MEĐUNARODNO REGIONALNO SAVETOVANJE O ELEKTRODISTRIBUTIVNIM MREŽAMA

REGIONAL CONFERENCE AND EXHIBITION ON ELECTRICITY DISTRIBUTION

Crna Gora, Herceg Novi, 5 - 8. oktobar 2004. / ***Montenegro, Herceg Novi, October 5 - 8, 2004***

EFFICIENCY ANALYSIS OF ELECTRIC POWER DISTRIBUTION SUBSTATIONS MODERNIZATION

I. FELEA[1], University of Oradea, Romania
N. COROIU[2], S.D. Oradea, Romania
D.C. SECUI[3], University of Oradea, Romania
I. BOJA[4], S.D. Oradea, Romania

Abstract: *Substations modernization actions means the ensemble of the operation performed for replacing the moral and/or physical wearing out equipments with new equipments having higher performances.*

An important number of distribution power substations (consumption) from Romania are now subject of modernization actions.

The paper has three parts. First part refers to actual state of distribution power substations and modernization trends of them.

The second part presents an evaluation model for the modernization actions. The used indicators for the efficiency analyze are: the investment recovering time, the actualized net income and the profitability index. The expenditure elements are: investments, operation expenditures and the relative damage related to undelivered energy. A important part of the paper content is dedicate for the evaluation of the safety indicators and failure indicators for the actual and modernized state of distribution power substations.

The third part presents the result of the care study, referred to the distribution power substations of SDFEE Oradea.

1. THE STATE OF POWER DISTRIBUTION SUBSTATIONS AND MODERNIZATION TRENDS

Distribution power substations (DPS) are very important subsystems of the electric power distribution systems.

DPS technical state analysis refers mainly to two aspects: technical state of the construction side and also technical state of the electrical equipment of DPS.

Specific DPS constructions (buildings, poles, gear support etc.) situation at Oradea Electric Distribution and Supply Subsidiary (SDFEE Oradea) is the same as in whole Romania and can be characterized as it follows:

- They have mostly over 30 years lifetime, so they are in advanced stage of depreciation;

[1] *University of Oradea, Armatei Romane street, 5, e-mail ifelea@uoradea.ro*
[2] *Electricity Distribution and Supply, Electrica Transilvania Nord, Oradea, e-mail: sdoradea@eldior.ro*
[3] *University of Oradea, str. Armatei Române nr. 5, e-mail: csecui @uoradea.ro*
[4] *Electricity Distribution and Supply, Electrica Transilvania Nord, Oradea, e-mail: sdoradea@eldior.ro*

- They are permanently subject of maintenance processes, thus to avoid the faults;
- There are preoccupations of technical and aesthetic modernization of the DPS buildings, just partially accomplished because the lack of funds.

The intended future works for the DPS constructions are:

- The rehabilitation of DPS centrifugation elements by means of hydro-insulation;
- The joint rehabilitation between poles and rules;
- Works designated to personal security and equipments protection.

The DPS electrical equipments state is very important for performance level of a distribution and supply activity, so representing its permanent preoccupation. After 1990, DPS of Romania were subject of a continuous modernization process. We give an example for SDFEE Oradea, where systematically have been done works for the replacement of classic equipments with modern equipments.

Hereby, nowadays, the technical state of equipments within the 21 DPS in the SDFEE operating network is diversified and structurally can be characterized as it follows:

- 110 kV circuit-breakers: IO (62%) and SF6 (38%);
- MV circuit-breakers: IO (78,5%) and SF6 (9,2%), vacuum (9,4%), IUPM (2,9%);
- Voltage transformer, are, mostly, unchanged (TECU – at HV, TERMO and TIRMI at MV);
- Current transformer are mostly of CESU and CESO type (mounted at DPS execution);
- Switch-disconnectors have passed a similar modernization process as the circuit breakers.

Other equipments are structured as it follows:

- Surge arrester mounted in DPS are of VA (60%) and ZnO (40%) type;
- Protection elements are mostly electromechanic.

