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RECOMMENDATIONS FOR THE IMPROVEMENT OF THE BRAZILIAN POWER SYSTEM SECURITY FOLLOWING THE 11TH MARCH 1999 OUTAGE BASED ON EDF EXPERIENCE

HR-19/99/010/B

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* Each document is identified by a number into brackets, like : [1].

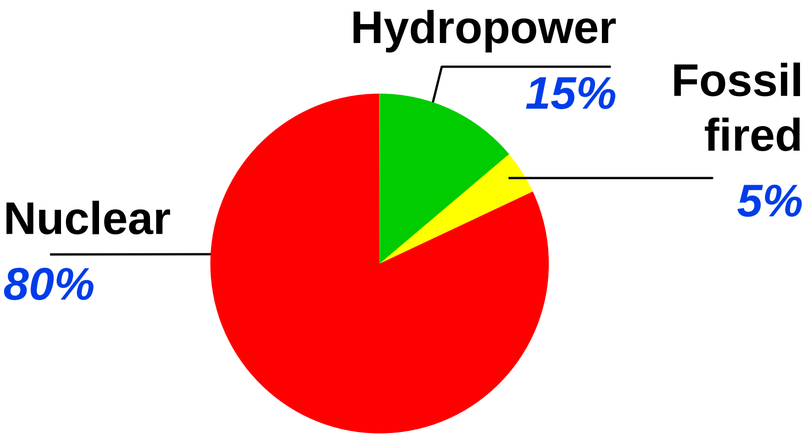
1. EDF PRACTICES TO PREVENT AND LIMIT THE CONSEQUENCES OF MAJOR DISTURBANCES

Preamble

We present first the main characteristics of the French Power System.

The consumption peak load is presently about 70 000 MW. The energy annually supplied is 460 TWh. The EDF installed generation capacity is 103 000 MW, composed of 62 000 MW of nuclear units, 23 000 MW of hydro units, and 18 000 MW of fossil fired units.

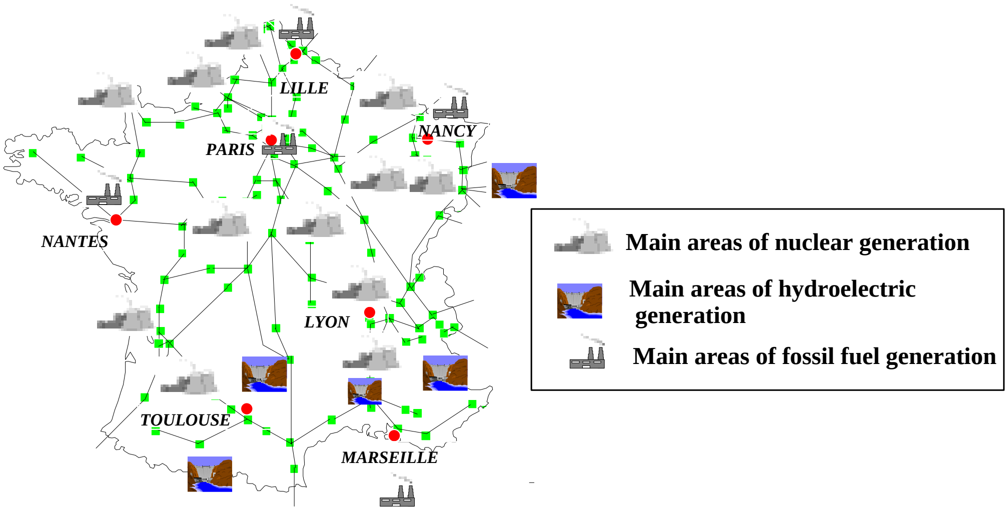
The use of the various means in the energy annually generated is represented on the following diagram.



Use of the various means in the energy annually generated by EDF

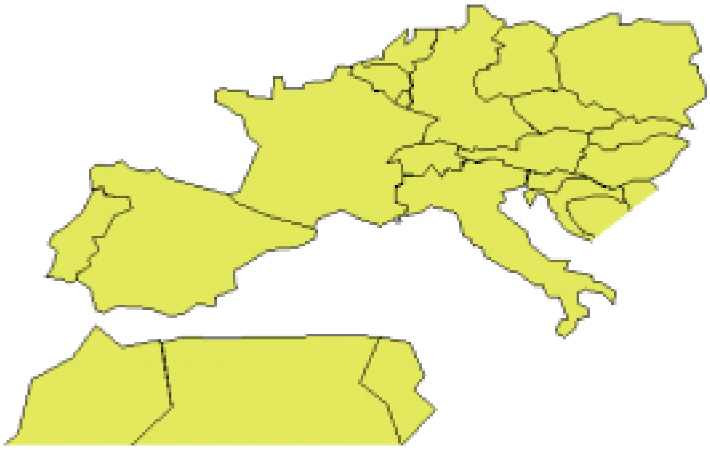
The EDF transmission system is mainly composed of 20 000 km of 400 kV circuits, with 130 substations at this voltage level, and 26 000 km of 225 kV circuits, with 500 substations at this voltage level.

The following map shows the location of the main generation sites and the structure of the EHV transmission system.



Synthetic map of the EDF power system

The EDF transmission system is strongly interconnected to the "Trans European Synchronously Interconnected System" (of about 300 000 MW peak load as a whole), which links now countries from Tunisia to Poland, as represented in the following map.



Extent of the "Trans European Synchronously Interconnected System"

1.1. Major French outages and lessons learnt

We present successively the French outages of 1978, and 1987.

On 19th December 1978 at 8:20 a.m., a cascade of overloads caused by excessive flows in the East-West direction, combined to a progressive voltage collapse in the Western half of the country, lead to a generalized loss of synchronism, and the loss of 75 % of the French consumption. The reenergization of the EHV network took 3 hours, and the complete restoration took 7 hours up to the recovery of all loads.

The lessons learnt and action taken following this outage were the following :

- A review of the operational procedures was undertaken (some were not sufficiently clear)
- It was decided to create a team among the control center operation planning staff to perform systematic dynamic studies
- It appeared necessary to enhance the training of control room operators, and the decision to develop a training simulator was made
- The communication tools available for control room operators were improved, in installing an independent and dedicated communication means for emergency purposes
- The decision was made to equip systematically new generating units with a high-performance power system stabilizer
- The study of a new defense plan against major outages was launched
- The restoration plan was strongly reviewed.

On 12th January 1987, the weather on France was exceptionally cold and the consumption high (due to electrical heating). As a result of this situation ("extreme cold" procedures), all available generation means were operating. Nevertheless, a succession of unit tripping on the same thermal site located in the Western part of the French system caused a severe voltage collapse. As a matter of fact, 3 units of 600 MW each tripped for independent reasons at the Cordemais site between 11:00 and 11:40 a.m. One unit was still remaining on the site, but strongly loaded with reactive power, it tripped rapidly at 11:40 too, due to problems in its excitation system. This last event was the starting point of a very large voltage decrease on the Western half part of France.

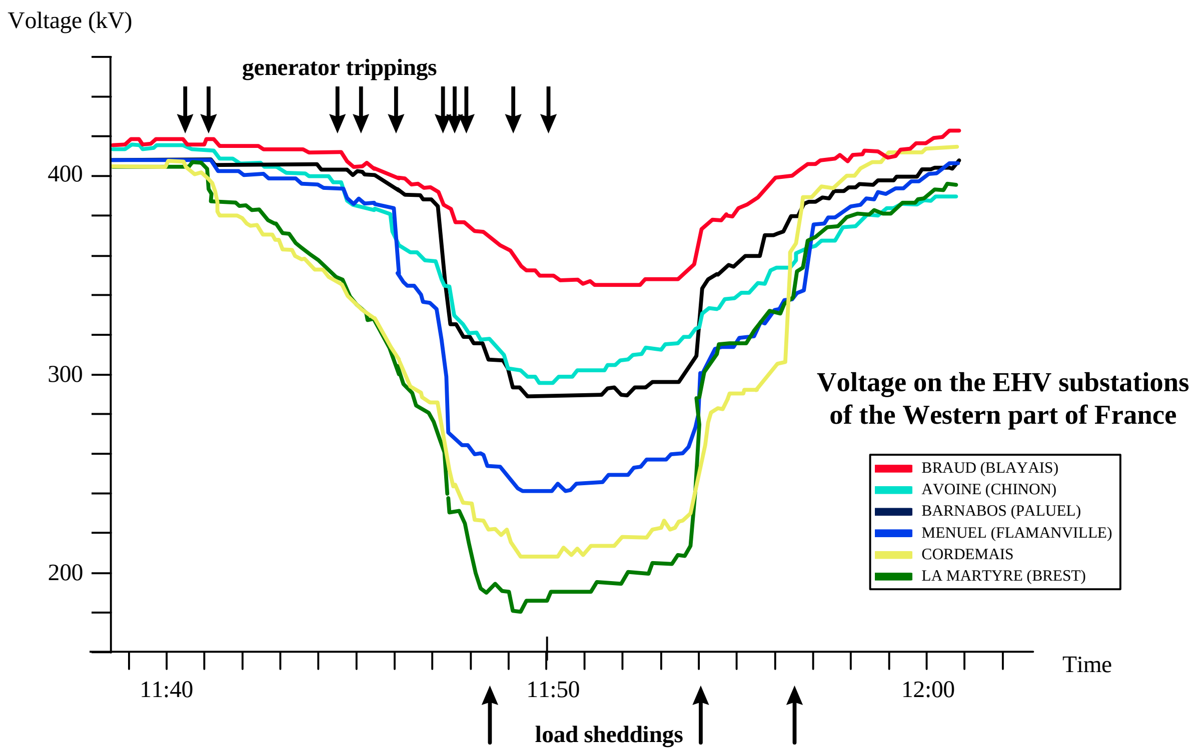
The effects of the disturbance were the following :

