Optimization of the Structures of the Electric Feeder Systems of the Oil Pumping Plants in Algeria

M. Bouguerra, F. Laaouad, I. Habi, and R. Azaizia

Abstract**—**In Algeria, now, the oil pumping plants are fed with electric power by independent local sources. This type of feeding has many advantages (little climatic influence, independent operation). However it requires a qualified maintenance staff, a rather high frequency of maintenance and repair and additional fuel costs. Taking into account the increasing development of the national electric supply network (Sonelgaz), a real possibility of transfer of the local sources towards centralized sources appears.These latter cannot only be more economic but more reliable than the independent local sources as well. In order to carry out this transfer, it is necessary to work out an optimal strategy to rebuilding these networks taking in account the economic parameters and the indices of reliability.

Keywords**—**Optimization, reliability, electric network.

I. Introduction

THE reliability problem's has always been one of the major concerns of electricians and manufactures for design and electric feeder systems (E.F.S.) exploitation of the industrial facilities. This problem is of fundamental importance in the E.F.S of the oil pumping plants (O.P.P.) in Algeria where oil industry has always played a determining role in its economic balance and will in future.

Now, the O.P.P. are fed with electric power by independent local sources. This type of feeding has many advantages (little climatic influence, independent operation). However, it requires a qualified maintenance staff, a rather high frequency of maintenance and repair and additional fuel costs.

Taking into account the increasing development of the national electric supply network (Sonelgaz), a real possibility of transfer of the local sources towards centralized sources appears. These latter cannot only be more economic but more reliable than the independent local sources as well.

In order to carry out this transfer, it is necessary to work out an optimal strategy to rebuilding these networks taking account of the economic parameters and the indices of reliability.

According to the criterion of the reliability required of the E.F.S, the electric installations are classified into three categories [1]:

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- First category: theses installations don't admit any stop (accidental or planned) of their E.F.S., the stop of the latter can has the human death consequence; this is why their E.F.S. must be carried out with two independent sources.
- Second category: theses installations don't admit any stop (accidental or planned) of their E.F.S., the stop of the latter can has a significant economic consequence, and this is why their E.F.S. must be carried out with two independent sources.
- Third category : these installations don't has a capital insert in the technological process, they can admit a stop (accidental or planned) of their E.F.S. going up to 24 hours; this E.F.S. is carried out with only one source.

The oil pumping plants belong to the second category. In order to ensure a high level of reliability of their E.F.S, two power supply sources are envisaged, one principal, the other of reserve.

II. Suggested Alternative for the E.F.S. of O.P.P.

The suggested alternative for the E.F.S. of the O.P.P. can be schematized as follows (Fig. 1):

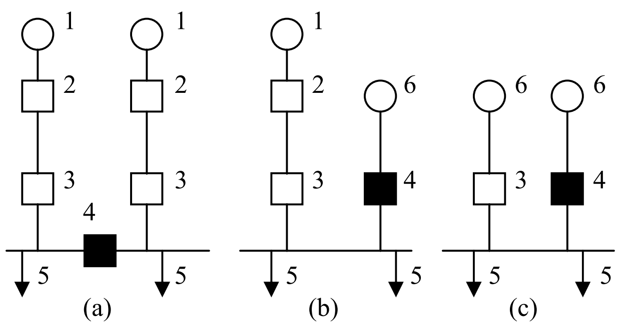


Fig. 1 Standard digram of the E.F.S. structures of O.P..P.

- 1.external source from the national electric network
- 2. circuit breaker of electric line
- 3. transformers and circuit breaker
- 4. coupling circuit breaker
- 5. electric load
- 6. local source.