The modernization process of DPS in Romania is continuing, the main directions in the case of DSFEE Oradea being:

- The replacement of MV IUP circuit-breakers with SF6 and vacuum circuit-breakers;
- The replacement of 110 kV IUP circuit-breakers with SF6 circuit-breakers;
- At MV there are promoted the remote switch-disconnectors air insulated (for light climatic areas and SF6 for the mountain areas;
- The extending of the vacuum circuit-breakers at MV and of SF6 circuit-breakers having spring actuation drive, at 110kV;
- The replacement of voltage transformers at MV with more reliable types;
- The replace of VA surge arresters with ZnO surge arresters;
- The modernization of the neutral point connection;
- The replacement of oil-paper insulation cables;
- The replacement of the electromechanical protection with electronic elements;
- The introduction of SCADA systems;
- The mounting of fault locators.

2. MODELLING THE EFFICIENCY OF DISTRIBUTION POWER SUBSTATION MODERNIZATION ACTIONS

It will be modelling the impact of the modernization actions of DPS on economic and social reliability performances expressed by means of some indicators.
We admitted the following suppositions:

- The probability of apparition the multiple faults (double, triple, or more) is negligible compared to the probability of a simple fault;
- Failure intensity is net inferior compared to the maintenance intensity ($\lambda<<\mu$);
- Technical performance of the new/modernized equipments (ENM) are superior to those of the old equipments, which influences in the same direction the reliability indicators and the power losses;
- The actualizing rate is a=0.1 and the inflation rate can be neglected (r=0), using a stable currency for computation (EUR);
- The interruption of electric energy supply has only economic and social consequences, the eventually ecologic consequences being counteracted by preventive measures.

The mathematic formulation witch will be presented as follows referred to a DPS, characterized by:

$i=\overline{1,n}$ - feeders; $k=\overline{1,C_i}$ - types of customers on feeder "i";

$j=\overline{1,m_i}$; $e=\overline{1,N}$ - equipments which affecting the feeder "i".

2.1. Reliability performances and the social risk

From the reliability point of view the following indicators are of a special interest: decrease of the interruptions number (Δv), decrease of the interruptions duration (Δβ) and decrease of the undelivered power (ΔW). If, sometimes, another indicators presents interest, they can similarly expressed [1, 4]. In the following, there will be expressed the above presented indicators, referred to a feeder "i", for the analyzed time (T_A).

- decrease of the interruptions number:

$$\begin{cases} \Delta\nu_i(T_A) = \nu_i^M(T_A) - \nu_i^E(T_A) \\ \nu_i^M(T_A) = \sum_{j=1}^{m_i} \nu_{ij}^M(T_A) \\ \nu_i^E(T_A) = \sum_{j=1}^{m_i} \nu_{ij}^E(T_A) \end{cases} \quad (1)$$

$$\begin{cases} \nu^M(T_A) = \dfrac{\lambda_M \cdot \mu_M}{\lambda_M + \mu_M} T_A \cong \lambda_M \cdot T_A \\ \nu^E(T_A) = \dfrac{\lambda_E \cdot \mu_E}{\lambda_E + \mu_E} T_A \cong \lambda_E \cdot T_A \end{cases} \quad (2)$$

- decrease of the interruptions duration:

$$\begin{cases} \Delta\beta_i(T_A) = \beta_i^M(T_A) - \beta_i^E(T_A) \\ \beta_i^M(T_A) = \sum_{j=1}^{m_i} \beta_{ij}^M(T_A) \\ \beta_i^E(T_A) = \sum_{j=1}^{m_i} \beta_{ij}^E(T_A) \end{cases} \quad (3)$$

$$\begin{cases} \beta^M(T_A) = \dfrac{\lambda_M}{\lambda_M + \mu_M} T_A \cong \dfrac{\lambda_M}{\mu_M} T_A \\ \beta^E(T_A) = \dfrac{\lambda_E}{\lambda_E + \mu_E} T_A \cong \dfrac{\lambda_E}{\mu_E} T_A \end{cases} \quad (4)$$

- decrease of the undelivered power:

$$\Delta W_i(T_A) = \Delta\beta_i(T_A) \cdot W_{hi}(T_A) \quad (5)$$

where:
(λ_M, μ_M) - failure and maintenance intensity for ENM;
(λ_E, μ_E) – the same, for existing equipments;
W_{hi} (TA) – average hourly consumption energy on the "i" line during the analyzed time.

