World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:1, No:3, 2007

Improvement of the Reliability of the Industrial Electric Networks

M. Bouguerra, I. Habi

Open Science Index, Electrical and Computer Engineering Vol:1, No:3, 2007 publications.waset.org/7438.pdf

***Abstract*—**The continuity in the electric supply of the electric installations is becoming one of the main requirements of the electric supply network (generation, transmission, and distribution of the electric energy). The achievement of this requirement depends from one side on the structure of the electric network and on the other side on the avaibility of the reserve source provided to maintain the supply in case of failure of the principal one. The avaibility of supply does not only depends on the reliability parameters of the both sources (principal and reserve) but it also depends on the reliability of the circuit breaker which plays the role of interlocking the reserve source in case of failure of the principal one. In addition, the principal source being under operation, its control can be ideal and sure, however, for the reserve source being in stop, a preventive maintenances which proceed on time intervals (periodicity) and for well defined lengths of time are envisaged, so that this source will always available in case of the principal source failure. The choice of the periodicity of preventive maintenance of the source of reserve influences directly the reliability of the electric feeder system In this work and on the basis of the semi- markovian's processes, the influence of the time of interlocking the reserve source upon the reliability of an industrial electric network is studied and is given the optimal time of interlocking the reserve source in case of failure the principal one, also the influence of the periodicity of the preventive maintenance of the source of reserve is studied and is given the optimal periodicity.

***Keywords*—**Semi-Markovians processes, reliability, optimization, industrial electric network.

I. INTRODUCTION

IT is known that the electric installations are classified on the basis of several criterions, the principal ones are follows:

- Operation mode;
- Nature of the current;
- Voltage and power level;
- Reliability required of their electric feeder system.

According to the last criterion, the electric installations are divided into three categories [2,3].

- first category: these installations don't admit any stop (accidental or planned) of their electric feeder system (E.F.S), the stop of the latter has the human death consequence, this is why their EFS must be carried out with two independent sources.
-second category: these installations don't admit any stop (accidental or planned) of their electric feeder system (E.F.S), the stop of the latter has a significant economic consequence, this is why their EFS must be carried out with two independent sources.
-third category: these installations don't have a capital insert in the technological process, they can admit a stop (accidental or planned) of their EFS going up to 24 hours, their EFS are carried out with only one source.

The great majority of the electric installations belong to the first and second category. In order to ensure a high level of reliability of their electric system feeder, two power supply sources are envisaged, one principal, the other of reserve, generally a cold reserve (electric diesel group) [2,3].

The avaibility of supply does not only depends on the reliability parameters of the both sources (principal and reserve) but it also depends on the reliability of the circuit breaker which plays the role of interlocking the reserve source in case of failure of the principal one. In addition, the principal source being under operation, its control can be ideal and sure, however for the reserve source being in stop, a preventive maintenances which proceed on time intervals (periodicity) P_m and for well defined lengths of time d_m are envisaged, so that this source will always available in case of the principal source failure. The choice of the periodicity of preventive maintenance of the source of reserve influences directly the reliability of the electric feeder system. In this work and on the basis of the semi- markovian's processes, the influence of the time of interlocking the reserve source upon the reliability of an industrial electric network is studied and is given the optimal time of interlocking the reserve source in case of failure the principal one, also the influence of the periodicity of the preventive maintenance of the source of reserve is studied and is given the optimal periodicity.

II. SUGGESTED ALTERNATIVE FOR THE EFS

The suggested alternative for the industrial electric networks can be schematized as follows (Fig. 1):

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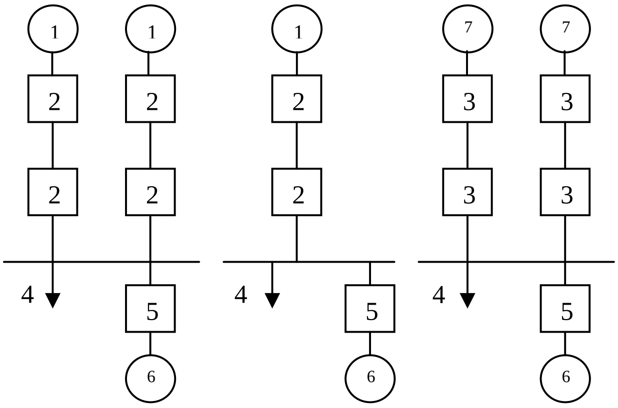


Fig. 1 Standard diagram of the EFS structure

1. external source from the national electric network;
2. circuit breaker of electric line;
3. circuit breaker;
4. electric load
5. circuit breaker for interlocking the reserve source;
6. reserve source;
7. local source (turbo generator).

III. ELEMENTS AND ELECTRIC FEEDING SYSTEM, NOTIONS AND CLASSIFICATION OF THE FAILURES

At the time of study of reliability, the concept of element and system is relatively conditional. Their difference is carried out on the level of the analysis of the system at the time of the resolution of a problem of reliability posed.

An object considered as element at the time of a study, can be seen as system if the study is directed towards another object of weak scale. As an example, at the time of the modeling of the reliability of an electro energetic system, the lines of electric transport of power are regarded as elements; on the other hand if this study is posed on the same line, the latter is regarded as system made up of several elements, support, insulators, and drivers. At the time of the study of the reliability of the support, this last is presented in the form of a system including several elements: foundation, fitting of fixing.

