equiv \{SC, IC, PP, MPP, C, SF, AD\} \qquad (1)$$

In case of EP switching (circuit breakers, disconnectors), besides the stages from the first group there are possible:

- in hypostasis "on": blocking at stress (BO), opening without stress (OWS);
- in hypostasis "off": the "on" at stress CS, blocking at stress (BC), on without stress (CWS). In hypostasis "on" the failures are possible only on pole at voltage.

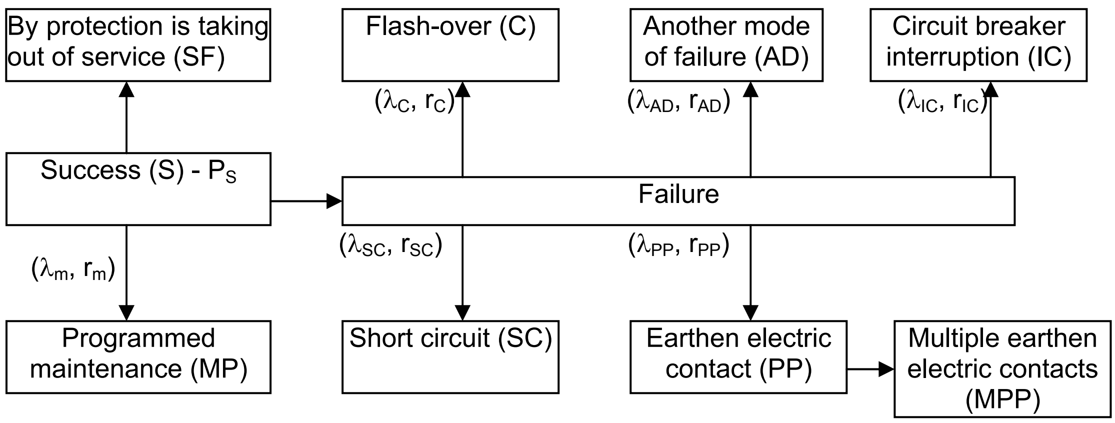

Fig. 1 Equipment's stages from the first group

The stages of second group for EP are presented in figure 1, characterized by indices (λ, r), with explanation that is useful to separate the set of values in relationship with both poles (1, 2);

$$\lambda^{(MD)_1} = [\lambda^{(SC)_1}, \lambda^{(IC)_1}, \lambda^{(PP)_1}, \lambda^{(MPP)_1}, \lambda^{(C)_1}]$$
$$\lambda^{(MD)_2} = [\lambda^{(SC)_2}, \lambda^{(IC)_2}, \lambda^{(PP)_2}, \lambda^{(MPP)_2}, \lambda^{(C)_2}] \qquad (2)$$

The special stages of EP from the second group are well characterized with the following probabilities:

$$P_j^O = \frac{N_j}{N_O} \qquad P_k^C = \frac{N_k}{N_C}, \; j=\{OS, BO, OWS\} \; \text{and} \; k=\{CS, BCS, CWS\} \qquad (3)$$

were, N_j, N_k – number of events apparition which characterizes the stages (j, k);

N_O, N_C – number of stress at opening and respective at shutting.
Obvious,

$$\begin{cases} P^{O}_{OS} + P^{O}_{BO} + P^{O}_{OWS} = 1 \\ P^{C}_{CS} + P^{C}_{BC} + P^{C}_{CWS} = 1 \end{cases} \quad (4)$$

The EP's failures mode which are taking into account by PDS reliability analyses are: passive (PFM), active (AFM) and total failure mode (TFM) [2,4], the blocking (B) –switching case of EP and respective the breaking – case of fusible.
Noting with (a, p, t), indices corresponding to three failures mode, are available the following relations:

$$\begin{cases} \lambda^{a} = \lambda^{a}_{1} + \lambda^{a}_{2} \\ \lambda^{p} = \lambda^{p}_{1} + \lambda^{p}_{2} \\ \lambda^{t} = \lambda^{a} + \lambda^{p} \end{cases} \quad (5)$$

The failures grouping and the evaluating of reliability indices allow:

- to evidence the place of apparition of failure which influences on a point at which is related the analyze;
- to specify the functioning of the switching elements EP after the failure: it can not be elucidate the self failures (hypothesis 1), can be elucidate the self failures (hypothesis 2) [4].