III. Mathematical Formulation

It is known that the reliability of the E.F.S of the industrial installations is linked to the exploitation of the capital costs of these networks, the increase in reliability involves a reduction in the costs of unavaibility of the E.F.S costs more [2], this is why the criterion of the optimal structures of the the E.F.S. of O.P.P. could be formulated as follows [3]:

$$C_T = C_{T1} + CT_{unav} \longrightarrow min \quad (1)$$

$$C_{T1} = C_{cap} + C_{exp} \quad (2)$$

$$C_{exp} = C_{fe} + C_{losses} \quad (3)$$

Where :

C_T : yearly total cost;
C_{cap} : capital cost including the costs of the network and the stations;
C_{exp} : cost of exploitation;
C_{fe} : cost of the electric invoice of power or fuel, this cost is formulated as follows [3]:

$$C_{fe} = C'_T \, . \, h'_T \, .B' \, . \, P' + C''_T \, . \, h''_T \, . \, B'' \, P'' \quad (4)$$

C'_T ,C''_T :cost of fuel of the local and centralized sources ($/T)
h'_T , h''_T :annual time of use of the installations (h/years);
B', B'' :annual average fuel consumption per Kwh (T/kWh);
P', P" : annual average power (kW).

C_{losses}: losses of electric power in the lines, this cost is obtained as follows:

$$C_{losses} = \sum_{i \in M_{exist}} \frac{Co\,.Ti\,.Ri}{U_i^2 \cos \alpha_i^2} P_i^2 + \sum_{j \in Mnov} \frac{Co\,.Tj\,.Rj}{U_j^2 \cos \alpha_j^2} P_j^2 \quad (5)$$

Co: cost per unit of kWh of the losses of power electric ($/kWh);
T : time of losses of power electric (h);
R : active resistance of lines (Ω);
U : voltage level of the electric network (kV);
P : active power transmitted (kW);
Mexist, M_{nov} : existing and lately build electric installations
Cos α : power factor.

CT_{unav}:cost of unavailability of the E.F.S. in case of failure ($)

The cost of unavailability of the E.F.S. of the O.P.P. is formulated as follows:

$$C_{unav} = W_o . T_r \, . \, \delta_o \quad (6)$$

Where:

$$\delta_o = g(C_g - C_p - C_t) \quad (7)$$

W_o : frequency of stop of the oil pumps ;
T_r : time of repair of the E.F.S. in case of failure;
g : reduction in the volume of oil transported at the time of stop of the O.P.P.;
C_g , C_p , C_t : cost of oil to export, cost of its production, cost of its transport respectively.

The frequency of stop of the oil pumps W_o and the time of repair T_r of the E.F.S. in case of failure can be obtained on the basis of the semi- Markovian's processes [4].

The structures of the E.F.S. (Fig.1) can be schematized with their reliability parameters as follows (Fig.2).

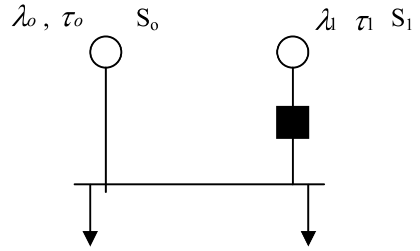
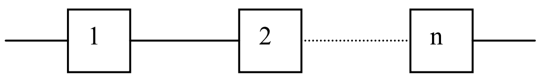


Fig. 2 Representative sources diagram

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.

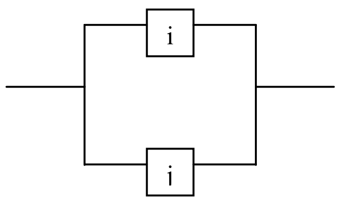
The failure rate and the time of repair of the elements in series are given as follows:



$$\lambda = \sum_{i=1}^{n} \lambda_i \quad (8)$$

$$\tau = \frac{\sum_{i=1}^{n} \lambda_i \tau_i}{\sum_{i=1}^{n} \lambda_i} \quad (9)$$

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



$$\lambda_{ij} = \lambda_i \ \lambda_j \ (\tau_i + \tau_j) \tag{10}$$

$$\tau_{ij} \ = \ \frac{\tau_i . \tau_j}{\tau_i + \tau_j} \tag{11}$$

Under operation, the E.F.S. of the O.P.P. can has several states, on the basis of the semi-Markovian's processes, the evolution of the E.F.S. operation can be described by the states and the probability of transition P_{ij} according Fig. 3.