As elements in the electric feeder systems, we distinguishes the lines, and electric cables, the turbo generators, the transformers and the apparatuses of commutation, the internal part of the EFS is introduced like only one element, if the study is carried out on a greater scale, in particular during the analysis of the effectiveness and the choise of the sources of power supply.

The final goal of the determination of the reliability of various elements and also of the EFS in its globality is related directly to the concept of failure.

We understand by failure of the EFS, the state during which the EFS loses completely or partially its capacity to provide its function, which results in the partial or complete stop of the technological process.

The failures are classified on the basis of several criterions: accidental failure, after wear failure, independent or dependent failure, stable or unstable failure.

An accidental failure is a failure which directly involves the release of the failing element under the action of its electric protection, the failure after wear is a failure bringing the element weakening to a not planed repair. The experiment of exploitation of the EFS showed the low level of the failures after wear and with their weak dangerosity.

The independent failures are failures in which the failure of an element does not involve that of another element, that dependent increases the probability of failure of the other element, in the case of absolute dependence, the failure of the other element is direct and sure, As an example if in an electric switchyard, the failure of a transformer involves the overload of a second transformer, we speak about dependent failure. Let us note that transformers of the EFS are generally calculated and chosen on the basis of 100 % of the load for each one, this is why the failures of transformers are regarded as independent. For the lines with double same circuits if their transport capacity can be unlimited, their failures can not be regarded as independent, very often the rupture of a driver of a circuit can involve with the failure of the other circuit. Also let us note, considering the characteristics of the installations electric of the EFS, the accidental stops are primarily due to stable failures, therefore we will limit ourselves to this type of failure.

The failures of the various elements are at the base of the failures of the EFS, however the reliability of the complex systems as the EFS depend primarily on their structure of the type of connection of the elements and of the dependability of operation of the elements. It is known that from elements of a no high level of reliability, the design of the reliable system can be obtained on the basis of optimal redundant structure, however to expect a great effectiveness of these systems cannot in no case to be assured. In order to locate the weak link of the EFS and its elements, allows to highlight the best means of improvement of their reliability and to determine the source data to ensure the requirements for the reliability of these systems, the first stage to be realized at the time of the study of the reliability of the EFS is the determination and the analysis the reliability of the various elements of these systems.

The information collected on a sample of several industrial electrical networks, located in the north of Algeria allowed us to represent the distribution of the failures of the various elements of these EFS, Table I, to the denominator is indicated the distribution of the failures in percent.

TABLE I
DISTRIBUTION OF THE FAILURE OF VARIOUS ELEMENTS OF THE EFS IN THE NORTH OF ALGERIA

Electric components	Number of analyzed failures	Number of failures of elements
Power lines	143	Electric drivers(11/7.7), insulators(132/92.3)
Transformers	96	Insulators(53/55.2), terminals (31/32.3), switch (12/12.5)

Circuit breakers of line	105	Insulators (27/25.7), control drive (58/55.3), system of drive (21/19.0)
Sets of bars	39	Contact with apparatuses (39/100)
Circuit breaker of interlocking of the source of reserve	67	Control devise (41/61.2), system of drive (26/38.8)
Local source turbo generator	137	System of excitation (28/20.4), mechanicals parts (109/79.6)

IV. BASIC PRINCIPLES, CHOICE AND EVALUATION OF THE PARAMETERS OF RELIABILITY OF THE EFS

The EFS, as any technical system must provide the function for which they are intended. During operation it is essential to have the certainty that these systems function correctly, while preserving their given technical properties. The certainty of correct operation of the EFS is based on the evaluation of the level of reliability required of these systems. In order to solve this problem, the quantitative parameters characterizing their reliability are necessary. The knowledge and the evaluation of these parameters not only make possible to carry out calculations of reliability, but also justify the level of reliability required of the elements of the EFS, to highlight the influence of the reliability of these systems on the effectiveness of operation of the EFS and to choose the optimal structure of the diagrams of these systems.

The great majority of the elements of the EFS are reparable equipment; the principal parameters of reliability of these elements are the failure rate and the average time of repair. In various case, during the study of the reliability of the EFS, several addional parameters of reliability are used, such us: the mean time between failures, the availability factor, the probability of operation, the cost of unavailability of the EFS, however, it is known that all these parameters can be easily determined from the failure rate and the average time of repair. This fact and in order to evaluate the reliability of the EFS, it is necessary to carry out a statistical analysis of the failures of the various elements and to determine their failures rates end the mean time of repair.

The failure rate W characterizing the frequency of failures is presented in the form of a relationship between number n of failures observed among k elements of same type during time Δt [4,6].

$$W=\frac{n}{k.\Delta t} \tag{1}$$

Generally, we summarize the behaviour of equipment over his lifespan by his curve out of bath-tub [1,7], as presented on Fig. 2.

