IMPROVING THE SAFETY PERFORMANCE OF POWER GRID EQUIPMENT AND INSTALLATIONS USING INFORMATIONAL FEEDBACK

Christiana BARBULESCU  Gabriel ROMASCU  Anca DIACONU  Stefan DIACONU
National Power Grid Company “Transelectrica” S.A. - România
cbarbulescu@transelectrica.ro, gromascu@transelectrica.ro

INTRODUCTION

One of Transelectrica’s (National Power Grid Company) missions as transmission and system operator is to ensure the National Power System operation under conditions of quality, safety, economic efficiency and environmental protection, while keeping neutral to all customers on the electricity market. The Company is a full member of the Union for the Coordination of Transmission of Electricity (UCTE) and is permitted to operate in permanent synchronous regime with the interconnected Western European system. Liberalisation of the power market and spinning off the electricity generation, transmission and distribution activities have pointed out how important is to cut down costs and to increase the reliability of the transmission grid.

Taking into account the need to sustain the reliability analysis to quantify performances using accurate input data at equipment and at installation level as a whole (system), the paper describes Transselectrica’s concerns with organising and using the information feedback in the transmission grid.

The mission of Transselectrica S.A is to grant regulated third party access to the electricity transmission network to all market participants under transparent, non-discriminatory and equitable conditions, as well as competitive electricity transmission and system services while observing the quality standards, under safe conditions for the national power system and at minimum reasonable costs, limiting the environmental impact to the admissible level in Europe.

GENERAL ASPECTS CONCERNING RELIABILITY ANALYSES

Power installations are highly complex for which reliability or safety analyses are required both in the design and in the operation stage. Such analyses contribute to making decisions on the best system structures, reaching the admitted quality level of components, as well as on the best maintenance policy.

Both the concerns described in the reference literature and our personal experience show how important is to:

- A full reliability review has to pass compulsorily through certain more important stages that can be grouped into two categories, a qualitative one relating to knowing, identifying and organising the information and a quantitative one, where the logical formalisms and the models are built and numerical data are obtained on the installation performance.

- Both categories require detailed analyses at component level, including the review of causes and failure modes of elements as well as of their consequences, which compromise one or more indicators of the safe operation of systems or even lead to possible extension in the adjacent systems. Certain items specific to reliability analyses of electric substations can be pointed out:
  - taking into account the three-fold and higher defects when analysing the diagrams of electric substations is not significant in most cases, with the exception of situations involving transformers, units from power plants and generally entities that can provide great periods of unavailability;
  - given the very low λ/μ ratios and generally the very small unavailability periods as well as the low probability of damage of most electric equipment in substations, the independence of elements can be assumed;
  - depending on the purpose of the analysis, various degrees of accuracy of input data can be accepted, as well as of the models used. Omitting certain contingencies in the reliability analyses can have outcomes more important than certain inaccuracies of input data;
  - analysis models have to allow consideration for the dynamics in configuring the electric substation diagrams depending on the aleatory states undergone, as well as of the effect of successful occurrences of certain defects, taking into account the many modes of damaging of electric equipment and the great variety of their influences on the operation of the system as a whole.

ENSURING THE INFORMATIONAL FEEDBACK

The experience and practice point out the need to use credible reliability data to sustain the safety analysis.

To obtain the reliability data it is preferable to use a strict analysis of the operational experience, by means of an efficient feedback. A proper use of the feedback improves the operation and maintenance of installations and the operational safety in general. These are the reasons why there are sustained concerns at international level for feedback management using general recommendations and procedures within specialised informational systems, as it was done in the case of power grid as well.

The accuracy of reliability analyses depends to a great extent on the precision of primary data and on the estimation techniques used for reliability parameters. In general, the truest and most numerous information comes from operation, then their proper acquisition and processing is a must.

Each failure mode of a piece of equipment is attributed a distinct defecting intensity, the same as there are various modes of restoration after a defect, and the danger of repeating the intensity. It follows that reliability calculations have to be sustained by correlating the statistical observations to the information requested.

Mention should be made that the electricity sector has recorded for several years the concern to promote investments and upgrade the power installations, taking into account the reliability analyses, and hence the need to develop a computerised system to process the operational data on equipment and installations behaviour.

The information needed is obtained at the level of component equipment of installations, by supervising their operational behaviour and especially their degree of defecting. Then these are used in analyses at installations level in the assembly (system) by monitoring the manner in which the quality of service is provided (especially the continuous operation), as described by
the indicators given in the Technical Code of power grid [1].