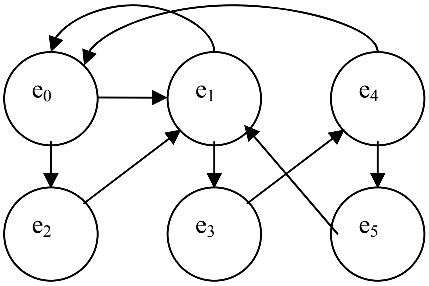


Fig. 3 Semi-Markovian's processes and transitions graph

e_o : 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 [5] , 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 follow:

$$P_{01}=1-q \tag{12}$$

$$P_{02} = q \tag{13}$$

q: probability of failure of the circuit breaker of interlocking the reserve source [6].

$$q=P(t_{encl}>t_{adm})=1-F_{encl}(t_{adm}) \tag{14}$$

For t_{encl} *= const and D(t) =P(*t_{adm} *< t) =* $\frac{t - t_{adm\min}}{t_{adm\max} - t_{adm\min}}$ (15)

$$q = \int_0^\infty [1 - F_{encl}(t)] dD(t) = \frac{t_{encl} - t_{adm\min}}{t_{adm\max} - t_{adm\min}} \tag{16}$$

where:

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

$$P_{10}=P\{ \eta_0 < \xi_1 \}= \int_0^\infty G_0(t) dP_1(t) = \frac{\mu_0}{\lambda_1 + \mu_0} \tag{17}$$

$$P_{13}=P\{ \eta_0 > \xi_1 \}= \int_0^\infty [1 - G_0(t)] dP_1(t) = \frac{\lambda_1}{\lambda_1 + \mu_0} \tag{18}$$

$$P_{40}=P\{ \xi_0 > \eta_1 \} = \int_0^\infty [1 - P_0(t)] dG_1(t) = \frac{\mu_1}{\lambda_0 + \mu_1} \tag{19}$$

$$P_{45}=P\{ \xi_0 < \eta_1 \}= \int_0^\infty P_0(t) dG_1(t) = \frac{\lambda_0}{\lambda_0 + \mu_1} \tag{20}$$

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

Knowing the existance 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:

$$F_i(t)= \sum_{j=0}^{n} P_{ij} T_{ij}(t) \tag{22}$$

$$T_{ei}= \int_0^\infty t dF_i(t) \tag{23}$$

Where :

$$T_{01}(t)= P\{ \xi_0 < t \,/\, t_{encl}< t_{adm} \} = 1 - e^{-\lambda_0 t} \tag{24}$$

$$T_{02} (t) \ = 1 - e^{-\lambda_0 t} \tag{25}$$

$$T_{21}(t)=P\{t_{encl}-t_{adm}<t\}= \frac{t}{t_{adm\max} - t_{adm\min}} \tag{26}$$

$$T_{10} \ (t)=P\{ \eta_0 < t \ / \ \eta_0 < \xi_1] = 1 - e^{-(\mu_0 + \lambda_1)} \tag{27}$$

$$T_{13} \ (t)=P\{ \xi_1 < t \ / \ \xi_1 < \eta_0 \} = 1 - e^{-(\mu_0 + \lambda_1)} \tag{28}$$

$$T_{34} (t)=P\{(\eta_0 - \xi_1) < t \,/\, \eta_0 > \xi_1 \} = 1 - e^{-\mu_0 t} \tag{29}$$

$$T_{40}(t)=P\{ \eta_1 < t \ / \ \eta_1 < \xi_0 \} = 1- e^{-(\mu_1 + \lambda_0) t} \tag{30}$$

$$T_{45}(t)=P\{ \xi_0 < t \ / \ \eta_1 > \xi_0 \} = 1- e^{-(\mu_1 + \lambda_0) t} \tag{31}$$

$$T_{51}(t)=P\{ \eta_1 <t\} = 1- e^{-\mu_1 t} \tag{32}$$

We determine that:

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

$$T_{e3}=\frac{1}{\mu_0}\ ;T_{e4}=\frac{1}{\mu_1+\lambda_0}\ ;\ T_{e5} = \frac{1}{\mu_1} \quad (33)$$

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

$$\left|\begin{array}{l} P_i = \sum_{j\in e} P_{ji}.P_j \\ \sum_{i=0}^{5} P_i=1 \end{array}\right. \quad (34)$$