We generally distinguish on the curve three parts:
A: childhood period, the failure rate decreases,
B: effective period, the failure rate is constant,
C: period of wear, the failure rate is increases

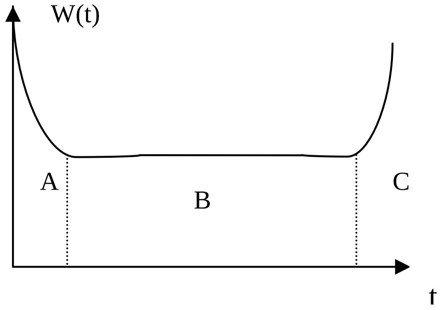


Fig. 2 Curve out of bath-tub of equipmenent

The evaluation of the frequency of failure on the interval of time (t, t+ Δt) can be obtained by the relationship between the number of failing elements n of the EFS and the total number of elements N in observation during time Δt .

$$W(t)=\frac{n(t,t+\Delta t)}{[N(t,t+\Delta t).\Delta t} \tag{2}$$

Fact and as it is known that N(t,t+ Δt)≠ N(t,t), the equation “refer to (2),” will arise as follows:

$$W(t)=\frac{2n(t,t+\Delta t)}{[N(t,t+\Delta t)+N(t,t)]\Delta t} \tag{3}$$

For the electric lines and cables:

$$W(t)=\frac{2n(t,t+\Delta t)}{[L(t,t+\Delta t)+L(t,t)]\Delta t} \tag{4}$$

L(t,t),L(t,t+ Δt): Overall length of the electric lines and cables at the beginning and the end of the period of observation.

Generally during the evaluation of the frequency of failure of the electric equipment, we consider the effective period [w(t)= w= λ =const], λ represents the failure rate, owing to the fact that this equipment is suitably developed wish we seldom distinguishes failures and also do not suffer from phenomena of wear[1].

The confidence interval for the failure rate is obtained using the confidence coefficient [6,8]. The higher and lower limits of the failure rate are calculated as follows:

$$\lambda_{\sup} = \frac{\lambda}{\nu_1} \tag{5}$$

$$\lambda_{\inf} = \frac{\lambda}{\nu_2} \tag{6}$$

with:

ν_1 , ν_2 : parameters dependent on the number n of failing elements and the probability of confidence [8].

The average time of repair of the elements of the EFS is estimed by the following relation:

$$T_r = \frac{1}{n}\sum_{1}^{n} T_i \tag{7}$$

$$\mu = \frac{1}{T_r} \tag{8}$$

T_i : duration of repair after appearance of failure,
μ : rate of repair.

The failure rate and the average repair time of the elements of the EFS determined with a probability of confidence $\alpha = 0.95$ are represented on the Table II.

TABLE II
PARAMETERS OF RELIABILITY OF THE ELEMENTS OF THE EFS IN NORTH OF ALGERIA

Elements of EFS	Failure rate 1/year			Average time of repair(h)
	$\lambda_{\inf}$	λ	$\lambda_{\sup}$	
Electric lines on100km (kV) :				
- 30	1.20	2.20	3.12	5.6
- 60	1.90	2.00	3.98	5.6
- 220	0.38	1.40	2.58	6.5
Transformers (kV)				
5.5 : 10	0.012	0.023	0.038	70
- 30	0.009	0.018	0.030	90
- 60	0.010	0.020	0.033	100
- 220	0.003	0.020	0.062	100
Disjoncteurs de lignes (kV)				
5.5 : 10				
- 30	0.003	0.005	0.007	10
- 60	0.002	0.005	0.008	10
- 220	0.002	0.005	0.008	10
	0.003	0.020	0.062	24
Electric cables on 100 km (kV)				
5.5 : 10	1.80	2.50	3.37	12
Turbogenerator	3.84	5.80	7.83	70
Sets of bars (kV)				
5.5 : 10	0.003	0.010	0.020	4
- 30	0.011	0.030	0.062	4
- 60	0.005	0.030	0.090	4
- 220	0.007	0.040	0.125	6

V. DETERMINATION OF THE OPTIMAL TIME OF INTERLOCKING OF THE RESERVE SOURCE

The structures of the E.F.S (Fig. 1) can be schematized with their reliability parameters as follows (Fig. 3):

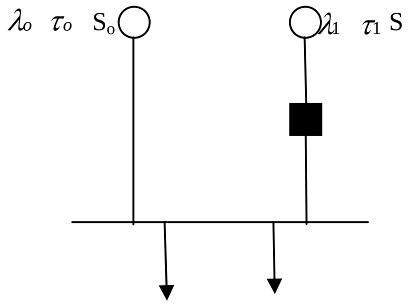
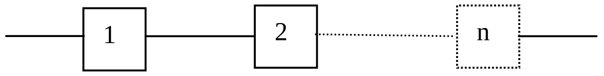


Fig. 3 Representative sources diagram

S_o: principal source;
S_1 : reserve source;
λ_o, τ_o : principal source failure rate and time of repair respectively;
λ_1, τ_1: reserve source failure rate and time of rapair respectively.

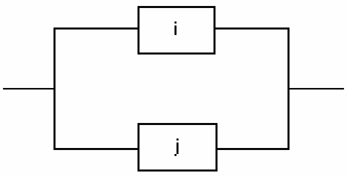
The failure rate and the time of repair of the elements in series are given as follows [9]:



$$\lambda = \sum_{i=1}^{n} \lambda_i \tag{9}$$

$$\tau = \frac{\sum_{i=1}^{n} \lambda_i \tau_i}{\sum_{i=1}^{n} \lambda_i} \tag{10}$$

The failure rate and the time of repair of the elements in parallels are given as follows [9]:



$$\lambda_{ij} = \lambda_i \, \lambda_j \, (\tau_i + \tau_j) \tag{11}$$

$$\tau_{ij} = \frac{\tau_i . \tau_j}{\tau_i + \tau_j} \tag{12}$$

Under operation, the EFS can have several states, on the basis of the semi-Markovian's processes [5,10,11], the evolution of the EFS operation can be described by the states and the probability of transition P_{ij} according Fig. 4.