To disconectors bus bars from EPS structure are necessary to make an adequate treatment.
As, by PDS with triangle, square or polygonal type [2, 5], the failure of a disconnector make unavailable the others which are electric connected to the same point, which makes obligatory to study the serial typical structures. The algorithm to stabilize the active and total failures is presented in [3, 4].

3. THE POWER SUBSTATION MODELING AND RELIABILITY EVALUATION

To evaluate the power substations reliability we must fix a consumer or a group of consumers in relation with the made analyzes. A criterion to reliability evaluating can be the voltage (or a certain power level) at a consumer or on a supplying bus bar. The reliability and availability indices evaluation by consumer's level connected to PDS bus bars refers to: safety characteristic quantities (safety of time, power safety, energy safety) and/or availability characteristic quantities (time, power, energy availability).

To determine reliability indices for a PDS is necessary to specify the events categories which leads to interruption of consumers supplying, as well as the method to estimate the basic indices – the intensity apparition of events (λ) and events duration (r) – and of the deduced indices – success probability (P_S) and refuse (P_R) in consumers supplying, the consumers interruption number of duration (λ_{ID}) and maneuver (λ_{IM}), the consumers total number of interruption (λ_A), total operating (α_A) and non operating (β_A) time, etc.

Considering the failures which appears by the equipment of power substations, can be evidenced with following event categories: first order total failure (of duration) (DT1), second order total failure (DT2), first order active failure (of maneuver) (DA1), first order active failure (DA1) overlapped with blocking of circuit breaker (B) [DA1+B≡DA2], second order active failure (DA3), preventive maintenance (m) overlapped with a first order total failure (m+DT1≡MPDT), preventive maintenance (m) overlapped with a first order active failure (m+DA1≡MPDA).

All enumerated event categories provide the consumers supply interruption. The supplying interruption can be of short duration – maneuvers interruptions determined by (DA1, DA2, DA3, MPDA) events, or interruption of duration, determined by (DT1, DT2, MPDT) events. It must be making the precision that to estimate the reliability is enough to consider the first and second order events, the other events has a negligible probability.

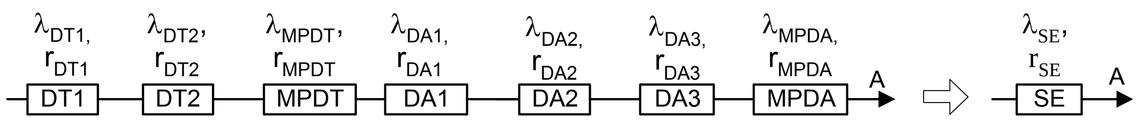

Fig.2 - Equivalent, fictitious elements which characterizes the event categories

The mentioned event categories may be evidenced by an equivalent reliability diagram (Fig.2). Every fictitious element, which represents a set of events of a certain type, is characterized by equivalent intensity event apparition of (λ_i) and by average equivalent rectify time of precise events (r_i), $i \in$ { DT1, DT2, DA1, DA2, DA3, MPDT, MPDA }. Fictitious elements may be serial grouped because DT1, DT2, DA1, DA2, DA3, MPDT, MPDA events are reciprocal excluding (any event appears leads to consumers supplying interruption, this characterizes a serial system), resulting the equivalent element (SE) characterized by (λ_{SE}, r_{SE}) indices.

It is not necessary every time to determine the reliability indices for all type of categories of events. In most of the cases the indices results from interruption of duration and maneuvers events are interesting. Consequently the seven events categories may be grouped as:

- interruption of duration by consumers (ID), including first order total failures (DT1), second order total failures (DT2) and overlapped failures – preventive maintenance with first order total failure (MPDT);
- maneuver interruption at consumers (IM), including: first order active failures (DA1), first order active failures with circuit breaker blocking (DA2), second order active failures (DA3) and overlapped failures - preventive maintenance with active failure (MPDA).

The reliability parameters for interruption of duration (λ_{ID}, r_{ID}) and maneuver (λ_{IM}, r_{IM}) are determining by serial equivalences of corresponding categories (Fig. 3, Fig. 4).

