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

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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 manufacturers 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]:

- First category: these 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: these 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 diagram 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 unavailability 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]:

\[
C_T = C_{T1} + CT_{unav} \quad \text{min} \quad (1)
\]
\[
C_{T1} = C_{cap} + C_{exp} \quad (2)
\]
\[
C_{exp} = C_{fe} + C_{losses} \quad (3)
\]

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]:

\[
C_{fe} = C'_T \cdot h'_T \cdot B' \cdot P' + C''_T \cdot h''_T \cdot B'' \cdot P'' \quad (4)
\]

\(C'_T, C''_T\) : 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:

\[
C_{losses} = \sum_{i \in M_{exist}} \frac{C_o \cdot T_i \cdot R_i \cdot \alpha_i}{U_i \cdot \cos \alpha_i} \cdot P_i^2 + \sum_{j \in M_{new}} \frac{C_o \cdot T_j \cdot R_j \cdot \alpha_j}{U_j \cdot \cos \alpha_j} \cdot P_j^2 \quad (5)
\]

\(C_o\) : 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 (\(\Omega\));
\(U\) : voltage level of the electric network (kV);
\(P\) : active power transmitted (kW);
Mexist, Mnew: existing and lately build electric installations
\(\cos \alpha\) : 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:

\[
C_{unav} = W_o \cdot T_r \cdot \delta_o \quad (6)
\]

Where:

\(W_o\) : 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).

\[
\lambda_o, \tau_o \quad S_o \quad \lambda_i, \tau_i \quad S_i
\]

\(S_o\) : principal source;
\(S_i\) : reserve source;
\(\lambda_o, \tau_o\) : principal source failure rate and time of repair respectively;
\(\lambda_i, \tau_i\) : reserve source failure rate and time of repair respectively.

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

\[
\lambda = \sum_{i=1}^{n} \lambda_i \quad (8)
\]
\[
\tau = \frac{\sum_{i=1}^{n} \lambda_i \cdot \tau_i}{\sum_{i=1}^{n} \lambda_i} \quad (9)
\]

The failure rate and the time of repair of the elements in parallels are given as follows:
\[ \lambda_{ij} = \lambda_i \lambda_j \left( \tau_i + \tau_j \right) \]  
(10)

\[ \tau_{ij} = \frac{\tau_i \tau_j}{\tau_i + \tau_j} \]  
(11)

Under operation, the E.F.S. of the O.P.P. can have 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](image)

e0: PS under operation, RS in reserve;
e1: PS in repair, RS under operation;
e2: PS in failure, \( t_{encl} > t_{adm} \);
e3: PS in repair, RS in failure;
e4: PS under operation, RS in repair;
e5: 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) \( \xi_0, \xi_1 \) as well the repair time \( \eta_0, \eta_1 \) of the principal source and the reserve source respectively follow an exponential law \([5]\), \( P_i(t), G_i(t) \) with the parameters \( \lambda_i, \mu_i \) \( (i = 0, 1) \).

The calculation probability \( P_{ij} \) of transitions between states could be calculated as follow:

\[ P_{01} = 1 - q \]  
(12)

\[ P_{02} = q \]  
(13)

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

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

For \( t_{encl} = \text{const} \) and \( D(t) = P(t_{adm} < t) = \frac{t - t_{adm}}{t_{adm} - t_{adm}} \)  
(15)

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

where:

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

\[ P_{01} = P(\eta_0 < t / t_{encl} < t_{adm}) = 1 - e^{-\lambda_0 t} \]  
(17)

\[ P_{02} = P(\eta_0 > \xi_1) = \int_0^{\infty} [1 - G_1(t)] dP(t) = \frac{\lambda_1}{\lambda_1 + \mu_0} \]  
(18)

\[ P_{03} = P(\eta_1 > \xi_0) = \int_0^{\infty} [1 - G_0(t)] dP(t) = \frac{\lambda_0}{\lambda_0 + \mu_1} \]  
(19)

\[ P_{04} = P(\xi_0 < t / \eta_0 < \xi_1) = \int_0^{\infty} P(t)dG_1(t) = \frac{\lambda_0}{\lambda_0 + \mu_1} \]  
(20)

\[ P_{21} = P_{34} = P_{51} = 1 \]  
(21)

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:

\[ F_i(t) = \sum_{j=0}^{\infty} P_{ij} T_{ij}(t) \]  
(22)

\[ T_{ei} = \int_0^{\infty} t dF_i(t) \]  
(23)