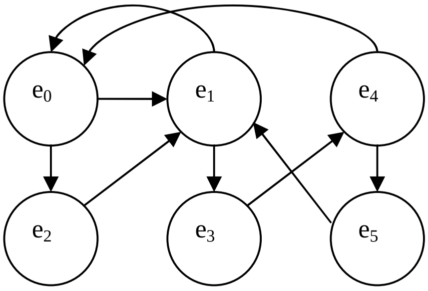


Fig. 4 Semi-Markovian's processes and transitions graph

e_0 : PS under operation, RS in reserve;
e_1: PS in repair, RS under operation;
e_2 : PS in failure, $t_{encl} > t_{adm}$;
e_3 : PS in repair, RS in failure;
e_4 : PS under operation , RS in repair;
e_5 : PS in failure, RS in repair.

where:

PS: principal source;
RS, reserve source;
t_{encl} : time of interlocking of the reserve source;
t_{adm} : acceptable time limits of interlocking of the reserve source .

The random values of the MTBF (middle time between failure) ξ_0 , ξ_1 as well the repair time η_0 , η_1 of the principal source and the reserve source respectively follow an exponential law [2,3] , $P_i(t)$, $G_i(t)$ with the parameters λ_i , μ_i (i = 0, 1).

The calculation probability P_{ij} of transitions between states could be calculated as follows:

$$P_{01}=1-q \tag{13}$$

$$P_{02} = q \tag{14}$$

q: probability of failure of the circuit breaker of interlocking the reserve source .

The failure of the circuit breaker of interlocking of the reserve source is the state when the time of interlocking t_{encl} is higher than the acceptable time supported by the industrial technological process t_{adm}. The time t_{encl} includes the clean time of operation of the circuit breaker and the time of starting of the reserve source if the latter is a local source (diesel electric group) or more time of interlocking of the circuit breaker of line of the national electric network if the line is the source of reserve.

$$q=P(t_{encl}>t_{adm})=1-F_{encl}(t_{adm}) \tag{15}$$

$$\text{For } t_{encl}=const \text{ and } D(t)=P(t_{adm}< t) = \frac{t-t_{adm\min}}{t_{adm\max}-t_{adm\min}} \tag{16}$$

$$q=\int_0^{\infty}[1-F_{encl}(t)]dD(t)=\frac{t_{encl}-t_{adm\min}}{t_{adm\max}-t_{adm\min}} \tag{17}$$

where:

$F_{encl}(t)$: distribution law of the random value t_{encl};
$D(t)$: distribution law of the random value t_{adm}.

$$P_{10}=P\{\eta_0 < \xi_1\}=\int_0^{\infty}G_0(t)dP_1(t) = \frac{\mu_0}{\lambda_1+\mu_0} \tag{18}$$

$$P_{13}=P\{\eta_0 > \xi_1\}=\int_0^{\infty}[1-G_0(t)]dP_1(t) = \frac{\lambda_1}{\lambda_1+\mu_0} \tag{19}$$

$$P_{40}=P\{\xi_0 > \eta_1\}=\int_0^{\infty}[1-P_0(t)]dG_1(t) = \frac{\mu_1}{\lambda_0+\mu_1} \tag{20}$$

$$P_{45}=P\{\xi_0 < \eta_1\}=\int_0^{\infty}P_0(t)dG_1(t) = \frac{\lambda_0}{\lambda_0+\mu_1} \tag{21}$$

$$P_{21}=P_{34}=P_{51}=1 \tag{22}$$

Knowing the existence distribution law $T_{ij}(t)$ in the state e_i at the time of the transition to the state e_j we determine the existence distribution law $F_i(t)$ and the existence mean time T_{ei} at the state e_i as follows:

$$F_i(t)=\sum_{j=0}^{n}P_{ij}T_{ij}(t) \tag{23}$$

$$T_{ei}=\int_0^{\infty}tdF_i(t) \tag{24}$$

where :

$$T_{01}(t)=P\{\xi_0 <t/t_{encl}<t_{adm}\}=1-e^{-\lambda_0 t} \tag{25}$$

$$T_{02}(t) = 1-e^{-\lambda_0 t} \tag{26}$$

$$T_{21}(t)=P\{t_{encl}-t_{adm}<t\}=\frac{t}{t_{adm\max}-t_{adm\min}} \tag{27}$$

$$T_{10}(t)=P\{\eta_0 <t / \eta_0 < \xi_1] = 1-e^{-(\mu_0+\lambda_1)} \tag{28}$$

$$T_{13}(t)=P\{\xi_1 <t / \xi_1 < \eta_0\} = 1-e^{-(\mu_0+\lambda_1)} \tag{29}$$

$$T_{34}(t)=P\{(\eta_0 - \xi_1)< t / \eta_0 > \xi_1\} = 1-e^{-\mu_0 t} \tag{30}$$

$$T_{40}(t)=P\{\eta_1 <t/ \eta_1 < \xi_0\} = 1-e^{-(\mu_1+\lambda_0)t} \tag{31}$$

$$T_{45}(t)=P\{\xi_0 <t/ \eta_1 > \xi_0\} = 1-e^{-(\mu_1+\lambda_0)t} \tag{32}$$

$$T_{51}(t)=P\{\eta_1 <t\}=1-e^{-\mu_1 t} \tag{33}$$

The time T_{ei} at states are equal to :

$$T_{e0}=\frac{1}{\lambda_0};T_{e1}=\frac{1}{\mu_0+\lambda_1};\ T_{e2}=\ t_{encl}-\frac{t_{adm\max}+t_{adm\min}}{2}$$

$$T_{e3}=\frac{1}{\mu_0};T_{e4}=\frac{1}{\mu_1+\lambda_0};T_{e5}=\frac{1}{\mu_1} \qquad (34)$$