- the voltage decreased up to 0.5 p.u. on EHV system in the extreme West part of France, ten minutes after the collapse beginning
- 9 000 MW of generation were lost
- 8 000 MW of consumption were lost and/or shed (i.e. 13 % of the whole French consumption)
- but hopefully, none of the 400 kV transmission lines tripped
- the whole restoration was performed in 8 h (it was necessary to wait for the recoupling of thermal units in the Western part of France)

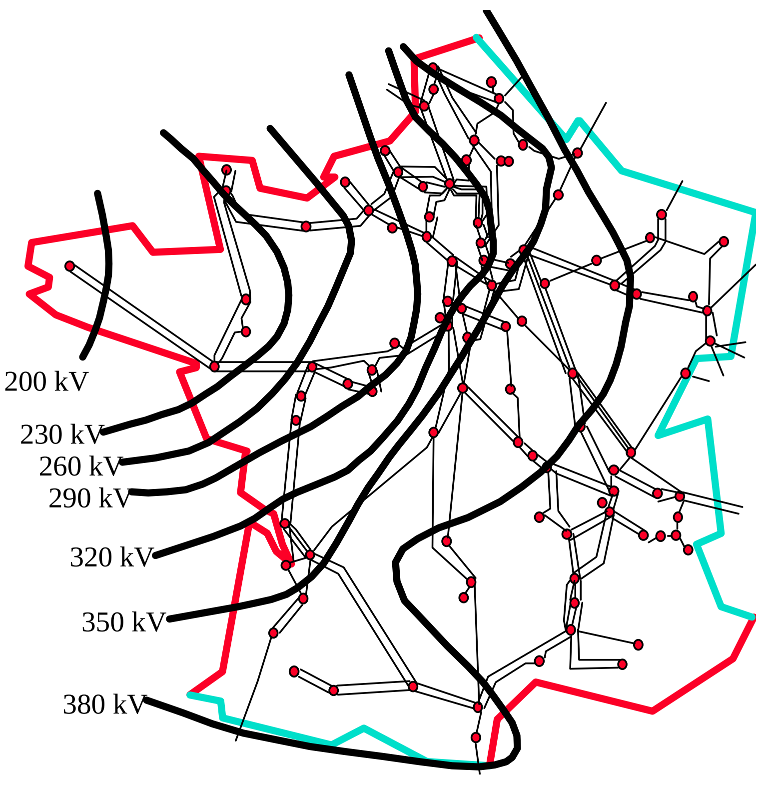
The analysis of the collapse highlighted the main following causes :

- it was due to an unpredictable multiple contingency (N-4 gen. in 45 min)
- a lack of quality existed in the setting of field current limiters and protective relays on generating units ; bad settings were unknowned but were revealed by the incident
- the manual emergency actions ordered by the control center staff were not completely efficient (the time of reaction and execution was too long).

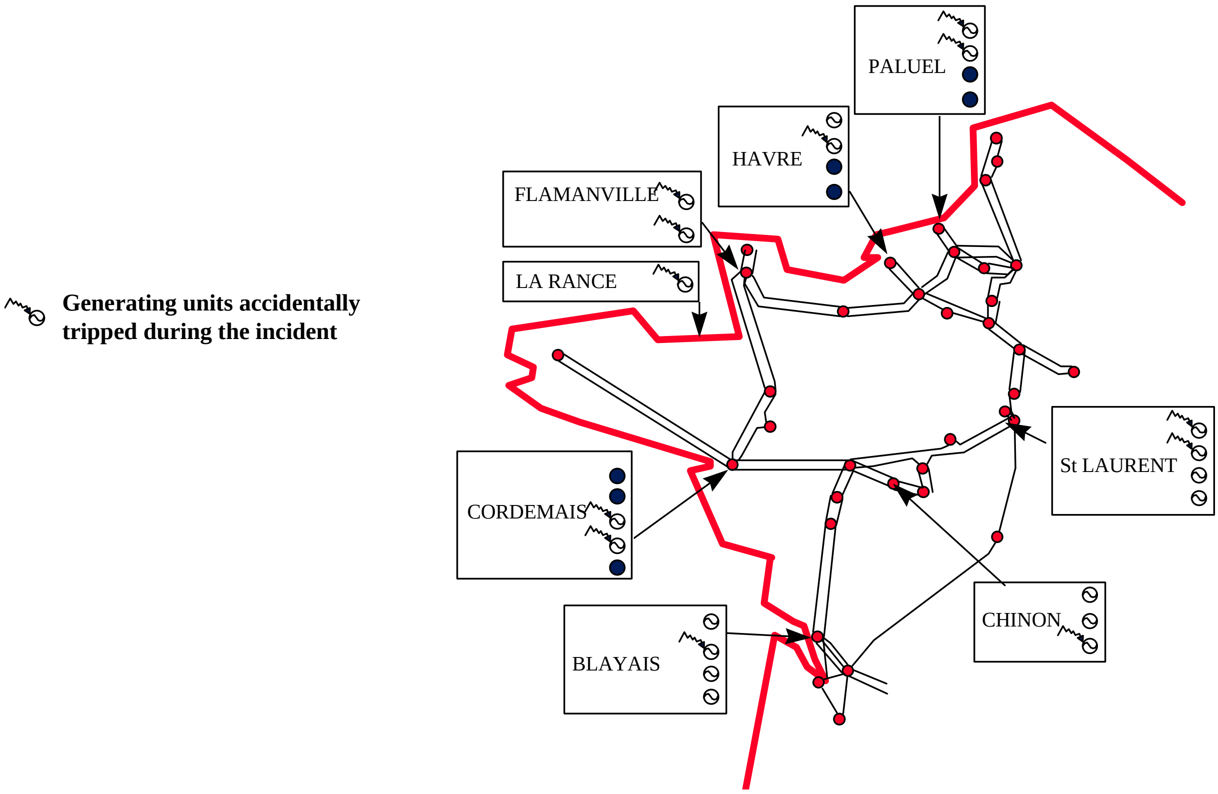
The following figures show the voltage profile on the EHV system, and the location of the generating units which tripped during the collapse.



Voltage vs. Time for some French EHV substations during the collapse



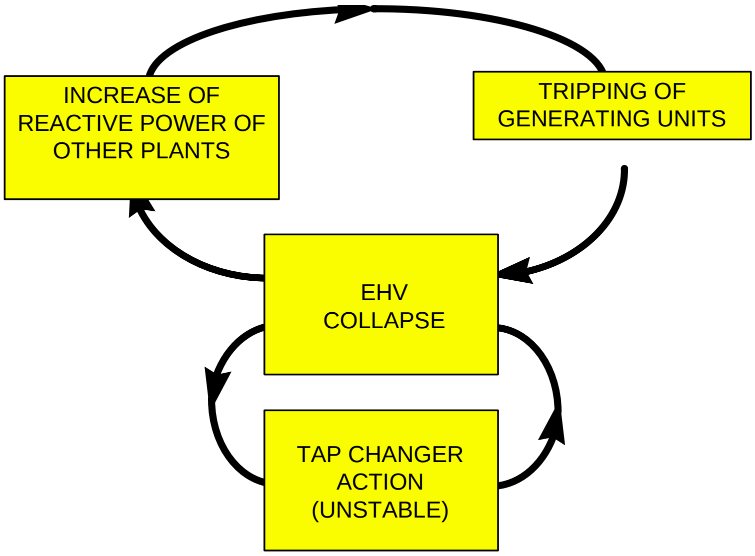
Geographical distribution of voltage 10 min. after the beginning, on the 400 kV network



Location of the generating units which accidentally tripped during the collapse

In fact, we can qualify the "engine" of the voltage collapse as double. On the one hand, the tripping of generating units induced voltage decrease on the EHV system, this voltage decrease induced itself an increase of reactive power generation of other plants. On some units this amount of reactive power generated provoked their tripping, which accelerated the voltage collapse phenomenon. On the other hand, the EHV voltage decrease led to the on-load-tap-changers action on the transformers between EHV and MV levels, and due to the lack of generation and voltage support, this process became unstable, inducing a deeper and deeper EHV voltage decline. This difficult situation was solved thanks to massive load shedding actions occurring 10-15 minutes after the beginning.