$P_0=P_{10}.P_1+P_{40}.P_4$ (35)
$P_1=P_{01}.P_0+P_{21}.P_2+P_{51}.\ P_5$ (36)
$P_2=P_{02}.P_0$ (37)
$P_3=P_{13}.P_1$ (38)
$P_4=P_{34}.P_3$ (39)
$P_5=P_{45}.P_4$ (40)
$P_0+P_1+P_2+ P_3 + P_4 + P_5 =1$ (41)

We determine that:

$$P_0=\frac{\mu_0(\lambda_0+\mu_1)+\mu_1\lambda_1}{(\lambda_0+\mu_1)[2(2\lambda_1+\mu_0)+q\mu_0]+q\mu_1\lambda_1}=\frac{\mu_0(\lambda_0+\mu_1)+\mu_1\lambda_1}{K}$$

$$P_1 = \frac{\mu_0(\lambda_0+\mu_1)+\mu_1\lambda_1}{K}$$

$$P_2 = \frac{q[\mu_0(\lambda_0+\mu_1)+\mu_1\lambda_1]}{K}$$

$$P_3 =P_4 = \frac{\lambda_1(\lambda_0+\mu_1)}{K}$$

$$P_5=\frac{\lambda_0\lambda_1}{K} \quad (42)$$

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

$$MTBF=\frac{\sum_{e_n\in e+} P_{e_n}.T_{e_n}}{\sum_{i\in e+,\,j\in e-} P_i.P_{ij}} \quad (43)$$

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

$$\text{MTBF}=\frac{(\lambda_0+\mu_1)+(\lambda_1+\mu_0)(1+\mu_1/\lambda_0)}{q[\mu_0(\lambda_0+\mu_1)+\mu_1\lambda_1]+\lambda_1(2\lambda_0+\mu_1)} \quad (44)$$

So the frequency of stop of the oil pumps W_0, Refer to "(6)," can be calculated as follows :

$$W_0=\frac{1}{MTBF} \quad (45)$$

The time of repair T_r Refer to "(6)," of the E.F.S in case of failure is calculated as follows:

$$T_r=\frac{\sum_{e_n\in e-} P_{e_n}.T_{e_n}}{\sum_{i\in e+,\,j\in e-} P_i.P_{ij}} \quad (46)$$

We determine that:

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

The cost of unavailability of the E.F.S. of the O.P.P. varies according to choise of the principal source and the source of reserve Fig. 4.

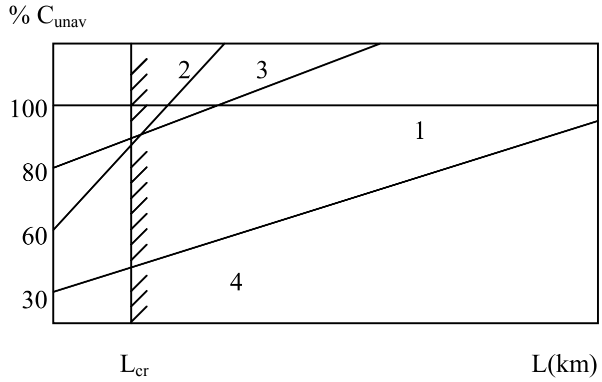


Fig. 4 C_{unav} Functions of the choise of the principal source and the reserve source and the length of feeders

- 1. both sources are autonomous;
- 2. the main source is a line, the source of reserve is autonomous;
- 3. The autonomous source is principal, the line is the reserve source;
- 4. the two sources are external lines.

L_{cr} : the length criticized of the line for a selected level of voltage.

IV. Calculation Algorithm of the Optimal Alternative

The E.F.S. of the O.P.P. are represented on the basis of general principle of the graph theory [7], where the whole of the O.P.P. and the sources of electric energy represents the nodes a_1, a_2, …,a_n connected to each other by bonds, the mutual geographical place between the sources and O.P.P are defined by the co-ordinates of the nodes (x, y), (Fig. 5), G{(x_1,y_1), (x_2,y_2),…..(x_n,y_n)}.