The stationary probabilities P_i of occupation at the state e_i can be given by solving the following system:

$$\left|\begin{array}{l} P_i=\sum\limits_{j\in e} P_{ji}.P_j \\ \sum\limits_{i=0}^{5} P_i=1 \end{array}\right. \qquad (35)$$

$$P_0=P_{10}.P_1+P_{40}.P_4 \qquad (36)$$
$$P_1=P_{01}.P_0+P_{21}.P_2+P_{51}.P_5 \qquad (37)$$
$$P_2=P_{02}.P_0 \qquad (38)$$
$$P_3=P_{13}.P_1 \qquad (39)$$
$$P_4=P_{34}.P_3 \qquad (40)$$
$$P_5=P_{45}.P_4 \qquad (41)$$
$$P_0+P_1+P_2+P_3+P_4+P_5=1 \qquad (42)$$

We determine that :

$$P_0=\frac{\mu_0(\lambda_0+\mu_1)+\mu_1\lambda_1}{(\lambda_0+\mu_1)[2(2\lambda_1+\mu_0)+q\mu_0]+q\mu_1\lambda_1}=$$
$$\frac{\mu_0(\lambda_0+\mu_1)+\mu_1\lambda_1}{K}$$
$$P_1=\frac{\mu_0(\lambda_0+\mu_1)+\mu_1\lambda_1}{K}$$
$$P_2=\frac{q[\mu_0(\lambda_0+\mu_1)+\mu_1\lambda_1]}{K}$$
$$P_3=P_4=\frac{\lambda_1(\lambda_0+\mu_1)}{K}$$
$$P_5=\frac{\lambda_0\lambda_1}{K} \qquad (43)$$

The mean time between failures (MTBF) of the EFS can be obtained as follows [5]

$$MTBF=\frac{\sum\limits_{e_n\in e+} P_{en}.T_{en}}{\sum\limits_{i\in e+,\,j\in e-} P_i.P_{ij}} \qquad (44)$$

where:

P_{en} : stationary probability at state e_n
T_{en} : average time of occupation at state e_n
e^+ : states of good functioning of system
e^- : failure's states of system.

So we determine that:

$$MTBF=\frac{(\lambda_0+\mu_1)+(\lambda_1+\mu_0)(1+\mu_1/\lambda_0)}{q[\mu_0(\lambda_0+\mu_1)+\mu_1\lambda_1]+\lambda_1(2\lambda_0+\mu_1)} \qquad (45)$$

The time of repair T_r of the E.F.S in case of failure is calculated as follows [5]:

$$T_r=\frac{\sum\limits_{e_n\in e-} P_{en}.T_{en}}{\sum\limits_{i\in e+,\,j\in e-} P_i.P_{ij}} \qquad (46)$$

We determine that:

$$T_r=\frac{q[\mu_0(\lambda_0+\mu_1)+\mu_1\lambda_1]T_{e2}+\lambda_1(\lambda_0+\mu_1)/\mu_0+\lambda_0\lambda_1/\mu_0}{q[\mu_0(\lambda_0+\mu_1)+\mu_1\lambda_1]+\lambda_1(2\lambda_0+\mu_1)} \qquad (47)$$

We notice that for q = 0, circuit breaker of interlocking the reserve source absolutely reliable and for $\lambda_0=\lambda_1=\lambda$ and $\mu_0=\mu_1=\mu$, we find the well-known formulas of the MTBF and T_r for an EFS with two sources of power supply.

$$\text{MTBF}=\frac{1}{\lambda}(1+\frac{\mu}{\lambda}) \qquad (48)$$

$$T_r=1/\mu \qquad (49)$$

Generally at the time of the exploitation of the EFS, we carry out planned repairs of the electric components of these systems. This is why the evolution of the EFS on the basis of semi-Markovian process is represented as follows Fig. 5:

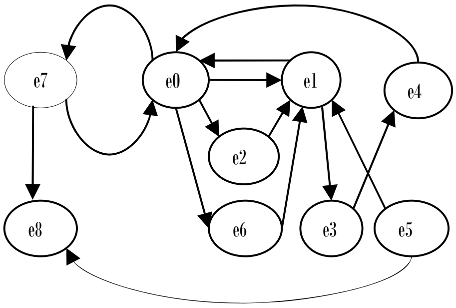


Fig. 5 Semi-Markovian Processes, graph of transitions between states, taking account of the planned repair of the elements of the EFS

e_0 : PS under operation, RS in reserve ;
e_1 :PS in repair, RS under operation ;
e_2 : PS in failure, $t_{encl} > t_{adm}$;
e_3 : PS in repair, RS in failure;
e_4 : PS under operation, RS in repair;
e_5 :PS in failure, RS in repair ;
e_6 :PS in failure, RS in planned repairs ;
e_7 : PS in planned repairs, RS under operation;

e_8 : PS in planned repairs, RS in failure.