This "double engine" of the voltage collapse is represented in the following diagram.



Mechanism of the incident

The lessons learnt and action taken following this outage were the following :

- It was decided to create a team supporting the control center for the supervision of projects impacting the power system security
- The anomalies in control and protection devices of generating units were corrected
- It was decided to implement an automatic system locking the on-load-tap-changers on a voltage criterion
- It was decided to implement a manual remote control load shedding in regional control centers (allowing to shed up to 30 % of load, for extreme emergency use only)
- A development of an indicator of proximity to voltage collapse for use in the national control center was launched
- It was decided to analyze systematically the minor incidents, to adopt a classification by seriousness degree, and to generalize efficient recording means
- It was decided to proceed to structural reinforcement of power system security in the area (e.g. two old 300 MVA thermal units were transformed in synchronous compensators).

Document related to the 12th January 1987 : [1] (see appendix).

1.2. Present EDF plan against major outages

The phenomena involved during power system collapses can be classified in five main classes : frequency collapse, voltage collapse, loss of synchronism, large power swings and cascades of overloads. Against each phenomenon, two complementary kinds of measures are taken : preventive measures which prevent the phenomena from occurring, and curative measures which prevent incidents from spreading. The curative measures are either manual or automatic depending on the quickness of the phenomenon involved.

Here are presented the preventive and curative measures which protect the electrical system against large disturbances. We give also some details about the protective relays which save our equipment.

1.2.1. Large frequency variations

In case of frequency collapse

All the pumped storage hydro power plants are automatically disconnected at 49.5 Hz (time delay : 200 ms).

Underfrequency load shedding
The EDF load shedding plan, acting only on a frequency criteria, is given in the table :

Step	Frequency	Load shedding % of the total demand
1	49 Hz	15
2	48.5 Hz	15
3	48 Hz	15
4	47.5 Hz	15

Nota : the nominal frequency in Europe is 50 Hz.

This load shedding is automatic and not delayed (action after 200 ms).
The load shedding actions are coordinated with capacitor bank trippings in MV substations, to avoid overvoltages induced by underload operation.

Protection on the units in case of frequency collapse
There is a coherence between the actions undertaken in case of frequency collapse and the behavior of the generating units, i.e. between the load shedding plan and the settings of the relays separating the units from the grid :

- For nuclear and thermal units, islanding at 47 Hz (action time of about 200 ms).
- For hydro units, tripping mainly at 46 Hz (action time of about 200 ms).

In case of frequency increase

When the frequency is higher than 51.5 Hz, action on the power set-points to bring back the frequency value below 51 Hz in 10 min.
After 10 min, islanding of the units by operator's action.

Protection on the units in case of high frequency
For nuclear and thermal units, tripping at 55 Hz (action time of about 200 ms).
For hydro units, tripping mainly over 55 Hz.

1.2.2. Large voltage variations

In case of low voltage

Preventive actions :
Adjustment of the voltage regulator set-points, switching capacitors or adjustment of generation schedule.
We have had in operation for 15 years now a Secondary Voltage Control which role is at the same time to harmonize the voltage level on the EHV network at the highest possible, to equilibrate the reactive generation of the units, and to enhance the margin of reactive power available to cope with potential hazards.

Curative actions :
Automatic blocking on-load-tap-changers on transformers and reduction of voltage references of OLTCs.
In France, on-load-tap-changers exist only on EHV/HV and on HV/MV transformers. Because of the larger number of HV/MV transformers to be equipped, it was decided to block *only* the EHV/HV ones in case of voltage collapse. As a consequence :

- most of the time, the blocking is done on a predetermined tap, chosen to take into account the fact that the HV/MV on-load-tap-changers are not blocked and can operate, in case of voltage collapse, as far as they hit the highest tap. This predetermined tap corresponds to a transformer ratio smaller than the rated ratio, which leads to an intentional drop of the secondary voltage.
- when there are many generators on the HV network, the on-load-tap-changers are blocked on the medium tap : the goal of this action is to minimize the risks of generators tripping because of a low voltage.
- in some cases, the on load tap changers are blocked on the current tap.

How does the blocking of OLTC operate ?
Our network is divided in different areas, predetermined by studies and experience, homogeneous as far as voltage collapse is concerned. When the voltage goes below a predetermined threshold in a substation chosen as a reference (roughly near 370 kV for the 400 kV network), a blocking order is elaborated in a regional control center calculator and is sent to all the OLTCs of the EHV/HV transformers located in the area. The total operating time is of 1min roughly.
The measure of reduction of voltage reference of OLTCs on HV/MV transformers (-5%) can be manually taken as a complement. This measure limits lightly and temporarily the MV demand.

Protection of the generating units in case of voltage collapse
In this case also, even though the operating point is degraded, there is a coherence between the actions made and the behavior of the units in particular towards generator protective relays based on undervoltage and overfield current criteria.
For nuclear units, islanding at 0.7 Un with a time delay of 2.5s,
For thermal units, islanding at 0.7 Un with a time delay of 0.9s.

In case of high voltage
Protection on the units in case of high voltage
In case of overvoltage, tripping of the units at 1.2 Un with a time delay of 3s.

1.2.3. Loss of synchronism

Preventive actions :
All thermal units are equipped with fast valving which acts as a very fast speed governor in case of a very close short-circuit. In addition, the voltage regulators induce an overexcitation in case of a fault. Both contribute to enhance the stability margins in operation.
The major part of the generating units are also equipped with voltage controllers very efficient towards the damping of power system oscillations (both local and inter-area modes). These regulators combine and coordinate in the same device the actions of a classical AVR and an advanced PSS.
Differential protection is used as base equipment for the 400 kV network (busbars and transmission lines).

Curative actions :
The principle is to island as fast as possible the out-of-step area in order to prevent the spreading and so to save the rest of the grid. Automatic islanding is made by out-of-step relays located at the boundaries of elementary dynamically coherent areas. There are 17 areas on the French network determined by off-line dynamic simulations. The principle of the out-of-step relays used is to act when they detect voltage beats due to a loss of synchronism. Depending on the location, the out-of-step relay act after the second or the third beat on the 400 kV network and after the first beat on the 225 kV network (i.e. roughly 2 or 3 s after the beginning of the disturbance).

In addition, all the generators of the thermal units which power is higher than 600 MW are equipped with out-of-step relays, which operate :
- as back-up protections for loss of synchronism occurring on the power system,
- as equipment protections in case of internal outage (e.g. loss of excitation).

Their main principles are the following : two ways are operating in parallel, the first one checks the power inversions and the other one checks the internal angle rotations. These two events are counted separately in a certain period of time and compared to two thresholds which are separately adjustable.
The settings are :
- for nuclear and thermal units, tripping after 4 rotations of internal angle or a number of power inversions adjusted distinctly on the various unit of the same power plant between 10 and 20 to avoid simultaneous trippings,
- for hydro units, tripping after 2 rotations of internal angle or between 12 and 20 power inversions.

Note that a new defence plan against loss of synchronism based on phase angle measurements is now under test in the South East region of France (see section 1.3.).

1.2.4. Large power swings

Preventive actions :
The major part of the generating units are equipped with voltage controllers very efficient towards the damping of power system oscillations (both local and inter-area modes). These regulators combine and coordinate in the same device the actions of a classical AVR and an advanced PSS.

Curative actions :
None, no risk of undamped power swing being identified.

<u>1.2.4. Cascades of overloads</u>

Preventive actions :
Single phase automatic reclosing is systematically used on EHV transmission lines and automatic three phase reclosing system on international and internal transmission lines (phase displacement between 20 and 60° depending on the length of the line and on possible stresses in the shafts of large generating units).
Distance protections are blocked against power swings.
Busbar connections are day by day adjusted in order to limit the consequences of "simple" busbar faults, or "complex" busbar faults (busbars due to the failure of a circuit breaker coupling two busbars). All substations are operated with at least 4 separable parts, either connected in a single node, or separated in two nodes composed each of two separable parts. Line connections are always mixed on the different busbars. These procedures aim at limiting the risk of multiple transmission line tripping (particularly in the same corridor) or multiple generator tripping of the same plant.
Automatic Generation Control is systematically used in Europe. This allows in particular to adjust automatically the load flows at the borders with the foreign partners interconnected synchronously.

Curative actions / protection of the electrical equipment :
The lines are equipped with protective relays which function is to trip the line when the current is over a predetermined value called Imax. The setting of this value changes depending on the season. There are three thresholds :
- I > Imax with a temporising of 20 mn
- I > 1.2 Imax with a temporising of 10 mn
- I > 1.6 Imax with a temporising of 1 mn

In case of very high overloads, the lines can be tripped on a criteria of impedance, because of the action of the distance protections. When the current is near 1.8 In , the lines can be tripped after 0.1 to 3s.