The social risk refers to the influence on life quality indices of the electric power supply interruption without jeopardizing the human life. The social consequence reduction referred to "i" line is expressed as it follows:

$$\begin{cases} \Delta K_i(T_A) = K_{\nu i} \cdot \Delta\nu_i(T_A) + K_{\beta i} \cdot \Delta\beta(T_A) \\ K_{\nu i} = \sum_{k=1}^{C_i} K_{\nu i}^k; \quad K_{\beta i} = \sum_{k=1}^{C_i} K_{\beta i}^k \end{cases} \quad (6)$$

where,

$K^{k}_{\nu i}$ – the specific social consequence caused by the interruption of power supply at "k" customer connected to "i" line [NC/inter.];

$K^{k}_{\beta i}$ – the specific hourly social consequence [NC/hour].

The consequence level (NC) can be given using some numeric or linguistic ratings. For the DPS ensemble, it is calculated referred to T_A duration, the decrease of undelivered power and the social consequence at DPS level:

$$\begin{cases} \Delta W(T_A) = \sum_{i=1}^{n} \Delta W_i(T_A) \\ \Delta K(T_A) = \sum_{i=1}^{n} \Delta K_i(T_A) \end{cases} \quad (7)$$

2.2. The Economic Efficiency of DPS Modernization

The economic efficiency of DPS modernization is estimated by evaluation of some indicators [4, 5], from which we will reproduce in this paper, the expressions of three indicators:

- Investment recovering time:

$$DR = \frac{I}{\Delta D + \Delta C} \quad (8)$$

- The actualized net income:

$$VNA = \sum_{t=1}^{T_s} \frac{H_t - G_t}{(1+a)^t} \quad (9)$$

- The profitability index:

$$IP = \frac{\sum_{t=1}^{T_s} \frac{H_t}{(1+a)^t}}{\sum_{t=1}^{T_s} \frac{G_t}{(1+a)^t}} \quad (10)$$

where:
I – the investment value for DPS modernization performed in a year or actualized for the first year;
ΔD –decrease of annual economic consequences at customers supplied from the analyzed DPS;
ΔC – decrease of the annual operating costs of the electric power supplier;
(H_t, G_t) – the economic effect (H) and the economic effort (G) of DPS modernization actions in the "t" year;
T_s – study duration (20 years).

The analyze can be performed referred to each line (feeder) or referred to DPS ensemble. The economic effort is practically composed of investment expenditures (equipment costs, carriage expenditures, design, mounting and commissioning). The expressions for the above-presented indicators referred to DPS are:

$$I = \sum_{e=1}^{N} I_e; \quad G_t = I_t = \sum_{\substack{e=1 \\ e \in \{t\}}}^{N} I_e \quad (11)$$

$$\Delta D = \sum_{i=1}^{n} \Delta D_i = \sum_{i=1}^{n} \Delta \nu_i \sum_{k=1}^{C_i} P_{ik} \cdot d^{i}_{PK} + \sum_{i=1}^{n} \Delta \beta_i \sum_{k=1}^{C_i} P_{ik} \cdot d^{i}_{WK} \quad (12)$$

$$\Delta C = \Delta C_M + \Delta C_{EF} + \Delta C_{PT} \tag{13}$$

$$\begin{cases} \Delta C_{EF} = \sum_{i=1}^{n} \Delta C_{EFi} = k_w \sum_{i=1}^{n} \Delta W_i \\ \Delta C_{PT} = \sum_{e=1}^{N} \Delta C_{PTe} = k_w \sum_{e=1}^{N} \Delta W_{PTe} \end{cases} \tag{14}$$