In this case, the following assumptions are taken into account: The mean time between failures ξ_0^a of the principal source as of the source of reserve ξ_1^a follows an exponential law with the parameters λ_0^a and λ_1^a respectively. The periodicities of planned maintenance θ_0^p and θ_1^p of the principal source and the source of reserve are at constant time, $\theta_0^p = \theta_1^p$ = const.

The durations of planned maintenance T_0^p and T_1^p of the principal source and the source of reserve are regarded as known. The average time of planned repair or accidental repair of the principal source and the source of reserve follow an exponential law with the parameters μ_0^a , μ_0^p , μ_1^a , μ_1^p respectively. If one of the sources is failing during the planned maintenance of the other source, we proceed directly to an accelerated repair of the latter, the time of accelerated planned repair follows an exponential law with the parameters μ_0^{pa} , μ_1^{pa} for the principal source and the source of reserve respectively.

In this case the probabilities Pij of transition of the semi-markovian models (Fig. 5) are formulated as follows:

$$P_{01} = (1-\gamma_0)\ (1-\gamma_1)\quad (1-q) \tag{50}$$

$$P_{02} = (1-\gamma_O)\quad (1-\gamma_1)\, q \tag{51}$$

$$P_{06} = (1-\gamma_0)\,\gamma_1 \tag{52}$$

$$P_{07} = \gamma_0 \tag{53}$$

Where:

$\gamma_0 = \dfrac{T_0^p}{T_{ann}}$: Probability that the principal source is in planned repair

$\gamma_1 = \dfrac{T_1^p}{T_{ann}}$: Probability that the source of reserve is in planned repair.

$$q = p\,\{t_{encl} > t_{adm}\}$$

$$P_{10} = \frac{\mu_0^a}{\lambda_1^a + \mu_0^a} \tag{54}$$

$$P_{13} = \frac{\lambda_1^a}{\lambda_1^a + \mu_0^a} \tag{55}$$

$$P_{40} = \frac{\mu_1^a}{\lambda_0^a + \mu_1^a} \tag{56}$$

$$P_{43} = \frac{\lambda_0^a}{\lambda_0^a + \mu_1^a} \tag{57}$$

$$P_{70} = \frac{\mu_0^p}{\lambda_1^a + \mu_0^p} \tag{58}$$

$$P_{78} = \frac{\lambda_1}{\lambda_1 + \mu_0^p} \tag{59}$$

$$P_{21} = P_{34} = P_{51} = P_{61} = P_{84} = 1 \tag{60}$$

The average times of occupation at state e_i are given “refer to (24),”

We determine that :

$$T_{e0} = \frac{1}{\lambda_0^a}\,;T_{e1} = \frac{1}{\lambda_1^a + \mu_0^a}\,;T_{e2} = t_{encl} - \frac{t_{adm\max} + t_{adm\min}}{2}\,;$$
$$T_{e3} = \frac{1}{\mu_0^a}\,;\ T_{e4} = \frac{1}{\lambda_0^a + \mu_0^a}\,;\ T_{e5} = \frac{1}{\mu_1^a}\,;$$
$$T_{e6} = \frac{1}{\mu_1^{pa}}\,;T_{e7} = \frac{1}{\lambda_0^a + \mu_0^p}\,;T_{e8} = \frac{1}{\mu_0^{pa}} \tag{62}$$

The analytical resolution of system “refer to (35),” for the determination of the stationary probabilities of the Markovian semi process, becomes in this case complex, this is why and in order to calculate these probabilities, we used the software Matlab, which gave the results for the MTBF according to tadm/tencl as follows Fig. 6.

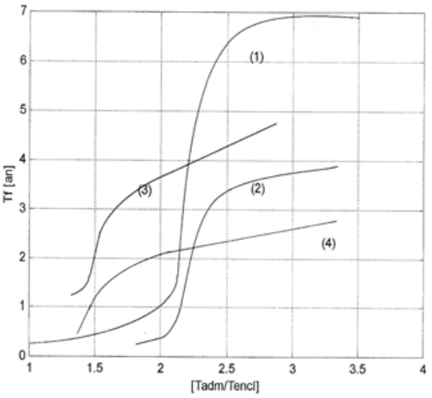


Fig. 6 Mean time between failures (MTBF) of the EFS according to t_{adm}/t_{encl}

where:

-1. T_{encl} = 3 min , λ_0^a = 0.00034 1/h

-2. T_{encl} = 3 min , λ_0^a = 0.00068 1/h;

-3. T_{encl} = 5 min, λ_0^a = 0.00034 1/h;

-4. T_{encl} = 5min, λ_0^a = 0.00068 1/h ; T_0^p = 50h; T_1^p = 150h

VI. DETERMINATION OF THE OPTIMAL PREVENTIVE MAINTENANCE OF THE RESERVE SOURCE

The principal source being under operation, its control can be ideal and sure, however for the reserve source being in stop, a preventive maintenance which proceeds on time intervals (periodicity) *Pm* and for well defined lengths of time *dm* are envisaged, so that this source will always available in case of the principal source failure. The choice of the periodicity of preventive maintenance of the source of reserve influences directly the reliability of the electric feeder system.