In accordance with the tasks from technical code, the transmission and system operator has the following obligations:

- To observe the quality technical parameters of the electricity transmission service and the safety and availability requirements for transmission power grid, according to the technical code
- Is responsible for the safe operation of the national power system and of its components and for the uninterrupted balancing of generation and consumption in the national power system
- To monitor, register and report the quality technical parameters of the transmission and system services

To report to ANRE (National Energy Regulatory Authority) the events resulting in important material damages, victims of significant interruptions of service occurring in installations. Monitoring the operational behaviour of equipment and installations as well as that of the entire Romanian Power System (RPS) is organised within Transelectrica as shown in Figure 1 (a manner resembling the concept presented in CIGRE [2] report), the respective activities being carried out in specialised compartments also by using IT systems and proper software.

![Figure 1- Organisation of equipment operational behaviour monitoring](image)

Table 1 shows the performance indicators of the electricity transmission system in 2001-2002.

<table>
<thead>
<tr>
<th>Performance Indicator/year</th>
<th>Measuring unit</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seriousness index</td>
<td>minutes/interruption</td>
<td>0.104</td>
<td>0.054</td>
<td>0.110</td>
</tr>
<tr>
<td>System minutes</td>
<td>minutes</td>
<td>0.677</td>
<td>0.18</td>
<td>1.47</td>
</tr>
<tr>
<td>Average interruption time</td>
<td>minutes/year</td>
<td>1.362</td>
<td>0.321</td>
<td>2.54</td>
</tr>
</tbody>
</table>

It was ascertained that equipment suppliers and network operators need to share their experience. To this effect recommendations are for manufacturers and operators to use reliability techniques, describe their experience in the feedback process, as the reliability studies required information on the equipment behaviour; to describe the processing of data gathered from feedback in order to evaluate and quantify damaging modes; to share their experience and the data on equipment and systems reliability.

**ASPECTS ON THE FAILURE MODES OF ELECTRIC EQUIPMENT AND INSTALLATIONS**

In the particular case of power installations, the issue of considering the failure modes is a complex one, given their great number and varied influence.

The deep study on the failure modes of electric equipment/sub-systems in reliability analyses can provide:

- taking in consideration form the conception stage all the failure modes and their influence on the scheduled functions of the system, thus obtaining a proper design;
- selecting the solutions (diagrams) of sub-systems;
- identifying certain redundancy needs;
- selecting type or re-usable solutions for technological diagrams;
- identifying the simple or common cause defects;
- determining the detection procedures of some periodic testing needs for each failure mode;
- determining the maintenance procedures for each failure mode etc.

Starting from the fundamental characteristics of defects to elements and from the system functional structure, FMEA allows determining the relations between the defects of elements and the malfunctions, degradation, limitations of system operation. To prove the seriousness of a defect the notion of criticality is used within an FMECA by determining the criticality level.

The consideration of failure modes can also depend on the occurrence of a certain failure mode, as against its consequences determined using a criticality analysis (appreciating the characteristic probability x seriousness) both at element level and at that of assembly as a whole.

As a specific characteristic, one can notice the great variety of types of diagrams (with bus bars, polygonal etc.) of electric sub-systems comprising complex equipment (switching equipment in normal off or normal on position, with different functions in diagrams, meters or power transformers, synchronous compensators or breaking units, metering, signalling, command, control, protection and automation installations etc.) found in various conditions (in operation, reserve, maintenance etc.), therefore having multiple failure modes and various influences over the reliability indicators of the system as a whole or over certain adjacent systems.
Description of the main aspects of failure modes of electric substations (systems)

To examine the modes in which electric substations as a whole get defected, the functions they perform have to be taken into account:

(a) discharging the power (from electric power plants or from system areas in excess);
(b) transfer of power on the bus bars of electricity transmission;
(c) injection of power in the consumer networks.

Against these, the substation can lose fully or partially the scheduled function following certain events. It is highly important to consider all contingencies (all events or sequences of events that might occur) in order to analyse the defecting modes of electric substations for reliability analyses, as omitting or neglecting them can have serious consequences.

Therefore, anyhow a detailed analysis on the failure modes of equipment (entities) in the substation has to be the starting point in analysing the failure modes, as many of them are actually common cause defects.

The difference of elements (equipment) defecting can influence in various ways the system reliability, depending on the consequences occurring in the moment of their occurrence or on the lasting ones produced after their occurrence, influencing one circuit (the one to which the respective piece of equipment is connected) or adjacent items as well.

The most complex situations are those of technological diagrams of transformer substations and posts from electric power systems against the behaviour of circuit breakers.

Failure modes have got different consequences on the reliability of electric substations, depending on their diagram, on the connection point of the item (circuit breaker) and its position (on or off).

Selecting the diagrams of electric substations with consideration of failure modes

Failure modes of equipment, especially of circuit breakers can influence the selection process of substation diagrams both in the design stage as well as in the operational one. Besides the economic principle of selection (or under equivalent conditions of variants in this respect), the solution variants can be distinguished using the safety principle compared to certain failure modes of equipment, taking into account their consequences on the scheduled function of the sub-system (electric substation).