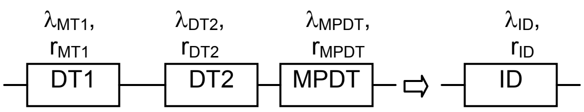

Fig. 3 Interruption of duration equivalence (ID)

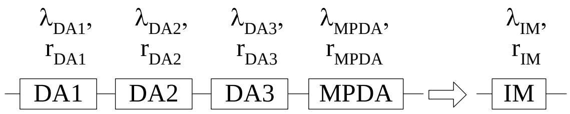

Fig. 4 Interruption of maneuver equivalence (ID)

At PDS level the reliability parameters stabilize considers the interruptions of duration and maneuvers, is made by connecting in serial of both fictitious equivalent element of ID and IM.

The two fictitious elements are serial connected (which characterizes the interruption of duration and maneuvers), in point of view of reliability they satisfy the requirements of a serial system:

- any interruption from this two elements results the interruption of system operating;
- the two situation are reciprocal excluding each the other (if the system is interrupt by maneuver is exclude the possibility of interruptions of duration and reverse);
- total number of interruptions is equal to number of interruption of maneuver plus number of interruptions of duration.

The compute relations which determine the intensity apparition of certain event (λ_i) or of remediate time of failure (r_i) due to the respective event ($i \in${DT1, DT2, DA1, DA2, DA3, MPDT, MPDA, IM, ID, SE}), as well as of indices which are calculated basing on these, are presented in [2].

4. STUDY CASE

For example is considered a single sectionalized bus bar subsystem, at medium voltage (Fig.5). To reduce the calculus is considered that the serial elements are equivalent. In table 1 is presented the elements equivalent mode and the equivalent reliability indices value (E1÷E6, B1 and B2).

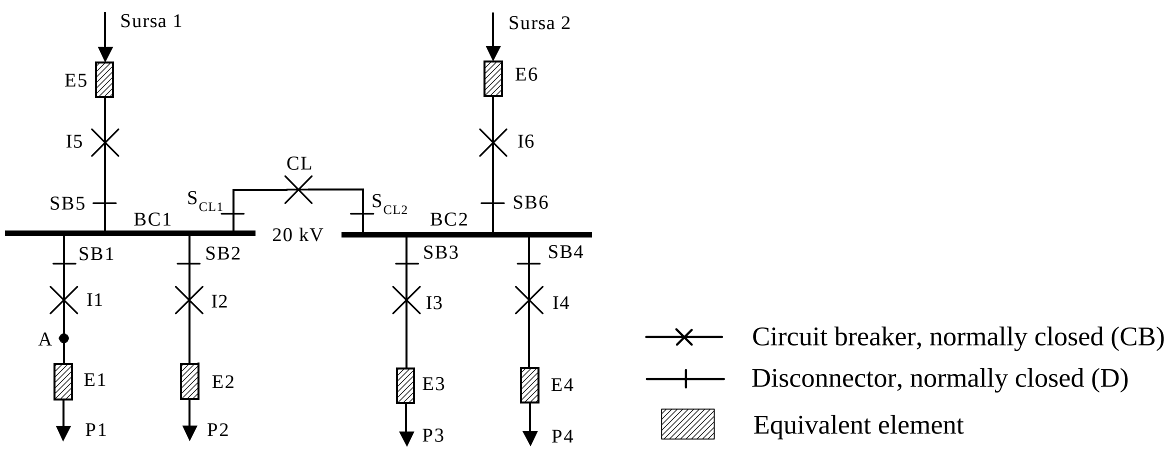

Fig. 5 - Single bus bar subsystem, sectionalized by CL

The first order reliability indices values are characterized by (I1÷I6, SB1÷SB6, CL, S_{CL1}, S_{CL2}, BC1 and BC2) elements, which are in concordance with PE 013 normative. For schemas elements are known the following reliability indices: total failures intensity (λ^t), active failures intensity (λ^a), average time of repartition (r), rectify intensity (μ), preventive maintenance intensity action (λ^m), average duration of preventive maintenance action (r^m) and the blocking probability of the interruptions (P_b). The computes were made using the coordinate preventive maintenance politics. Also, it was considered that P_b=0.05 and the maneuvers effecting time is equal to t_m=1 hour.