Under operation, the EFS can has several states, on the basis of the semi-Markovian processes [5,10,11], the evolution of the EFS operation can be described by the states and the the probability of transitions P_{ij} according to fig.7

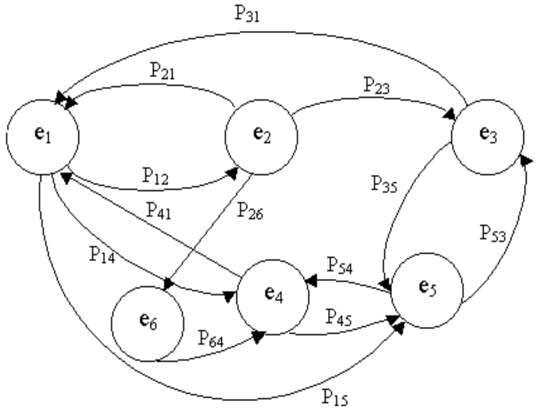


Fig. 7 Semi-Markovian process states and transitions graph

e_1 : PS under operation, RS in reserve;
e_2 : PS under operation, RS in preventive maintenance;
e_3 : PS under operation, RS in repair;
e_4 : RS under operation, PS in repair;
e_5 : PS and RS in repair;
e_6 : SR is started.
PS: principal source, RS: reserve source.

The random values of the good functioning, ξ_0, ξ_1 as well as the repair time η_0, η_1 of the principal source and reserve source respectively follow an exponential law [4] P(t) and G(t) with the parameters λ_i, μ_i (i = 0, 1). The reserve source failure rate is taken equal to $\alpha\lambda_1$ with
$0 < \alpha < 1$.

We suppose that the reserve source interlocking in the event of the principal source failure is absolutely reliable, the reserve source starting is immediate.

The transitions probability P_{ij} could be calculated as follows:

$$P_{12} = P\{\xi_0 > P_m\} = e^{-\lambda_0 P_m}$$

$$P_{14} = P\{\xi_0 < P_m\}\cdot P\{\xi_1 > P_m\} = (1-e^{-\lambda_0 P_m}).e^{-\alpha\lambda_1 P_m}$$

$$P_{15} = P\{\xi_0 < P_m\}\cdot P\{\xi_1 < P_m\} = (1-e^{-\lambda_0 P_m}).(1-e^{-\lambda_1 P_m})$$

$$P_{21} = P\{\xi_1 > P_m\}\cdot P\{\xi_0 > d_m\} = e^{-(\lambda_0 d_m + \alpha\lambda_1 P_m)}$$

$$P_{23} = P\{\xi_1 < P_m\} = (1-e^{-\alpha\lambda_1 P_m})$$

$$P_{26} = P\{\xi_1 > P_m\}\cdot P\{\xi_0 < d_m\} = e^{-\alpha\lambda_1 P_m}(1-e^{-\lambda_0 d_m})$$

$$P_{31} = P\{\xi_0 > \eta_1\} = \int_0^\infty [1-P_0(t)]dG_1(t) = \frac{\mu_1}{\lambda_0+\mu_1}$$

$$P_{35} = P\{\xi_0 < \eta_1\} = \int_0^\infty P_0(t)dG_1(t) = \frac{\lambda_0}{\lambda_0+\mu_1}$$

$$P_{41} = P\{\eta_0 < \xi_1\} = \int_0^\infty G_0(t)dP_1(t) = \frac{\mu_0}{\mu_0+\alpha\lambda_1}$$

$$P_{45} = P\{\eta_0 > \xi_1\} = \int_0^\infty [1-G_0(t)]dP_1(t) = \frac{\alpha\lambda_1}{\mu_0+\alpha\lambda_1}$$

$$P_{53} = P\{\eta_0 < \eta_1\} = \int_0^\infty G_0(t)dG_1(t) = \frac{\mu_0}{\mu_0+\mu_1}$$

$$P_{54} = P\{\eta_1 < \eta_0\} = \int_0^\infty G_1(t)dG_0(t) = \frac{\mu_1}{\mu_0+\mu_1}$$

$$P_{64} = 1 \tag{63}$$

where:

P_m : periodicity of preventive maintenance of the source of reserve;
d_m : time duration of the preventive maintenance;
P : probability;
λ_0, λ_1: failure rate of the principal and reserve source respectively;
μ_0, μ_1, repair rate of the principal and reserve source respectively,
ξ_0, ξ_1 : random time of good functioning of the principal and reserve source respectively,
η_0, η_1: repair random time of the principal and reserve source respectively,
P_0 (t) , P_1 (t) : failure law distribution of the principal and reserve source respectively,
G_0 (t) , G_1 (t) : repair law distribution of the principal and reserve source respectively.

The average time T_{ei} of occupation at state e_i could be calculated as follows :

$$T_{e_1} = E\min\{\xi_0, P_m\} = \int_0^{P_m}[1-P_0(t)]dt = \frac{1-e^{-\lambda_0 P_m}}{\lambda_0} \tag{64}$$

$$T_{e_2} = E\min\{\xi_0, d_m\} = \int_0^{d_m}[1-P_0(t)]dt = \frac{1-e^{-\lambda_0 d_m}}{\lambda_0} \tag{65}$$

$T_{e_6} = 0$ (the reserve source starting is immediate. (66)

where:

E: expected valued.