In case of slow cascade of overloads, the control engineers in the dispatching centers have a permanent survey of the network and especially the constraints (current) on the lines. They can order emergency ramping on generating units, or (in extreme cases) remote controlled load shedding.

Implementation of Special Protection Schemes (in some particular corridors), in order to cope with high speed overload cascade risks : disconnection of hydro and/or nuclear units in case of severe overloads on monitored transmission lines (see section 1.4.).

Documents related to this theme : [2] for the French defence plan, [3] for a UNIPEDE comparison with other European practices (see appendix).

1.3. New scheme against losses of synchronism

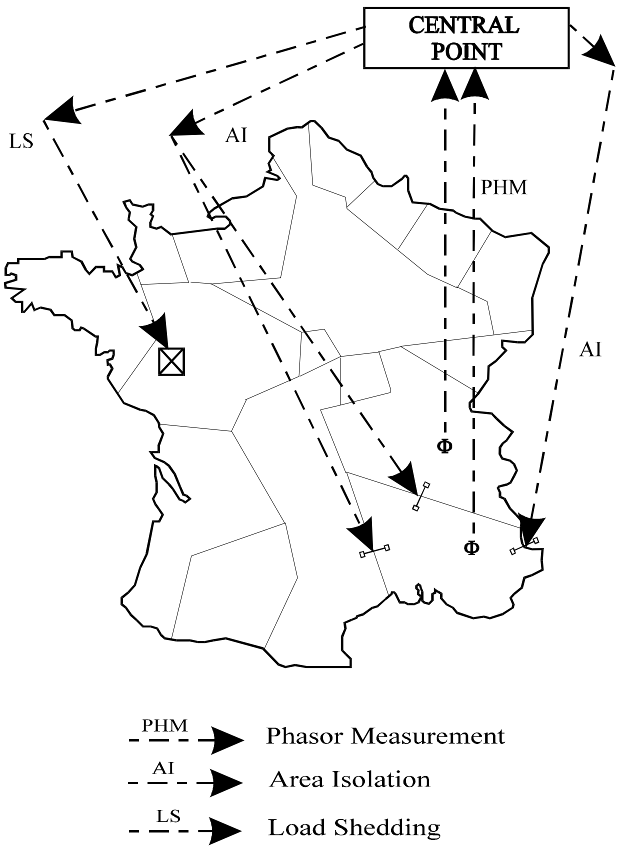
We have designed a new scheme against losses of synchronism because our studies have shown that a plan based on independent out-of-step relays becomes less efficient as the network becomes more meshed. This is first due to the fact that an out-of-step relay can only have an indirect view of the phenomenon, thus is not perfectly selective. Furthermore, it acts independently from other devices in the network, thus their combined actions can be insufficient to remedy the disturbance (in particular such relays cannot order load shedding, although sometimes it is required).

The new scheme is a coordinated system, based on the following principles :

- voltage phase angles are measured in the heart of the zones which are electrically coherent
- these measurements are transmitted to a central point
- they are processed to detect losses of synchronism
- in case a loss of synchronism is detected, the following actions are decided :
    - ◊ the out-of-step area is separated
    - ◊ a load shedding is performed (when necessary) in weak parts of the power system to avoid them being destabilized.

We use Phasor Measurement Units (6 for each protected area), which measure voltage phasor (magnitude and angles) and frequency. The devices are time-synchronized by the Global Positioning System (network of low orbiter satellites). The performance of the PMUs are the following : response time of 150 ms, angle precision of 1°, magnitude precision of 2.5 kV (base 400 kV), frequency precision of 20 mHz (these performances are reached statically and dynamically on the whole domain 45Hz-55Hz, 5kV-600kV).

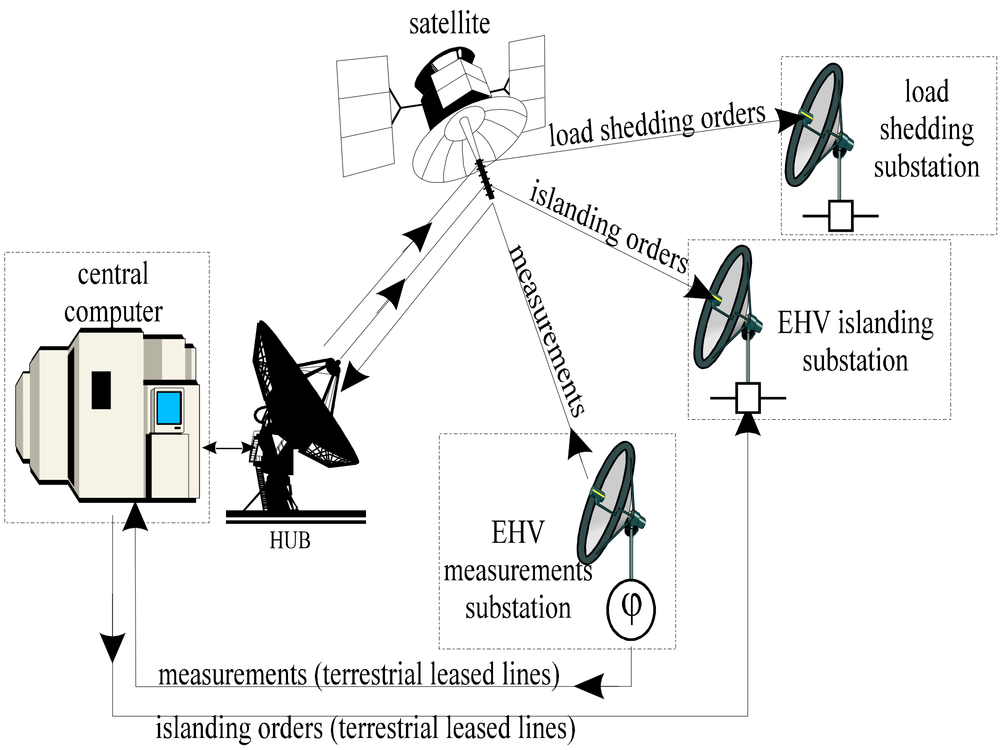
The following diagram shows the synthetic organization of the scheme.



Principles of action of the new scheme

The scheme is an automatic system, acting in real time. The measurements are sent to the central point every 50 ms (20 times per seconde). The central points detects potential losses of synchronism through comparison between phase angles of neighboring areas. The total response time of the system is 1.3 s (all included, i.e. from the response time of the phasor measurement unit up to the action time of the circuit breakers).

The communication needs are covered both by a service provided by a geostationary satellite and terrestrial means, as presented in the following diagram.



Communication architecture of the new scheme

The scheme is being implemented in 2 zones of the South-East region of France, including 15 000 MW of nuclear generation, 10 000 MW of hydro generation, and 15 000 MW of peak load. Each zone is equipped with 6 phasor measurement units. The rest of France id equipped with 6 other PMUs. 40 EHV substations at the border of the South-East region are equipped with line tripping devices. 500 MV substations in the Western part of France are equipped with load shedding devices (representing a total amount of 5 000 MW).

A strong attention has been put on reliability aspects, from the very beginning of the project. Let us remind that the reliability covers two different points :

- the possibility for the scheme to be subject to undesired operation, in situation for which the scheme is not planned to operate
- the possibility for the scheme to execute imperfectly or unsuccessfully the required actions.

Here are listed the different steps of the reliability studies performed :

- First the reliability objectives were determined. It consisted in fixing the rate of undesired operation and unsuccessful operation in coherence with the function of the scheme, and the consequences of a misoperation. Here the values retained were respectfully one undesired operation every 1 000 years, and one unsuccessful operation every 1 000 cases (for an estimated operation rate of once every 10 years).

- Then a preliminary decomposition of the scheme was made. A comparison between various architectures was performed, in terms of functions realized, and reliability obtained. This step resulted in the choice of a preferential architecture (here, based on the use of a central point).
- The next step consisted in defining, for the chosen architecture, the reliability objectives for each subsystems, in a top-down approach. This procedure showed clearly the critical paths of the scheme, where redundancy had to be employed.
- Then a complete verification analysis was performed, and after some iterations, it resulted in the detailed specifications of the scheme.
- We can say that this process do not stop with the realization and implementation of the scheme, because an analysis of the operation feedback allows to regularly update the studies with real failure rates and repairing times. This is highly useful to maintain the level of reliability required, through the assessment of the need of corrective measures, or maintenance procedure modifications.

The time schedule of the whole project is the following :

- 1989-1991 : realization of the functional studies
- 1991-1992 : technological feasibility studies (mock-up)
- 1992-1993 : specification redaction
- 1993 : call for tender
- 1994-1996 : realization of hardware and software
- 1996-1997 : progressive installation, step-by-step test and validation
- 1997-1998 : additional validation of the software by formal proof methods
- 1999 : open-loop operation
- 2000 ? closed-loop operation

Documents related to this theme : [4], [5], [6], [7], [8] (see appendix).