$$H_t = \Delta D_t + \Delta C_t \tag{15}$$

where:
P_{ik} – average power consumption of "k" costumer on the "I" feeder;
d^i_{PK} - relative damage related to the power failure [UM/kW];
d^i_{WK} - relative damage related to undelivered energy [UM/kWh];
ΔC_M – the maintenance costs decrease (human, material, energy);
ΔC_{EF} – the reduction of the supplier losses by reduction of undelivered energy (UM);
ΔC_{PT} – the costs decrease by reduction of losses [UM];
k_W – the average specific cost of electric energy [UM/kWh];
ΔW_{PTe} – the decrease of losses in the "e" equipment during the analyzed time [kWh];
(ΔD_t, ΔC_t) – the values (ΔD, ΔC) in year "t";
UM – monetary units.

Calculating any of the feasibility indicators (DR, VNA, IP) for each "i" line, it is possible to make a hierarchy of the lines from the modernization profitability point of view, according to indicator values. For example, the variation series of IP indicators value is:

$$IP : IP'_1 \le IP'_2 \le \cdots \le IP'_n \tag{16}$$

$\longrightarrow$

Profitability growth

If the allocated sum of money does not cover the necessary amount for DPS modernization, the operations will take place in the following order: IP'_n, $IP'_{n-1} \dots$

For the SED ensemble, the economic efficiency conditions of modernization are [5]:

$$DR \le \frac{1}{a} = 10 \text{ years; } VNA > 0\text{; } IP > 1 \tag{17}$$

3. CASE STUDY

Between 1994 and 2003 were modernized 6 of the 21 DPS managed by SDFEE Oradea.

We present the case study results made regarding the Velenta-Oradea substation, (SDE V – O), 2x16 MVA, 110/20/6 kV. Some previous (qualitative) reasons, which justify SDE V – O modernization are:

- MV equipments and power transformers passed 40 operation years, which is reflected in their state and in the fault intensity;
- In the area, there are important (socially and economically) electric power customers, sensitive at disturbances;
- Necessity of some constructive, structural and functional adjustments, in concordance with utility and customer standards evolution in the area.

SED V – O is on the 110 kV side without busbar; on MV side it has two voltage levels (20 and 6 kV) and double busbar system. On the high voltage level there are two lines. On the medium voltage there are 18 feeders. Their destination is presented in Table 1.

Three alternatives were analyzed [8], obtaining the best values of economic efficiency for B variant – "The building of a new command and connection substation. Applying this alternative implies, concerning primary equipments:

- The equipment of the substation with two power transformers: 20 kV/6 kV (10 MVA) and 110/20 kV (16 MVA);
- The equipment of the substation with 30 medium voltage bays at 20 kV, having vacuum circuit-breakers and digital protection.

TABLE 1 – Consumes structure on feeds from SED V - O

Feeder nmb. (i)	Medium annual consumption [MWh]	Consumption structure	Feeder nmb. (i)	Medium annual consumption [MWh]	Consumption structure
1	5.181,5	0,2C+0,8IU	10	2.575,7	EC
2	1.833,1	EC	11	7.884,5	0,25C+0,75EC
3	2.566,8	EC	12	1.526,3	CM
4	2.336,2	0,35EC+0,65IA	13	327,9	0,9EC+0,1IE
5	3.719,3	0,7EC+0,1IU+0,2IA	14	1.350,8	IA
6	98,3	IA	15	1.097,6	0,6IU + 0,4 IE
7	2.231,4	0,3C+0,7CM	16	10.003,3	0,9C + 0,1 EC
8	2.265,8	0,05C+095IU	17	371,6	0,1C+0,9EC
9	4.407,2	0,1C+0,85IU+0,05IA	18	357,5	0,5C+0,5EC

where:
C – residential consumption;
EC – public and commercial consumption;
IU – light industry;
IA – food industry;
IE – mining and oil industry;
CM – machine building industry.

In the following we present the evaluation results referred to the MV bays designated for the existing 18 feeders of DPS V – O.

Input data reliability indicator values for DPS V – O equipments in the existing and modernized alternative are extracted from [7], respective [2, 3, 6].

