REFITTING STRATEGY FOR THE TRANSFORMER SUBSTATIONS IN THE ROMANIAN NATIONAL POWER SYSTEM

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INTRODUCTION

In the context of the national power system’s interconnection to the power systems of the Union to Co-ordinate the Transmission of Electricity (UCTE) - priority objective of Romania’s power sector under the country’s accession to the European Union, the refitting/repair of the electric substations requires a new approach in line with the Development plan for 2001-2010 and its component, the Business plan 2001-2004 issued and carried on by Transelectrica s.a. - the Romanian national company enabled as power transmission and system operator (TSO).

Transelectrica’s objectives, as established in the above documents are:

- Increasing the quality and safety conditions of the electricity transmission grid (ETG)
- Ensuring the interconnection conditions for UCTE
- Increasing the company’s turnover
- Growing the company’s efficiency.

CHAPTER I: THE NEED FOR REFITTING

The following assumptions of elaborating a certain refitting strategy for the electric substations of the ETG have to be taken into account in order to carry out the above objectives:

- The technological development of the last years, both in the field of primary equipment and in that of the control, protection and telecommunication systems;
- The exceeded operational life and the current condition of primary and secondary equipment in the electric substations, the concept of control, protection, communication included;
- The necessary increasing degree of computerization for operation, maintenance, supervision of operational behavior of the equipment in electric substations.

It follows clearly from the above the need to refit the transformer substations within the NPS in order to ensure a reliability degree at the level of UCTE’s technical and quality requirements.

CHAPTER II: REFITTING METHODS APPLIED. THE EXPERIENCE GATHERED

The refitting of electric substations is a main component of Transelectrica’s investment program in terms of size and importance (about 70% of the investment funds). The refitting methods include:

a. Reconsidering the single line diagrams of the substations in terms of the structural changes occurring in the related industrial environment, the interconnection priorities to UCTE’s power systems and, last but not least, the reliability of the new equipment (allowing the spectacular simplification of the one-line diagrams and of the operation and maintenance concept);

b. Replacing the primary equipment as well as the control-protection one at de-centralised level;

c. Reconsidering the concept of control at the 21st century’s technological level (control rooms with advanced visual technique, using SCADA and up-to-date principles of process control and supervision), the so-called “next generation control”;

d. Remaking the own system of services in agreement with the new requirements from the norms and to a performance level as needed to sustain the electric technical system in terms of reliability;

e. Remaking the construction part and the cables system;

The latest world technologies will be applied in the projects of refitting the substations from the ETG, including:

- **for primary circuits**: Solutions using compact or combined, high reliable equipment;
- **for secondary circuits**: Control-protection terminals with digital technique, with facilities for serial communication to the superior hierarchical levels;
- **Centralized control system** based on the latest concepts of
human-machine interface, information classification system, event recording, etc.

The experience gathered with the refitting of the substations Portile de Fier, Urechesti, Tantareni, Arad and Mintia consists mainly of:

- The contracting of the refitting projects: ‘turnkey project’
- The need to harmonize the Romanian norms and standards to the legislation and equipment solutions that the suppliers promote under the projects;
- The unity of technical solutions and of supplies under a project, with highly advantageous consequences on the compatibility between functional groups, for instance between the primary equipment and the control-protection systems at centralized and de-centralized level;
- Simplifying of the connections diagram (giving up the transfer bus bars, using compact or combined equipment, etc.) and increasing the flexibility of diagrams by means of the quality of the equipment;
- Finding and applying proper financing schemes adapted to the scope of such important work;
- Phasing out the installation work so that to minimize the impact of interruptions over the system;
- Supervising the project development using a dedicated software compatible to that currently used in Transselectrica (Microsoft Project, Primavera);
- Knowing and applying the legislation of quality assurance and environmental protection in each stage-beginning from the preparation of the project until the final reception;
- Ensuring of balanced geographical coverage of the country in what regards the retrofitted substations.

CHAPTER III: CURRENT STRATEGY OF TRANSFORMER SUBSTATIONS REFITTING BASED ON THE MULTI - CRITERIA METHOD

Using the experience gathered with the first refitting projects, Transselectrica has drawn up the company’s strategy of substations refitting based on a multi criteria analysis (the Significance & Reliability Method- SRM) that hierarchically classifies the substations to be refitted, but also taking into consideration:

A. The advanced technology and the new concepts of operation and process control electrical as they are on world level in the electric substations;

B. The (computerized) correlation of the repair program for electric substations (on voltage levels) with the refitting program stated in the Business Plan 2001-2004;

C. The experience gathered with refitting the substations of Portile de Fier, Urechesti, Tantareni, Arad and Mintia, mainly consisting of ‘turnkey’ contracts;

D. Environmental protection through application of minimum impact technologies;

E. Risk Management principles and solutions.

The hierarchical classification during 2001-2004 and the general overview up to 2010 of the substations to be refitted was made using applied criteria of various shares which follow from Transselectrica’s objectives and activities and through the provisions of the electricity transmission license and of the technical code of the ETG.