1.4. Feed-back experience on Special Protection Schemes design and implementation

We have just a few SPS in France. Here are the main features of one example of such a scheme implemented in one of our areas. It was designed to avoid the consequences of a cascading line tripping in a corridor. The action realized by the scheme is the tripping of hydro pumps units (on one receiving end of the corridor), and/or the tripping of nuclear units (on the emitting end of the corridor). The amount of load or generation tripped can reach 1 800 MW. The criterion used by the scheme is overload thresholds (each line is systematically equipped with overcurrent protection in France). The action time presents several steps, depending on the severity of the overload to be counteract, and the efficiency of the trippings already ordered : it spreads from 30 s to 9 min. The scheme uses a local Programmable Logic Controller to realize securely the faster action, and the EMS-SCADA system for the slower ones. The scheme is supervised and configured by the regional control center (the arming, and the choice of the units to trip).

Our feedback experience leads us to highlight the importance of the following steps in the functional and design studies to be realized at the beginning of an SPS implementation project :

- identification of the risks to be covered (the combination of dangerous events leading to an uncontrollable situation in the power system)
- elaboration of the remedies (and test of their efficiencies depending on their criteria, types of action, time delays)
- analysis of their impact on the system. Can a successful operation create sometimes other problems? What are the consequences of an undesired operation ?
- investigation of the functional robustness of the scheme, i.e. the sensitivity of its efficiency to the power system conditions
- examination of the flexibility needs : which parameters have to be fixed, which must be adjustable ? In which range of tuning ?
- analysis of the evolutivity needs, in case of commissioning of new facilities, or increase of load
- choice among the possible architectures : take carefully into consideration both reliability and technical performances (especially if very rapid action time is required)
- study of the compatibility with other existing "classical" protection devices
- analysis of the interaction with other SPSs. From this point of view, the pros and cons of the possible coordination methods must be carefully examined : exchange of some information between autonomous SPSs, or elaboration of a two-level system, with master and slaves. Comparison in terms of simplicity, performance, reliability.

The SPS efficient for meshed networks will be necessarily more complex than those for radial networks.

Reliability aspects need to be treated with a rigorous approach (see section 1.3.). Below, we give some pieces of advice on this topic :

- One difficulty consists in determining the reliability objectives for the whole scheme. We suggest to fix the acceptable rate of undesired operation at a certain level (for example 10%) of the power system disturbance rate leading to the same consequences. For the rate of unsuccessful operation, we suggest to take as a reference the probability of unaccomplishment of actions of similar purposes by "classical" means.
- Redundancy is not an input requirement for the design, but results from a precise reliability study of the whole scheme. As a matter of fact, only the reliability study can indicate where the critical paths are (i.e. where redundancy is required), and the type of difficulty encountered (i.e. the type of redundancy which is needed). Because several dispositions of redundancy exist, each presenting pros and cons from the point of view of the two reliability aspects (undesired/unsuccessful operations).
- The reliability performance of the extremity equipment is often determinative (sensors and circuit breakers).

- It is profitable to explicitly integrate in the specifications the possibility to validate easily all its various components of the scheme. It has concrete consequences in terms of hardware and software realization.
- The maintenance aspects have a strong influence on the resulting reliability of the scheme. Such aspect can be usefully anticipated.

The SPSs have a strong impact on the operation environment. SPSs increase the complexity of operator tasks. As a matter of fact, the operators must integrate the SPS actions in their mental process, which is not so easy, particularly in disturbed situations. Furthermore, they might have to adapt regularly the SPS parameters to the network or generation configuration, which represent an additional charge.

The whole cost of SPSs depends on their architecture, complexity, and location. Here are described the main cost components :

- the cost of the functional studies
- the cost of the design studies
- the cost of hardware
- the cost of software
- the cost of installation (including costs linked to EHV facility disconnection)
- the telecommunication charges
- the cost of training
- the cost of maintenance.

Designing and implementing a new SPS is a complex project, and we retained the following lessons from our recent experience, from the project management point of view :

- a clear distinction must be made between the roles of the project team representing the client, and the team in charge of the realization and implementation
- a procedure of quality insurance helps to avoid major problems
- the steps of need expression and functional definition must not be skipped, in spite of the emergency pressure
- it is useful to define at the very beginning the reliability objectives, with a precice identification of the consequences of an undesired or unsuccessful operation
- it is profitable to integrate from the beginning some possibilities of later evolution
- aspects linked to the integration of the SPS in the operation environment need to be anticipated, as well as maintenance organization and procedures
- it is highly recommended to adopt measures allowing to guarantee the perennity of the required quality : documentation, training of participants, continuous coordination of operation and maintenance teams, updating of functions with the power system evolution, as long as the equipment is still in service.

1.5. State-of-the-art on SPS development. Main features - Some samples

The following table present the various types of SPS which can be implemented, decomposed by collapse phenomenon involved.

Phenomenon	Criteria	Time delay	Actions
generation / demand balance (problems of frequency)	frequency thresholds rate of frequency variation predetermined events (loss of gen. units, big consumers)	0.1 s to several minutes (depends on system size and magnitude of disturbance)	load shedding hydro pumps tripping fast unit starting DC import
voltage	voltage thresholds rate of voltage variation predetermined events (loss of gen. units and/or transmission lines)	1 s to 2 minutes (depends on system configuration and associated risks)	load shedding tap changer locking reactive compensation connection/disconnect. fast gen unit starting
overload	current thresholds predetermined events (loss of gen. units and/or transmission lines)	1 s to 1-10 minutes (depends on system configuration and protection)	network maneuvering gen unit tripping load shedding fast gen unit starting
transient stability	preventive : predetermined events (loss of gen. units and/or trans. lines) remedial : impedance, voltage beats, phase angles	0.1 s to 1.5 s	gen unit tripping load shedding controlled network islanding
steady state stability	preventive : predetermined events (loss of gen. units and/or trans. lines) remedial : undamped oscillations	several seconds	network maneuvering gen load reduction DC control

Table of SPS characteristics classified by collapse phenomenon involved

<u>Description of the Italian SPS " Critical Section Control"</u>

In the 90's, the Italian company ENEL developed a Special Protection Scheme called "Critical Section Control". We describe here its main features.

The objective assigned to the SPS is to avoid the cascade line tripping and the consecutive splitting of the Italian power system (whose main characteristics are to be essentially radial, and to import much power from other European countries). The function realized by the scheme is load shedding, or, in some special cases, generating unit tripping. The main principles are the following :

- there are several critical sections monitored along the country (e.g. Sicilia, Rome, at the border with France and Switzerland)
- the SPS is armed when the load flows on the section exceed a predetermined threshold, which depends on the number of residual transmission lines.

The triggering criteria are the tripping of one or the combination of the monitored transmission lines, if the SPS is armed for this event. The action time is 1 s. This scheme has been commissioned in 1992.

Description of the Japanese SPS of the Chubu company

The Japanese Chubu company has developed another interesting SPS, called "Transient System Control". Here are its main characteristics.

The objective assigned to this scheme is to avoid losses of synchronism, in a part of the Japanese power system. The function realized is a very fast generation tripping (up to 2 000 MW). Its principle is as follows :

- the precise actions required (which unit to trip, for which fault ?) are preprocessed every 5 minutes, by means of automatic dynamic calculations
- the system uses real time data issued from a state estimator
- fast dynamic assessment methods are used to rank the disturbances
- detailed simulations are performed on the cases selectionned
- on the unstable cases, the number of units to be tripped is determined by iterative calculations
- the results of these off-line computations are regularly communicated to the substations concerned (short circuit feared, remedial actions).

The action criteria are only local : they consist on the detection of the short-circuit feared. The action time is very short : 0.15 s. This system has been commissioned in 1995.

We can remark the use of the transient variations at the terminals of the unit tripped, as a local validation signal of the remote received order : a good way to reduce the probability of undesired action in quiet operation (as a matter of fact, we can consider that the system is quiet at least 99% of the time).

Description of the Japanese SPS of the Tokyo company

The Tokyo electric company has developed a similar scheme. Its description is presented hereafter.

As for the Chubu one, this scheme aims also at avoiding losses of synchronism in another part of the Japanese power system. Here again, the function realized is a very fast generation tripping (up to 2 000 MW). Its principle is slightly different :

- it is based on an on-line prediction of the phase angle between two electrical areas of the system for the next 0.25 s
- the scheme uses voltage, current and power signals measured in several substations
- transient calculations are performed, after simplification of the system and reduction to a two-machine model
- the number of units to be tripped are computed by iterations.

The tripping action is ordered when the displacement of phase angle predicted between the two areas exceeds a predetermined threshold. The action time is 0.25 s. This system has been commissioned in 1992. It has operated successfully once several months after its commissioning. It uses also transient variations at the terminals of the generating units to be tripped as a local validation signal of the remote received order.