TABLE 1 Reliability indices value for equivalent elements of schema Fig.5

Symbol of equivalent element	Elements	λ^t x 10^4 [h^{-1}]/ λ^t [an^{-1}]	λ^a x 10^4 [h^{-1}]/ λ^a [an^{-1}]	μ x 10^4 [h^{-1}]	r [h]
E5, E6	$TC^{20\ kV}+TT^{20\ kV}+S^{20\ kV}+LEA^{20\ kV/5\ km}+S^{20\ kV}+TT^{20\ kV}+TC^{20\ kV}+IO^{20\ kV}+S^{20\ kV}$	0,3605/ 0,3158	0,3126/ 0,2738	694,86	14,39
E1÷E4	$TC^{20\ kV}+TT^{20\ kV}+S^{20\ kV}+LEA^{20\ kV/5\ km}+S^{20\ kV}+TT^{20\ kV}+TC^{20\ kV}+IO^{20\ kV}+S^{20\ kV}$	0,3605/ 0,3158	0,3126/ 0,2738	694,86	14,39
B1	BC1+SB1+SB2+SB5+S_{CL1}	0,0240	0,0178	584,82	17,10
B2	BC2+SB3+SB4+SB6+S_{CL2}	0,0240	0,0178	584,82	17,10
LEA	$LEA^{20\ kV/5\ km}$	0,2425/ 0,2124	0,226/ 0,1975	1260,82	7,93
I1÷I6, CL	Circuit breaker IO 20 kV, with actuating appliance	0.0316/ 0.0277	0,008/ 0,0072	649,59	15,39
SB1÷SB6, S_{CL1}, S_{CL2}	Three polar disconnector 20 kV	0.0030/ 0.0026	0,0022/ 0,0019	588,34	17,01
BC1, BC2	Bars 20 kV	0.0119/ 0.0104	0,009/ 0,0079	576,49	16,76

The used notations represent:
E1, E2, E3, E4, E5, E6 – equivalent element, which may contain a certain serial connected elements; I1, I2, I3, I4, I5, I6 – circuit breaker of IO, CL type– longitudinal couple; S_{CL1}, S_{CL2} – couple disconnectors; SB1, SB2, SB3, SB4, SB5, SB6 –three polar disconnectors bars; P1, P2, P3, P4 – departures from substation to consumers, BC1, BC2 – bus bars; A – point in relation with which is made the analyze; TT^{20kV}, TC^{20kV} voltage, respective current transformer at 20 kV voltage level; S^{20kV}, IO^{20kV} disconnector, respective circuit breaker of IO type of 20 kV;
$LEA^{20kV/5km}$ electric line, at 20 kV voltage and 5 km length;

Will be symbolic established (Table 2) and numeric estimate (Table 3) the enumerated events categories: DT1, DT2, DA1, DA2, DA3, MPDT, and MPDA. The reliability indicators (λ_A, r_A, ν_A, α_A, β_A, P_S, P_R) estimate is made in relation with A point voltage (P1 consumer), basing on the presented relations in [2].

TABLE 2 Symbolic establishing of events set DT1, DT2, DA1, DA2, DA3, MPDT and MPDA

Schemas Type	Interruptions of duration (ID)			Maneuvers interruptions (IM)			
	DT1	DT2	MPDT	DA1	DA2	DA3	MPDA
Single sectionalized bar	$B1^t$	$E5^t+E6^t$	$C5^{m(t)}+C6^{t(m)}$	$I5^a$	$E2^a+I2^B$	$I3^a+E5^t$	$C5^m+I3^a$
	$I1^t$	$E5^t+I6^t$	$C5^{m(t)}+B2^{t(m)}$	CL^a	$I6^a+CL^B$	$I3^a+I5^t$	$C5^m+I4^a$
		$E5^t+B2^t$	$C5^{m(t)}+CL^{t(m)}$	$I2^a$	$B2^a+CL^B$	$I4^a+E5^t$	$C5^m+I2^a$
		$E5^t+CL^t$			$I3^a+CL^B$	$I4^a+I5^t$	CL^m+I2^a
		$I5^t+E6^t$			$I4^a+CL^B$		$B2^m+I2^a$
		$I5^t+I6^t$			$E5^a+I5^B$		$C6^m+I2^a$
		$I5^t+B2^t$					
		$I5^t+CL^t$					