Analysing the influence of failure modes of equipment over the substations reliability can help also selecting the operational running diagrams [3], for instance in terms of the influence of longitudinal couplings (on or off) between the bus bar sections of a substation, taking into account the reliability of circuit breakers. The failure mode of the circuit breaker is that of failing to operate in case of defect ("do not open on order"), influencing to the greatest extent the performances of substations electric diagrams.

The consequence of such refusal to operate is always the disconnecting of some additional items in the diagram. To provide an example, a discharge diagram is examined in terms of the influence of longitudinal couplings located in the middle of bus bars, taking into account the quality of circuit breakers with respect to their failure mode "refusal to operate".

In terms of reliability, circuit breakers are described by the probability of tripping refusal, \( q_r \), which takes into account as well the behaviour of associated protection in this respect.

This probability helped calculating the average number of unlimited short-circuits through one's own circuit breakers and not even following the consecutive operation of DRRI (device to reserve the refusal of circuit breakers) for three variants of operational diagrams: with continuous bars, with sectioned bars and open longitudinal couplings, with sectioned bars and closed longitudinal couplings.

Figure 2 shows the variation of the number of DRRI refusals depending on the quality of circuit breakers (described by probability \( q_r \)) and on the operational diagram. A certain dependence of this number of the \( q_r \) and on the operational diagram is noticed.

![Fig. 2. Number of refusals of the DRRI depending on the circuit breakers quality and the operational diagram](image)

The operational diagram and the substation configuration are influenced all the more as the quality of circuit breakers is lower compared to the failure mode tripping refusal (as the probability \( q_r \) of refusal upon order is higher).

The above show the importance of feedback, since the operational behaviour of equipment making up the diagrams (circuit breakers) can influence— as shown when using the statistical-probabilistic computation techniques are used—the substation diagrams both in the design stage and in the operational ones, which can be different from those initially considered, taking into account the operational experience gathered.

Such analyses can be used for decision making, for instance to select the diagram of a substation in compliance with the reliability level of component equipment.
INFORMATIONAL FEEDBACK USED IN IMPROVING THE MAINTENANCE STRATEGIES

The following aspects are taken into account when taking objective decisions to improve the reliability and maintainability based on informational feedback:
- analysing the degree of defecting and the development of operational characteristics of equipment in order to determine the technical condition;
- analysing the importance of installations in the national power system;
- costs analysis.
All these aspects are included in the general concept of RCM (Reliability Centred Maintenance), a systematic process of decision taking and of standardised approach to the maintenance activity currently used within power grid [4, 5, 6]. RCM helps putting to value the conventional theory of reliability, orientating the maintenance activities where the installation is vulnerable and where economic efficiencyjustifies it. Thus, the time-centred maintenance has been gradually replaced by condition-centred maintenance, respectively reliability.
The priority of preventive maintenance is determined depending on the technical condition of equipment/installations, quantified using the statistical processing of information on operational behaviour: frequency and duration of accidental unavailability intervals; development of operational parameters and characteristics; history of maintenance, costs and on the installation significance within the power system.

Maintenance is carried out under the „Maintenance Insurance Programme” in accordance with the regulations of ANRE (National Regulatory Authority in the energy field). The proven performance of equipment is essential for the design stage of a new project and also for the installation maintenance. A major concern of maintenance activities is to keep performance in time.
All types of maintenance contracts are found in Transelectrica’s case - with many pieces of equipment of long operational life, but also with new or retrofitting projects.

CONCLUSIONS

➢ Transelectrica provides on the domestic market the required infrastructure and non-discriminating third party access to the grid for all market participants.
➢ Transelectrica furthers the tradition and experience that have gathered in 50 years of National Power System operation and maintenance.
➢ Although the sector has separated in commercial and legal terms into many entities, Transelectrica ensures the functional unity of the National Power System, its safe and best operation.
➢ The Romanian electricity sector's integration in the European and regional market is provided by the interconnection of the electricity transmission grid to the UCTE power systems.
➢ The informational feedback from the supervision of operational behaviour finally leads to increasing the operational safety, both by specific operation and maintenance activities and by joint actions with the equipment suppliers in order to improve their reliability and provide the possibility to select simplified diagrams.
➢ A mode of management and prediction for maintenance costs and equipment-related risks needed.
➢ Transelectrica included exigency in its relationships to partners and equipment and/or service suppliers.

REFERENCES

[1].*** “Technical Code of the transmission power grid”
[6]. M. Stein, C. Radu, C. Barbulescu, A. Valecceanu, S. Diaconu, A. Molnar, “Capitilising the data from operation in assistance to decision taking with respect to the opportunity and specificity of certain preventive maintenance activities, Energetica magazine no. 10/2002, 452-457