Document related to the Italian SPS : [9] (see appendix).

Document related to the Chubu SPS : [10], [11], [12] (see appendix).

Document related to the Tokyo SPS : [13] (see appendix).

1.6. Security rules in operation

The objectives of operation actions towards security are the following :

- to respect equipment constraints (i.e. no exceeding values for active and reactive power on generators, current on transmission lines, voltage on electrical equipment and auxiliaries, short circuit power on substations)
- to keep the integrity of the power system (insuring there is no unsustainable overloads, no frequency or voltage stability problems, no angle stability problems, no risk of undamped oscillations)
- to maintain the supply to customers within contractual limits, in terms of continuity and quality of service
- to choose the solution minimizing the impact on commercial transactions between market participants (except in emergency cases)

both for the N situation and during/after a credible contingency.

The classical approach considers for the credible contingencies all the single outages (N-1 rule).

We consider this N-1 rule unsatisfactory because the economic pressure joint to the enhanced operating tools lead to a dramatic reduction of the effective margins. Furthermore, the major power failures are less and less economically and socially acceptable.

That is why we adopted an approach based on the risks. The risk can be defined as the product of the probability of an event, and the magnitude of consequences of this event (measured by the undelivered power or energy, for example).

Risk = probability x consequences

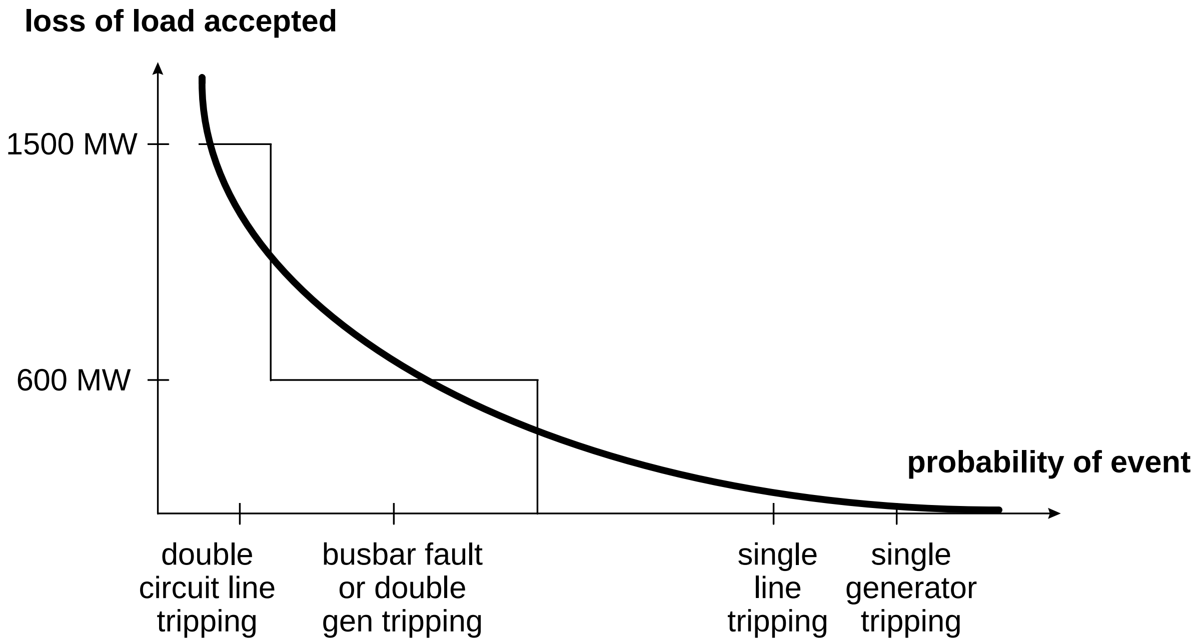
The probability considered here is the mean rate of occurrence of the category of event.

The present EDF security rules can be summed up in the following table.

Event	Consequences (limited to the load shedding of)
Tripping of a single transmission line, transformer, or generating unit, following a three-phase short circuit cleared normally	none
Tripping of two generating units	600 MW
Three-phase busbar fault	600 MW
Tripping of a double-circuit line following a three-phase short circuit cleared normally	1500 MW

Table of the present EDF security rule

This rule corresponds to a risk accepted which is materialized on the following diagram.



Curve of accepted risk

Some reflections have been launched to go further in this direction. The developments concern :

- the possibility to take into account the weather conditions ; as a matter of fact, we consider that the probability of a double-circuit line fault during thunder storms is 100 times greater than by clear weather. However, one of the difficulties to solve if we adopt this distinction, is the complexity induced on the operational planning process.
- the possibility to take into account individual probabilities instead of mean values ; this would allow to better represent local particularities, and the difference between technological performance of equipments. But the constitution of the database, its regular updating and analysis bring difficulties, as well as the application of deterministic tools in this context.
- the extension of the reasoning up to a real cost-benefit analysis, i.e. measuring the consequences of a disturbance in term of cost to be supported.

1.7. Restoration plan

The EDF restoration plan is adapted to the main characteristic of the French power system, i.e. its large proportion of nuclear generation.

All our thermal units (including nuclear units) are planned to island in case of unacceptable network conditions. But we know that the complete success of such islanding procedure during disturbed conditions cannot be guaranteed. That is why the restoration strategy we follow aims at re-supplying as fast as possible the auxiliaries of the nuclear units that have tripped. As the nuclear site are dispersed on a large part of the country, our priority is to constitute viable re-energizing paths between black-start units (hydro units, gas turbine) or islanded units, and nuclear sites.

These re-energizing paths are predetermined thanks to studies and periodic field tests. Their constitution in case of black-out is facilitated by the action of dedicated relays installed on all EHV bays, which open all the circuit breakers automatically in case of a loss of voltage (with a certain time delay), except the main breakers of the re-energizing paths.

The re-energizing procedure is also facilitated in using a gradually increasing voltage procedure on our hydro units, to avoid switching overvoltages. The principle is to constitute the path from the hydro generator up to the receiving transformer without voltage first (this necessitates to inhibit some protections in substations). Then the excitation of the hydro unit is progressively increased to the normal level (in 20 s), this low speed does not excite the electromagnetic modes of the system.

The next step in the restoration process is to constitute isolated regional subsystems, putting in parallel progressively the re-energizing paths constituted. At this stage, the amount of consumption picked up is voluntarily limited at a level (30 %) allowing a stable operation of the generating units, but without excess to avoid overload problems on such weak transmission systems.

When the regional subsystems are constituted, they are recoupled together, and the load can finally be progressively re-supplied, at a speed depending on the ability of the thermal units to increase their own generation.

Documents related to this theme : [14] and [15] for the French restoration plan, [16] for a UNIPEDE reflection on the coordination need of service restoration (see appendix).

1.8. Use of dispatching training simulator

EDF has been exploiting a dispatching training simulator for 12 years. This simulator is used both for initial training of new operators, and refresher courses and skill development for experienced operators.

It allows to cover the following training needs : the every day switching operations, the emergency actions during disturbances, and restoration after outages.

It is based on a software allowing a real time simulation on a complete model of the power system, including slow dynamics and even a simplified transient dynamic representation, and the modeling of the protection actions. It is completely interactive between the trainer and the trainee. The instructor can introduce disturbance at any time. The system has extended possibilities to freeze the action, to play in slow motion, to replay actions, and to memorize situations at any time.

EDF has now available a new version of its simulator, called SIDERAL. It has extended possibilities of modeling (up to 1 500 nodes), and is open to any network configuration : it can present the same images as in the control room; and represent any area particularity.

The benefits in using a dispatching training simulator can be summed up as follows :

- it speeds up the training period of beginners
- it enhances the professionalism of experienced operators
- it is an essential tool for all to acquire secure reflexes under disturbed situation.

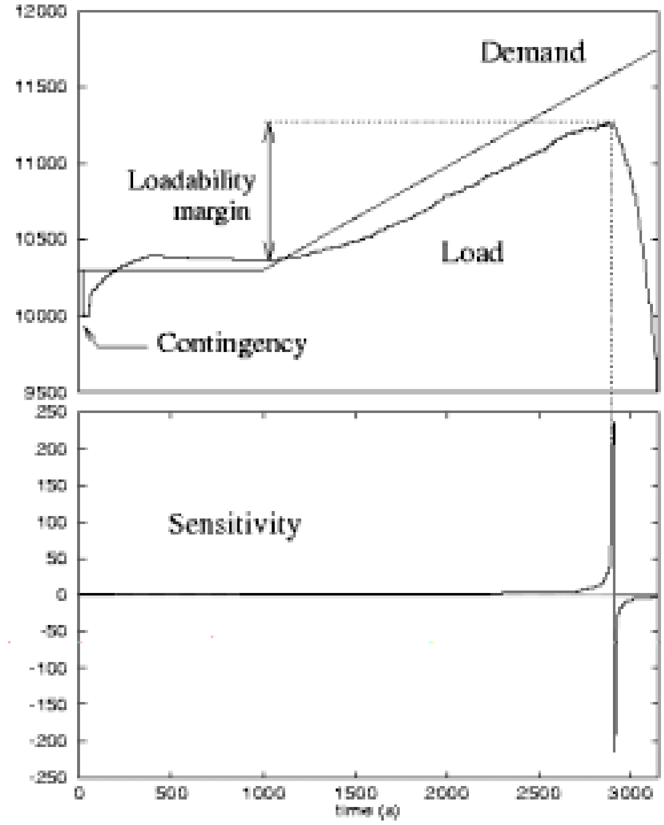
Documents related to this theme : [17],[18] (see appendix).