Where:

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

\[ T_{02}(t) = 1 - e^{-\lambda_0 t} \]  
(25)

\[ T_{21}(t) = P(t_{encl} - t_{adm} < t) = \frac{t}{t_{adm} - t_{adm}} \]  
(26)

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

\[ T_{13}(t) = P(\xi_1 < t / \xi_1 < \eta_0) = 1 - e^{-\mu_1 t} \]  
(28)

\[ T_{34}(t) = P(\xi_0 < t / \eta_0 < \xi_1) = 1 - e^{-\mu_1 t} \]  
(29)

\[ T_{0d}(t) = P(\eta_0 < t / \eta_0 < \xi_0) = 1 - e^{-\lambda_0 t} \]  
(30)

\[ T_{e5}(t) = P(\xi_0 < t / \eta_0 < \xi_0) = 1 - e^{-\lambda_0 t} \]  
(31)

\[ T_{51}(t) = P(\eta_0 < t) = 1 - e^{-\lambda_0 t} \]  
(32)

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

$$P_i = \sum_j P_{ij}P_j$$

$$\sum_{i=0}^{5} P_i = 1$$

$$P_0 = P_{01}P_1 + P_{02}P_2 + P_{03}P_3 + P_{04}P_4 + P_{05}P_5$$

$$P_1 = P_{10}P_0 + P_{12}P_2 + P_{13}P_3 + P_{14}P_4$$

$$P_2 = P_{20}P_0$$

$$P_3 = P_{31}P_1$$

$$P_4 = P_{34}P_3$$

$$P_5 = P_{45}P_4$$

$$P_0 + P_1 + P_2 + P_3 + P_4 + P_5 = 1$$

We determine that:

$$P_0 = \frac{q_0}{K}$$

$$P_1 = \frac{q_1}{K}$$

$$P_2 = \frac{q_2}{K}$$

$$P_3 = \frac{q_3}{K}$$

$$P_4 = \frac{q_4}{K}$$

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

$$MTBF = \sum_{i\in e+,j\in e-} P_{ij}T_{ej}$$

where:

$P_{ij}$: stationary probability at state $e_i$

$T_{ej}$: average time of occupation at state $e_i$

$e+$: states of good functioning of system

$e-$: failure’s states of system

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

$$T_r = \sum_{i\in e+,j\in e-} P_{ij}T_{ej}$$

So we determine that

$$MTBF = \frac{K}{q_0q_1q_2q_3q_4}$$

We determine that:

$$K = q_0q_1q_2q_3q_4$$

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

$\% C_{unav}$

Fig. 4 $C_{unav}$ Functions of the choice 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 critizized 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 $a_1, a_2, \ldots, a_n$ 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), $G\{(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)\}$.

$$W_0 = \frac{1}{MTBF}$$

$$T_r = \frac{q_0q_1q_2q_3q_4}{K}$$
The complete representation of the graph (Fig. 5.) is defined algebraically using the matrix \( A_{ij} \) (Fig. 6.) which is formulated as follows:

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

The length of lines should not exceed the length critized \( L_{ij} \) for a selected level of voltage.

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 \( L_{ij} \):

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

During the presence in the E.F.S. of a j\(^{\text{th}}\) O.P.P. an autonomous source i\(^{\text{th}}\), the length of the line is equal zero same if the j\(^{\text{th}}\) and i\(^{\text{th}}\) 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 \( L_{ij} \neq 0 \), 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 \( L_{ij} \neq 0 \) 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 unavailability 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

<table>
<thead>
<tr>
<th>( A_{ij} ) and the N(i) Operator</th>
<th>1 s/system</th>
<th>2 s/system</th>
<th>N(i)</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A_{ij} = 1, L_{ij} \neq 0 )</td>
<td>( A_{ij} = 1, L_{ij} \neq 0 )</td>
<td>2</td>
<td>2 externes sources</td>
<td></td>
</tr>
<tr>
<td>( A_{ij} = 1, L_{ij} = 0 )</td>
<td>( A_{ij} = 1, L_{ij} \neq 0 )</td>
<td>1</td>
<td>1 line and 1 autonomous sources</td>
<td></td>
</tr>
<tr>
<td>( A_{ij} = 1, L_{ij} = 0 )</td>
<td>( A_{ij} = 1, L_{ij} = 0 )</td>
<td>0</td>
<td>2 autonomous sources</td>
<td></td>
</tr>
</tbody>
</table>

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

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 \( L_{ij} \) 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.

### References