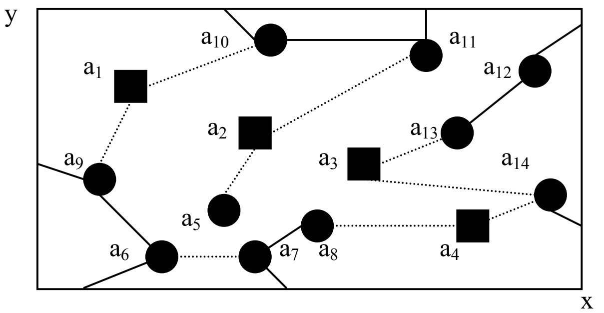


Fig. 5 Chart of the E.F.S. and the O.P.P.

a_1, a_2, a_3, a_4 : oil pumpings plants;
a_5, a_6,…., a_{14} : external sources or autonomous;
----------------: lately built lines;
———— : already existing lines.

The complete representation of the graph (Fig. 5.) is definited algebraically using the matrix A_{ij} (Fig. 6.) which is formulated as follows:

$$A_{ij} = \begin{cases} -1 \text{ if } (a_i, a_j) \text{ nodes bound by existing line} \\ 0 \\ 1 \text{ if if } (a_i, a_j) \text{ nodes bound by new line} \end{cases} \qquad (48)$$

	a_5	a_6	a_7	a_8	a_9	a_{11}
a_1	0	1	1	0	0	0
a_2	-1	0	0	1	0	0
a_3	0	0	-1	0	1	0
a_4	0	-1	-1	0	0	0

Fig. 6 A_{ij} matrix defining the structure of the diagrams of the E.F.S. of the O.P.P.

On the basis of matrix A_{ij} defining completely the structure of the diagrams of power supply of the O.P.P., it easy to determine the length of the feeder L_{ij}:

$$L_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \qquad (49)$$

During the presence in the E.F.S. of a j^{-rd} O.P.P. an autonomous source i^{-rd}, the length of the line is equal zero same if the j^{-rd} and i^{-rd} nodes are bound i.e. A_{ij} =1, L_{ij} =0.

The calculation of costs C_{T1} will thus carrying out as follows:

If A_{ij} = 1 and L_{ij} # 0, so the calculation costs C_{T1} is for the external source of the network, if A_{ij} = 1 and L_{ij} = 0 then the calculation of the C_{T1} is determined for the autonomous sources, in this case the losses of electric power are null, if A_{ij} = -1 and L_{ij} # 0 the calculation of the costs C_{T1} is made or the already existing lines, this cost includes only the losses of electric power.

When considering that the cost of the unavaibility depends on the structure's alternative of the E.F.S. of the O.P.P.,(Fig. 1), it is necessary to determine the type of the structure's alternative chosen, that can be possible thanks to matrix A_{ij} and the N(i) operator, who fixes the number and the type of the source (Table I).

TABLE I
MATRIX A_{IJ} AND THE N(I) OPERATOR

1 s/system	2 s/system	N(i)	sources
A_{ij} =1, L_{ij} # 0	A_{ij} = 1, L_{ij} # 0	2	2 externales sources
A_{ij} = 1, L_{ij} = 0	A_{ij} = 1, L_{ij} # 0	1	1 line and 1 autonomous source
A_{ij} = 1, L_{ij} = 0	A_{ij} = 1, L_{ij} = 0	0	2 autonomous sources

If N(i) = 2, the cost of unavailability is calculated for the structure's alternative (Fig. 1a.).
If N(i) = 1, the cost of unavailability is calculated for the structure's alternative (Fig. 1b.).
If N(i) = 0, the cost of unavailability is calculated for the structure's alternative (Fig. 1c.).

During calculation, it is necessary to take into account the following technical contraints:

1. the number of sources is limited to two.
2. The sources where the O.P.P. are dependent must have a sufficient power.
3. The length of lines should not exceed the length critized L_{cr} for a selected level of voltage.

V. CONCLUSION

The method presented makes it possible to determine the optimal structure's alternative of the E.F.S. of the O.P.P. taken in a single system (technological process and electric feeder system). This method doesn't take into account economic parameters but the indices of reliability as well.

In this context, a data-processing program was elaborate to offer best alternative of the electric feeder systems of the oil pumping plants. This program has been approved by the national company of oil and gas (Sonatrach) in Algeria.

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