1.9. Voltage dynamic security assessment

A new tool performing Voltage Dynamic Security Assessment has been developed and put recently in test in the operational planing team of the EDF national control center. It is fed with SCADA-EMS data, extrapolated to the time horizon studied.

The next figure gives an example of a simulation performed on a case. The upper curve shows the total load consumed in a region vs. time. At the time 0, a disturbance is considered (tripping of a generating unit). The simulation shows that a stable regime near to the initial state is obtained in 400 to 500 s. Thus, first result, the case is stable towards this disturbance.

Then, from 1 000 s, the demand is progressively increased in order to determine the loadability margin of the system. The examination of the operating point behavior on the upper curve, and the sensitivity factor on the lower curve shows that the instability is reached when the load increase reaches approximately 1 000 MW. Thus, second result of this simulation, the loadability margin here is equal to 10 % of the initial load, which is comfortable : the situation is secure. There is no need to undertake preventive actions against this contingency.



Example of simulation performed with the Voltage Dynamic Security Assessment tool

The main advantages of such a tool is to allow :

- the detection of voltage constraints (through unstabilities, or low margins)
- the measurement of the disturbance effects
- the test of remedy efficiency.

Document related to this theme : [19] (see appendix).

1.10. Statistical approach developed for dynamic security analyses

Classical deterministic dynamic studies reach sometimes their limits. In particular the justification of security rules or investments in emergency actions require to take into account the complexity of the power system, characterized by :

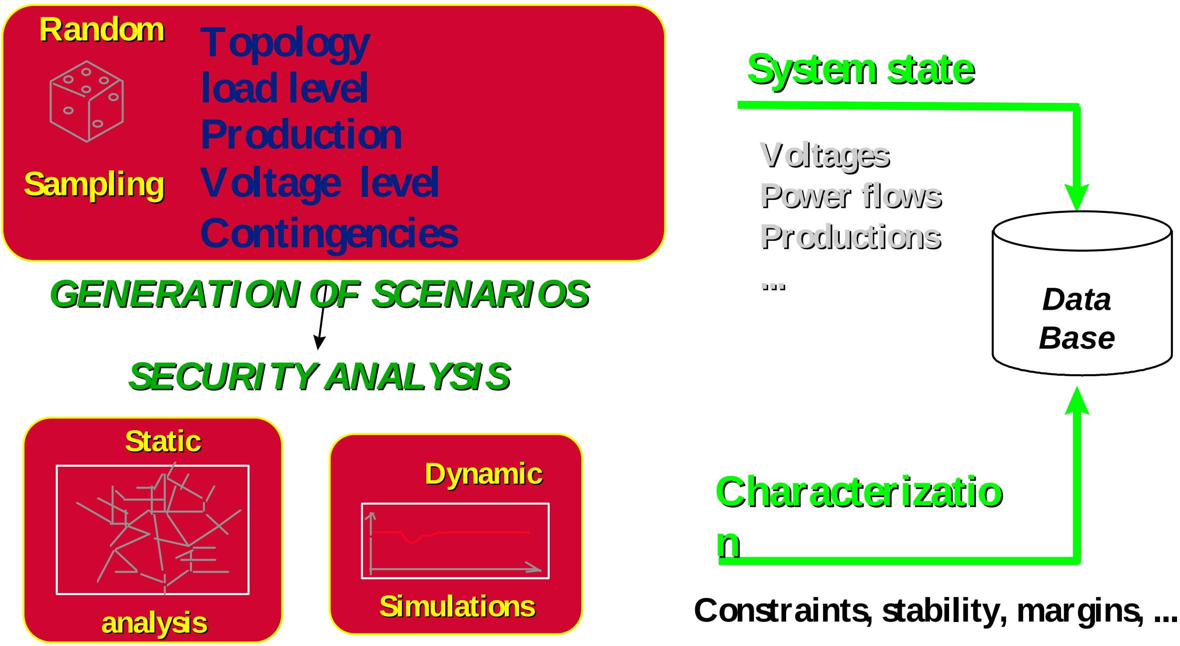
- the large number of operating points (combination of changes in load consumption, network topology, production mix)
- the possible contingencies
- the precise dynamic behavior of the components of the system (generating units, protective relays, defense plans).

The interest of a statistical approach developed to face this complexity is shown through 2 examples, after having presented the main features of this new methodology.

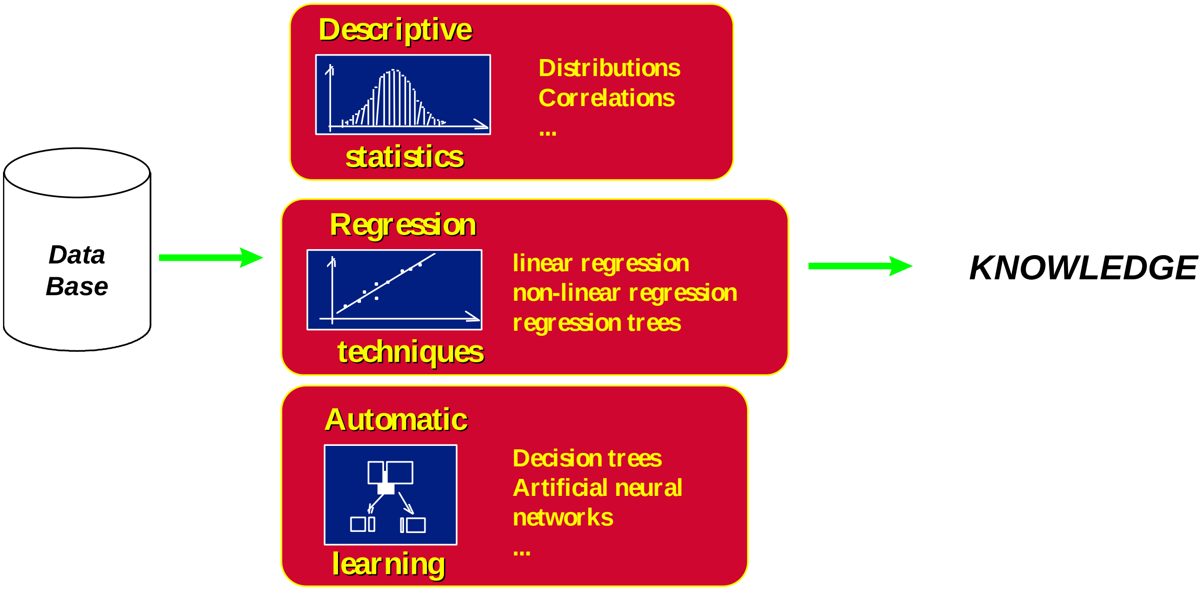
The methodology consists of 3 steps :

- first, a set of several thousands of scenarios is automatically generated, taken into account given probability rules for all the factors taking place (transmission line availability, load level, generation, voltage levels, contingencies)
- then, all the dynamic simulations are run on a set of workstations (depending on the size of the system, the simulation time can last several weeks)
- at last, we dispose of a database containing the dynamic variations of the main parameters of the system, and the work consists in analyzing this amount of information thanks to modern methods (descriptive statistics such as correlation factors, regression techniques, and automatic learning such as decision trees or artificial neural networks).

This method is graphically represented on the following two figures.



Step 1 and 2 of the method : construction of the scenarios, and generation of the database



Step 3 of the method : statistical analysis of the data base

First illustration of the application of such method : it was used to measure precisely the risk of voltage collapse in a specific part of the power system (the French Riviera), identifying the key parameters for system security, comparing the severity of several disturbances, measuring the security margin brought by various means (unit preventive starting, emergency action), and determining the order and at which thresholds the actions must be carried out to manage the level of risk/cost compromise at a given value. It allowed the operators to better control the margins of the system and the real security of the system, and to make an annual gain comprised between 1 and 2 M US $.

Second illustration, this methodology was also applied to determine on another French region the possible modes of collapse in the system, to determine their probable consequences, their main characteristics (speed of evolution), to detect possible weak points, particularly severe disturbances, to test the efficiency of solutions, and to see if there is lack in protection. One potentiality of such method is to be able to measure directly the efficiency of a remedial action, depending on the precise setting of a parameter, and thus to provide precious information to adjust thresholds of SPS or other defence device.