$^{(t)}$ – total failure, $^{(a)}$ – active failure, $^{(m)}$ – preventive maintenance, $^{(B)}$ – circuit breakers blocking
C5÷C6 – circuits cells for bus bars feeding BC1 and BC2

TABLE 3 Numeric estimating of events set DT1, DT2, DA1, DA2, DA3, MPDT and MPDA

Interruption of duration (ID)						Interruption of maneuvers (IM)							
DT1		DT2		MPDT		DA1		DA2		DA3		MPDA	
$\lambda x10^4$ $[h^{-1}]$	r [h]	$\lambda x10^8$ $[h^{-1}]$	r [h]	$\lambda x10^8$ $[h^{-1}]$	r [h]	$\lambda x10^4$ $[h^{-1}]$	t [h]	$\lambda x10^8$ $[h^{-1}]$	t [h]	$\lambda x10^8$ $[h^{-1}]$	r [h]	$\lambda x10^8$ $[h^{-1}]$	r [h]
0,0240	17,10	3,740	7,19	7,32	6,73	0,008	1	156,3	1	0,044	0,94	0,145	0,97
0,0316	15,39	0,339	7,44	7,31	9,68	0,008	1	4,0	1	0,004	0,94	0,145	0,97
		0,273	7,82	7,65	9,57	0,008	1	9,0	1	0,044	0,94	0,145	0,97
		0,339	7,44					4,0	1	0,004	0,94	0,145	0,97
		0,339	7,44					4,0	1			0,145	0,97
		0,031	7,70					156,3	1			0,145	0,97
		0,024	8,10										
		0,031	7,70										
0,0556	16,13	5,116	7,28	22,28	8,67	0,024	1	333,6	1	0,096	0,94	0,87	0,97
λ_{ID}=0,0583·10^{-4} h^{-1}, r_{ID}=15,78 h, β_{ID}=0,81 h/yr, α_{ID}=8759,19 h/yr, ν_{ID}=0,051 interruptions/yr						λ_{IM}=0,05746·10^{-4} h^{-1}, $r_{IM}\approx$1 h, β_{IM}=0,050 h/yr, α_{IM}=8759,95 h/yr, ν_{IM}=0,05 interruptions/yr							
λ_A=0,11576·10^{-4} h^{-1}, r_A=8,48 h, P_S=0,999902, P_R=0,000098 α_A=8759,14 h/yr, β_A=0,86 h/yr, ν_A=0,102 interruptions/yr													

The conclusions from Table 3 are: the weight of interruptions of duration from total interruptions (λ_{ID}) is more than 50,4% and of interruptions of maneuvers is of 49,6% (λ_{IM}). The non feeding duration (β_A) is due to interruptions of duration -β_{ID} (94,2 %), and only 5,8% to -β_{IM}. This is in concordance with reality, because the average of interruption duration is r_{ID}=15,78 h, while the interruption of maneuvers is less $r_{IM}\approx$1 h.

5. CONCLUSIONS

In a first step, the power stations reliability estimate supposes to identify and estimate the main events categories which results the consumers feeding interruption. In this sense were identified seven events categories as: first and second order total failures, active failures overhead with circuit breakers blocking, active failures overhead with preventive maintenance actions.

Total failures estimate is made by stabilizing of minimal cutting sets, applying a specifical algorithm. To identify the active failures is used an algorithm which apply supposes to stabilize the connections paths between source – consumers and source – source.

Is useful to attach an indices pair to each of mentioned failure type, which characterizes the failure in point of view of failure intensity (λ_i) and of duration (r_i). As, a power equipment is characterized by an indices pair (λ_i, r_i) equal with the registered failures type number by the respective equipment.

The events which appear by the electric stations may be grouped in two categories – viewing the practical aspect - : events which lead to interruptions of duration, and respective to interruption of maneuvers. The made applications highlighted the necessity to estimate the maneuvers interruptions too. The maneuvers interruptions weight is significant to "interruption intensity - λ" (in the case of considered application it is 50%) and lower referring on "interruptions of duration" - $\beta(T_A)$" (approx. 6 %).

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