For the other states, knowing the existence distribution law $T_{ij}(t)$ in the state e_i at the time of the transition to the state e_j, we determine the law of distribution $F_i(t)$ and the existence mean time at the state e_i, T_{ei} as follows*:*

$$F_i(t) = \sum_{j=0}^{n} P_{ij} T_{ij}(t) \tag{67}$$

$$T_{e_i} = \int_0^\infty t dF_i(t) \tag{68}$$

where:

$$T_{31}(t) = P\{\eta_1 < t / \eta_1 < \xi_0\} = 1 - e^{-(\mu_1 + \lambda_0)t} \tag{69}$$

$$T_{35}(t) = P\{\xi_0 < t / \eta_1 > \xi_0\} = 1 - e^{-(\mu_1 + \lambda_0)t} \tag{70}$$

$$T_{41}(t) = P\{\eta_0 < t / \eta_0 < \xi_1\} = 1 - e^{-(\mu_0 + \alpha\lambda_1)t} \tag{71}$$

$$T_{45}(t) = P\{\xi_1 < t / \eta_0 > \xi_1\} = 1 - e^{-(\mu_0 + \alpha\lambda_1)t} \tag{72}$$

$$T_{53}(t) = P\{\eta_0 < t / \eta_0 < \eta_1\} = 1 - e^{-(\mu_0 + \mu_1)t} \tag{73}$$

$$T_{54}(t) = P\{\eta_1 < t / \eta_1 < \eta_0\} = 1 - e^{-(\mu_0 + \mu_1)t} \tag{75}$$

We determine that:

$$T_{e3} = \frac{1}{\mu_1 + \lambda_0}, \quad T_{e4} = \frac{1}{\mu_1 + \alpha\lambda_1}, \quad T_{e5} = \frac{1}{\mu_1 + \mu_0} \tag{76}$$

The stationary probabilities P_i of occupation at the state e_i can be given by solving the equations system according to:

$$\left| \begin{array}{l} P_i = \sum_{j \in e} P_{ij} . P_j \\ \sum_{1}^{6} P_i = 1 \end{array} \right.$$

$$P_1 = P_{21} . P_2 + P_{31} . P_3 + P_{41} . P_4$$
$$P_2 = P_{12} . P_1$$
$$P_3 = P_{23} . P_2 + P_{53} . P_5$$
$$P_4 = P_{14} . P_1 + P_{54} . P_5 + P_{64} . P_6$$
$$P_5 = P_{15} . P_1 + P_{35} . P_3 + P_{45} . P_4$$
$$P_6 = P_{26} . P_2$$

The mean time between failures system (EFS) can be obtained as follows:

$$T_f = \frac{\sum_{e_n \in e^+} P_{e_n} . T_{e_n}}{\sum_{i \in e^+, j \in e^-} P_i . P_{ij}}$$

where :

P_{en} : stationnary probability at state e_n ;
T_{en} : average time of occupation at state e_n;
e^+ : states of good functionning of system;
e^- : failure's states of system.

The mean time between failures variation curve obtained according to the ratio P_m/d_m is as follows Fig.8):
$d_m = 8$ h.

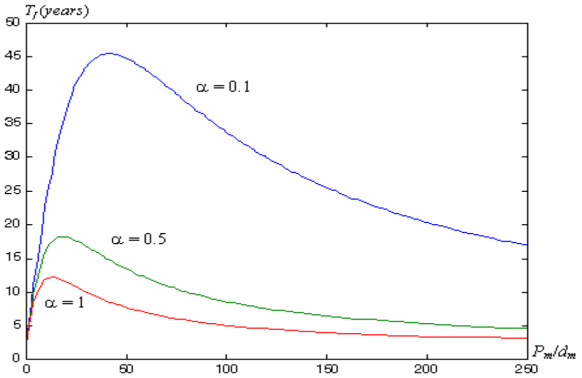


Fig. 8 mean time between failures variation according to ration *Pm/dm.*

VII. CONCLUSION

The analysis of resulted obtained allows establishing the following conclusions:

The parameters of reliability of the EFS influence particularly over the mean time between failures of the EFS. The influence over the mean repair time is practically negligible what is explained by the high values of the failure rates of the two sources of power supply. The principal parameters of reliability of the influential EFS over the mean time between failures are the failure rate of the principal source and the tadm/tencl report/ratio. Not to take into account, the frequency and the duration of planned repairs of the sources involves an increase in the mean time between failures of the EFS going of 1.5 to 2 times. The influence of the report/ratio tadm/tencl over the mean time between failures of the EFS is appreciable. As example, for tencl = 3 min, λ_0^a = 0.00068 1/h and tadm/tencl = 2.2, the mean time between failures is equal Tf = 1 year (Fig. 6, curve. 2). In order to increase Tf by two time it is necessary to decrease by two time the failure rate of the principal source (curve.1) or to increase the ratio by 2.2 to 2.4, the practice of exploitation of the RAE showed that the increase in this report/ratio can be obtained easily and with a negligible cost. The optimal interval of the report/ratio for an appreciable increase in the time of correct operation of the EFS ranges between 1.5 and 3.

An optimal periodicity of preventive maintenance of the reserve source has been found which corresponds to the maximum time between failures of the system**.**

An optimal periodicity of preventive maintenance of the source of reserve can be explained as follows:
a great periodicity of preventive maintenance of the source of reserve has a consequence a great probability of having a failure of this source so we have a reduction in the mean time between failures, for a weak periodicity the probability to have a failure of the principal source during a preventive

maintenance of the source of reserve is significant so we have a reduction of the mean time between failures of the system.

ACKNOWLEDGMENT

Our thanks go for the department of distribution of the electric power of Boumerdes and Algiers (sonelgaz) for their assistance, in particular on the statistical data of failures of the electric components.

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Open Science Index, Electrical and Computer Engineering Vol:1, No:3, 2007 publications.waset.org/7438.pdf