The analysis has focused on the criteria below:

1. Synchronous and asynchronous interconnection to the neighboring electric power systems; this criterion covers the ensuring of technical conditions required by the interconnection to UCTE’s systems;

2. The physical wear and the obsolescence of the outfits determine their technical condition - evaluated in accordance with: the substations incidents number, the area pollution degree and the systematic performance of the maintenance programs.

This criterion quantifies the quality increase and the availability of services provided to the users of the transmission grid.

As a new element of the proposed method, the assessment of the technical condition of the outfits will be done based on the measurements, technical expertise regarding the power outfits functional parameters evolution; these data are gathered using the Reliability Centralized Method (RCM). The data resulting from this evaluation will allow the reliability indexes calculation for the power substation, as shown in Chapter IV, as main element in the hierarchy establishing the substations to be refitted.

3. The importance of the substations for the safe operation of the National Power System (NPS) is a criterion covering both the quality requirements for the services to the ETG users and the increase of the company’s turnover.

In order to establish the refitting priorities for substations, besides the technical status, their importance within NPS has to be determined.

The importance of each line or transformer connected in the respective substation as well as the importance of the node representing the substation in the NPS grid are needed in order to determine the mode of assessment of the significance of various substations into the ETG (see chapter IV A).

4. The electricity transmitted yearly through the substations is the reference criterion that mirrors the company’s turnover increase.

Mention should be made that the value of the transmitted electricity was calculated for each substation with a view to set up the hierarchy using the SRM and the operational regimes characteristic of 2001, for seasons and calendar days.

5. The economic-financial criterion quantifies the efficiency of the entire process of substations refitting at company level.
The criteria listed and detailed above - especially the one relating to reliability (mirroring the technical condition of the outfits in the substation) and the one setting the substation’s position for the NPS safety are the foundation of the multi-criteria method providing the substations hierarchy according to significance and reliability, which method is described in chapter IV.

The hierarchy set using the SRM provides the decision-making support in determining the sequence of refitting projects start-up. This method will allow to know when and what degree of refit will be performed, at the following levels:

1. Complete replacement of the primary and secondary equipment;
2. Replacing the control system;
3. Replacing the protection and control system;
4. Installing the monitoring system for the equipment parameters;
5. No intervention.

An important aspect is the correlation of the refitting strategy with the repair programme, which completes and/or determines the application of the refitting programme in the light of a more realistic notion of capital repair (in the context of the technological advance, the exceeded operational life of substation equipment, the absence of spare parts, the requirement to use the production money efficiently).

This new approach of the notion of capital repair provided in the economic and legislative framework is, together with the technological development, a fundamental and topical component of Transelectrica’s strategy of electric substations refitting.

CHAPTER IV: DESCRIPTION OF THE SIGNIFICANCE & RELIABILITY METHOD

Besides what has been stated in the previous chapter, both the assessment of the technical condition of substations and the determination of their significance in the Electricity Transmission Grid (ETG) are based on a system of marks used as relative per cental amounts with values from 0 to 100%.

A. The Significance & Reliability Method Description

To begin with, there is need to know the calculation results of a set of stationary regimes representative for the NPS over a number of years comprising the horizon considered for refitting.

The importance for the ETG connections (line or transformer) is written down using an algorithm that assesses the disturbances occurring in the NPS by disconnecting each ETG connection in turn during the pre-set peak regimes; a set of synthetic indicators including the effects of this connection over the system is determined from the regime results obtained:

a) A stationary regime criterion mixed with a stability criterion is used in order to determine the mark. Thus, upon successively disconnecting each line or transformer from the ETG we determine:

- a coefficient showing the relative deviations of the voltage values in all the NPS nodes, compared to their previous values, as reported to their nominal ones and the relative deviations of the currents of all the lines and transformers in the NPS compared to their previous values as reported to their admissible ones (thermal limit), for the stationary regime resulting after a contingency;
- the minimum value of the static stability reserve of the NPS sections that include the respective line or transformer from the ETG, for the second component - the static stability.

b) In case the disconnection of a link in the ETG leads to the failure to supply certain consumers or to deliver the amount of power to a power station, the significance criterion will be given by the relative amount of the unsupplied power.

c) In case following the disconnection of some links the static stability reserve is reduced under the value admitted in the norms, a separate sequence is entered under which the loading of the NPS units is changed (the load given under the initial merit order) through an optimum reduction in the load of certain economic power stations and the loading of certain uneconomic power stations until the detected restrictions are eliminated.

In this case the importance of the disconnected link will be assessed from the value of the increase of the cost of supplied energy.

The significance of the node or nodes representing a substation belonging to Transelectrica is written down upon assessing the short-circuit strength of the respective busbar sections in terms of transient stability.