I_e = 26757,4 EUR/bay $\qquad$ $\Delta C_M = \frac{\lambda_E}{\lambda_M}$ 683 EUR/an /bay

k_w = 0,051 EUR/ kWh, $\Delta C_{PT} = 0$, $K_{vi} = 0$

For the estimation of the c ($K_{\beta i}$) consequence we proceed to a relative evaluation referred to a medium value at the level DPS Oradea – Velența, which is:

- for the customers of type „C”: $K^{C}_{\beta med} \hat{=} 0{,}0479\,\text{kWh}/\text{h}$
- for the customers of type „EC”: $K^{EC}_{\beta med} \hat{=} 0{,}244\,\text{kWh}/\text{h}$

The social consequence level is estimated by:

$$K^{C}_{\beta_i} = \frac{W^{k}_{hi}(T_A)}{0{,}0479} K^{C}_{\beta med}; \qquad K^{EC}_{\beta i} = \frac{W^{k}_{hi}(T_A)}{0{,}244} K^{EC}_{\beta med} \qquad (18)$$

The relative fault values (d_{PK}, d_{WK}) for the customers supplied from DPS V – O are presented in the Table 2 [4]:

TABLE 2 – The indicator values d_{PK}, d_{WK}

Customer type	IU	IA	IE	CM
d_{PK} [EUR/kW]	0,5	-	-	0,32
d_{WK} [EUR/kWh]	3,8	3,5	1,6	2,1

The results concerning reliability and economic indicators, for the 18 feeder circuits are presented, synthetically, in the Table 3.

TABLE 3 – The reliability and economic indicators evaluated concerning the feeders

Feeder nmb.	$\Delta\nu_i$ [faults/year]	$\Delta\beta_i$ [hours/year]	ΔW_i [kWh/year]	ΔK_i	ΔD_i [EUR/year]	ΔC_i [EUR/year]	IP_i
1	0,186	1,35	797,81	3	2471,5	2977,4	1,907
2	0,184	1,347	281,83	4	0,0	2951,1	1,033
3	0,184	1,347	394,63	5	0,0	2956,8	1,035
4	0,185	1,348	359,44	2	817,9	2942,3	1,316
5	0,185	1,348	572,24	5	622,0	2953,1	1,251
6	0,186	1,35	15,13	-	53,0	2934,3	1,046
7	0,205	1,365	347,65	2	522,8	3195,5	1,301
8	0,204	1,364	352,75	1	1298,7	3185,2	1,569
9	0,204	1,364	686,13	1	2380,3	3180,9	1,946
10	0,204	1,364	401,00	5	0,0	3187,6	1,116
11	0,204	1,364	1227,50	5	0,0	3208,5	1,123
12	0,204	1,564	237,62	-	583,6	3179,3	1,317
13	0,227	0,71	231,97	1	37,1	4491,8	1,585
14	0,227	0,71	109,39	-	383,2	4485,5	1,704
15	0,262	0,711	89,01	-	270,0	4498,5	1,669
16	0,227	0,71	811,23	5	0,0	4521,3	1,583
17	0,227	0,71	30,14	1	0,0	4481,5	1,569
18	0,227	0,71	28,99	1	0,0	4481,4	1,569

Fig. 1 presents the hierarch of feeder circuit by profitability index IP_i presented in the Table 2, that is the order that circuits has to be modernised thus reaching the maximum profitability.

At the whole substation level DPS V – O for the economic indicators (ΔD, ΔC, I, DR, VNA and IP) and for the social consequence decrease (ΔK) results the following values:

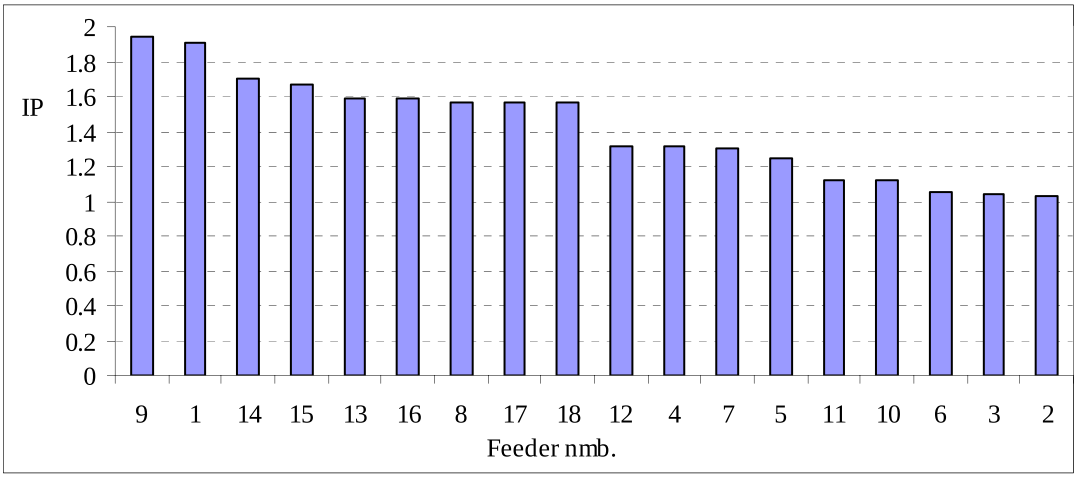

Fig. 1 – The hierarch of the feeders from the substation concerning profitability index (IP)

The total investment for modernization of the MV cells: I=481633,2 EUR;

The decrease of cost due to the faults at all customers supplied from the Velența Substation at 20 kV: ΔD=9440,1 EUR/year;

The decrease of cost at the substation level due to corrective and preventive maintenance actions: ΔC=63812 EUR/year;

Investment recovering time: DR=6,58 years;

Profitability index at the substation level: IP=1,30;

The social consequence decrease for all the householder and town customers: $\Delta K=4$;
Actualized net income, after 20 years of operating: VNA=185826,7 EUR.

4. CONCLUSIONS

- It is necessary and advantageous that the modernization actions of DPS from Romania to be intensified;
- For the modernization actions efficiency evaluation is imposed the determination of some indicators concerning: the reliability performances, the economic efficiency of modernization and the social risk.

It is recommended the use of the following indicators for the evaluation of the modernization actions performance:

- the decrease of the interruptions number;
- the decrease of the interruptions duration;
- decrease of the undelivered power
- the social consequence decrease of the interruptions;
- the investment recovering time;
- the actualized net income;
- the profitability index.

- The evaluation of economic efficiency and social risk indicators as a consequence of DPS modernization, imply profound studies concerning the consumption structure and the consequences of the EE unavailability.
- Referred to the analysed „SED V – O" substation on can affirm that even we considering only the economic consequences, the investment is (DR = 6,58 an, IP = 1,3), VNA = 185826,7 EUR.

References

1. BillintonR., Allan R.: 1984, „Reliability Evaluation of Power System", „Plenum press", New York,
2. Carvalho A., Bosshart P., Christiansen U., Guerra G., Tang L., Olovsson H.: 2000, „Functional Specification As Driver for Technical / Economical Optimisation Of Substation", CIGRE Session, Paris ,
3. Georgopoulus A., Papadopoulos C., Agoris D. – 2002, „A 170 kV Compact Switchgear Module Application At Komotini Open – Air Substation In Northeastern Greece", CIGRE Session, Paris,
4. Felea I.: 1996, „Ingineria Fiabilităţii În Electroenergetică", E.D.P., Bucureşti,
5. Leca A., ş.a.: 1997, „Principii de Management Energetic", Ed. Tehnică, Bucureşti,
6. Megdiche M., Besanger Y., Aupied J., Garnier R., Hadjsaid N. – 2003,"Reliability Assesment of Distribution Systems With Distributed Generation Including Fault Location And Restoration Process", Cired, Barcelona
7. *** PE013/94 – 1994, Normativ privind metodele şi elementele de calcul al siguranţei în funcţionare a instalaţiilor energetice, Bucureşti,
8. *** Lucrări pentru mărirea gradului de siguranţă în funcţionarea capacităţilor existente la Staţia 110/20/6 kV Velenţa – Oradea, lucrare nr.5-6/2003