To this effect a synthetic indicator allowing to compare the nodes between themselves is determined by means of a direct method type Liapunov; this is the deadline for the disconnection of the short-circuit simulated near the respective busbar.

It is known that the system stability is ensured if the short-circuit produced in a certain place is eliminated within a shorter time than a limit value; therefore, if this time has a small value for a certain node, it means the node is highly sensitive and consequently very important for the future refitting.

In the end the marks obtained for the importance of the links connected to a certain voltage level in each substation are combined in a weighted mode with reliability coefficients and with the mark of the respective voltage level of the considered substations.

Based on the above principles a computation programme
entitled IMSTAT was elaborated. This operates on the network of the Romanian system with the data obtained from a set of stationary regimes representative for a horizon of a few years, calculated by the forecast departments and delivers notes on the importance of all substations in Transelectrica or in each individual substation. A calculation for the whole network takes about 5 minutes on a Pentium II PC (300 MHz).

B. Calculation of the reliability indexes

In order to establish a hierarchy for the electric power systems, a defining criterion is the reliability calculation from the static stability prospective.

The following steps have to be considered for the busbars calculation of the substations:

- to determine the one-line-diagram of the busbar taken into consideration
- dividing into simple busbars in case of a multiple busbar substation
- calculation of multiple busbars reliability
- calculation of multiple busbars risk (insuccess probability)
- calculation of multiple busbars reliability seen as simple NPS elements
- calculation of multiple busbars risk, seen as simple NPS elements
- eventual calculation of other reliability indexes: medium total duration of insuccess for a certain period; the total medium number of insuccess states within a certain period; the medium period for a success state.

Reliability “R” and insuccess Risk “Q” is determined by:

\[
R_{ST} = e^{-\lambda_{ST} \cdot t}
\]

\[
Q_{ST} = 1 - e^{-\lambda_{ST} \cdot t}
\]

where:

\[
\lambda_{ST} = \text{substation failure intensity}
\]

\[
\mu_{SBj} = \frac{\lambda_{SBj}}{\sum_{j} \frac{\lambda_{SBj}}{\mu_{SBj}}}
\]

\[
\lambda_{SB1} = \lambda_{B1} + \sum_{j} S_{j}
\]

\[
\lambda_{SB2} = \lambda_{B2} + \sum_{j} S_{j}
\]

where:

\[
\lambda_{SBj} \text{ represents the disconnecting switch “j” failure intensity}
\]

\[
\mu_{SBj} \text{ represents the disconnecting switch “j” repair intensity}
\]

If the technical status is established by observations, supposing we take into consideration “v” observations, parameters, for each of them making “r” determinations, we have the reliability formula:

\[
R = e^{-(\lambda_{med} + \alpha t) t}
\]

where \( \alpha \) is calculated as follows:

\[
\alpha = \sum_{i=1}^{m} \left( \frac{kmed_i}{kpif_i} \right)^{bi} + \sum_{s=1}^{n} \left( \frac{kmed_s}{kpif_s} \right)^{gs},
\]

having conditions (1) and (2) accomplished:

\[
\sum_{i=1}^{n} \beta_i + \sum_{s=1}^{m} \gamma_s = 1 \quad (1)
\]

\[
\sum_{i=1}^{n} i + \sum_{s=1}^{m} s = v \quad (2)
\]

The reliability relation according to the technical status established through observations, in case of aged outfits becomes:
\[
R(t) = e^{-\left(\sum_{i=1}^{m} \left( \frac{k_{med i}}{kp_{i(t)}} \right)^{\beta_i} + \sum_{s=1}^{n} \left( \frac{k_{med s}}{kp_{s(t)}} \right)^{\gamma_s} \right) t}
\]

where:

\[
\lambda_{med} = \frac{\lambda_{max} + \lambda_{min}}{2}
\]

and

\[
\beta_i and \gamma_s \text{ are indexes having values according to specialists’ experience;}
\]

\[
\lambda_{max} and \lambda_{min} \text{ are pointed out within Romanian Regulation Documents (PE 013/1994).}
\]

### CHAPTER V : CONCLUSIONS

The realistic approach to the refitting projects of the substations in the ETG is based on a stable and modern strategy that:

- Is conceptually structured in technical terms by means of advanced equipping solutions and the control of the electrical technological process at current world level;
- Is based on multi-criteria methods determining the sequence of refitting projects start up;
- Uses the global solution of “turnkey project”;
- Provides an efficient project management using the Project managers;
- Monitors by computers the project development at different competence levels using a specialized software.

The strategy regarding the refitting/repair of transformer substations will be obviously continued to be put into practice in 2003, in order to ensure an European level of performance and efficiency for Transelectrica s.a..

A large capital repair program completed with modernization works in order to increase the technological level of the substations installations, as well as large investment projects for complete modernization of the important Romanian substations as Bucharest Fundeni, Cernavoda, Gutinas and Iernut are based on the strategic concepts mentioned in the present paperwork.