Documents related to this theme : [20] ,[21] ,[22] (see appendix).

2. RECOMMENDATIONS FOR THE IMPROVEMENT OF THE BRAZILIAN POWER SYSTEM SECURITY FOLLOWING THE 11TH MARCH 1999 OUTAGE

PREAMBLE

1. Process put in place in Brazil after the outage

The efforts deployed by all the actors of the Brazilian electric sector to analyze and remedy the outage are quite impressive. The work performed in just a few weeks is enormous. The occurrence of the outage is not seen as a fated event, but as a **good opportunity to improve** the planning and operation practices of the power system. The lessons of the event are analyzed in order to gain experience from it, in a very positive approach. ONS, ELETROBRAS and CEPEL must be congratulated for their capacity to mobilize all the partners involved.

2. Hierarchy of the remedies

Most of the remedies presently studied involve Security Schemes or Special Protection Schemes. These means are certainly quick ways to bring solutions to some weaknesses detected. But attention must be paid to the fact that **these means do not replace structural reinforcements** of the power system, which are anyway necessary to enhance the transfer capabilities of the Brazilian grid and preserve its security in the phase of sustained development it is living now. With this end in view, the extension of **national interconnection between states and companies** is certainly profitable.

SHORT TERM ANALYSES AND REMEDIES

3. Identification of the critical points and cascading effects risked

The most part of the analyses performed by the Group #1* aims at identifying the critical substations in terms of structural layout, protection equipment and consequences of the loss of a major part of the transmission lines connected. We suggest to extend this investigation to the sensitivity to short-circuit severity, i.e. its nature and duration. The method of **"critical clearing time" calculation applied to 3-phase short circuits** can be usefully employed to this purpose.

The **combination of hazards affecting the generation** schedule could also be examined (multiple tripping of units of the same plant or neighboring plants, common mode failure on generator controllers, etc.).

4. Integrate busbar switching as operating possibilities

Some substations have a very unfavorable layout (e.g. Bauru, Ilha Solteira). The adaptation of the busbar connections to minimize the consequences of a fault is under study (Group #2). But, as we understood, the aim of this study is to determine the new configuration to be adopted once for all. We recommend to investigate the possibility to **adapt more frequently the busbar configuration to the operating situation**, for example after contingencies (reconnection of the two busbars at Bauru, instead of generation dropping), or in case of particular generation schedule, or in case of maintenance works.

EDF has a long experience of such frequent manoeuvres, and is ready to present this practice and its implication (in terms of procedures) to a Brazilian delegation.

5. Feasibility of the solutions based on Security Schemes

Studies of Group # 5 and 6 show that some actions require both a complex triggering criterion and a very short time of execution in order to be efficient (e.g. the generation dropping at Itaipu in 300 ms, in case of excessive active and reactive power variations on the 765 kV corridor, to avoid loss of synchronism). Such **complex processing and very short reaction time can be impossible to satisfy securely, unless adopting high-performance measuring devices, algorithms, communication**

* We remind the mission of each joint work group ELETROBRAS/CEPEL/ONS in section 3.1.

means and protocols. Thus the cost and development time of such complex Schemes are much more higher than those of more simple Schemes based on logical and/or local functions.
We suggest to examine the profile of **phase angles** along the corridor on the simulation results to see if correlation can be made with this quantity and the problem feared.
We suggest to study the application of a **rapid overload protective relay on the North-South 500 kV interconnection link** (based on directional active power flows), and to see how it could complete or replace the present out-of-step relay.

6. Reliability of the solutions based on Security Schemes

The reliability of the solutions based on Security Schemes or Special Protection Schemes lays on several aspects : the extent of the functional studies performed, the interaction problems, the precaution taken against possible misoperations, the validation process, the maintenance and evolution aspects.

6.1. Extent of the functional studies performed to define Security Schemes

The actions to be applied by the Security Schemes must be efficient in all the various system conditions encountered in operation. Insuring such robustness requires to study a very large number of simulation cases. Our experience is that the **transmission line maintenance cases must be included** in such studies, because they represent a rather big part of the situations lived.
We recommend also to adopt a **process of validation** of the functional studies by an entity which was not involved in them, in order to better guaranty that no influent parameter variation has been omitted, and so to counterbalance the pressure effect due to the short time allocated for the study completion.

6.2. Potential interaction between Security Schemes

One way to limit the risk of interaction between local Security Schemes is to **adopt a selectivity** based on either the criterion, or the action time. Problems can occur when independent Security Schemes located in the same area are based on different criteria but act in the same time range. Their actions may add, endangering the system, or cancel each other, impeding the remedies to be efficient. The risk is greater with very fast actions. One solution is **to coordinate the Schemes of a given area**, with a consequent increase of complexity (implementation of a second level Scheme mastering the others).

6.3. Precautions taken against possible misoperations of the Security Schemes

We suggest to perform **reliability studies on the Security Schemes elaborated**, in order to choose their adequate architecture.
The main aim of this study would be to determine the location where redundancy is needed, along with the type of redundancy required (double circuits with AND or OR gates, votes, other dispositions).
If these techniques are not mastered, we suggest to rely on support brought by experts on this field.
Group #4 could usefully define **reliability requirements** for the PLC : undesired operation rate, availability objective.

6.4. Validation of the Security Schemes

From our experience, this point would benefit to be anticipated from the very beginning. Our recommendation would be to integrate a **clause of "easy testability"** in the Security Scheme requirements. The aim is to have at disposal the right physical outputs, and the adequate routines on the various components of the Scheme allowing to perform partial and complete tests.

6.5. Organization of the maintenance and adaptation of the Security Schemes to the power system evolution

The experience of Itaipu 14 PLCs can be used in order to build a **reliable organization for the maintenance** of such devices. As the system evolves, it will be necessary to check periodically that the Security Schemes remain **adapted to the changes** brought (new lines, new plants, etc.), and to adjust their settings if necessary. Including when other Security Schemes are added.

7. Costs of Security Schemes

The costs include the functional studies, the design studies, the hardware, the software, the installation cost, the telecommunication charges, the training and maintenance costs. From our experience, **the total can exceed several times the sole price of the equipment implemented**.

8. Development time of Security Schemes

Security Schemes are not products off the shelf. Their development must follow several steps : functional definition, determination of performance objectives, design studies including reliability studies, writing of specifications, hardware development including communication means if needed, software development, validation and tests, installation, qualification. The time needed to proceed through these steps depends on the complexity and the geographic extension of the Scheme. A total duration of about eight months (including all) seems to be a minimum for the most simple Scheme : one radial part of the network, one need appearing clearly, one PLC installed in a substation, processing only logical data, having only local actions. For more complex Schemes, the duration can increase very much. For example the development time of the new EDF Scheme against losses of synchronism presented in section 1.3 has taken about 10 years (the development time of the Japanese Schemes presented in section 1.5 has also been similar). Of course this time corresponds to a first and unique exemplar of the given Scheme. One question raised : how much time could be spared if we developed another exemplar of the Scheme, taking into account the first experience ? The answer can be the following : all parts using state-of-the-art techniques could be accelerated (i.e. simulations and reliability studies, because their methodologies are well established), but the developments which are adherent to new technologies may need adaptation efforts which could lead to similar duration periods as in the first implementation. As a whole, the total duration could probably be reduced to the half, but not more.

We think this duration time must not be a brake to develop such complex Schemes when they are necessary. At the contrary it leads to anticipate the needs in studying such matters in the planning stage, in order to be ready when the Schemes are useful on the power system.

LONGER TERM ANALYSES AND REMEDIES

9. Systematic analyses of possible collapses and efficiency of remedies

The use of dynamic simulations to determine the stability limits of the system is a practice well established, at least in the operation stage. We would like to highlight the interest of performing regularly at the planning and operating planning stages **systematic analysis of modes of collapse** and investigation on the efficiency of the defense measures already in service. The way to reach this objective is to simulate voluntarily combinations of situations and disturbances which lead the system to collapse, and to observe the behavior of the system and the response of the protective relays, Security Schemes and defense measures. The lessons learnt from such studies help to build a more complete, robust and secure defense plan, and in particular to adapt its features and settings to the power system evolution.

One of the methodologies available now in this field lies on a **statistical approach** of a large number of dynamic simulations generated and processed automatically (2000 for example). Its advantages are to give a global view of the coherence of the various measures composing the defense plan, to classify the possible risks the system has to face, and to detect remaining weak points (sensitive areas in the system, or critical contingencies, or lack of dedicated protection, for example).

10. Reactive compensation

Some interlocutors pointed out the low voltage profile and high reactive flows between EHV and HV levels in consuming areas during peak hours, and others did not mention any difficulties. This **question must be tackled and treated**, if necessary, in adding compensation means in the adequate substations.

11. Study of the gain brought by the adoption of 1-phase line tripping and reclosing

3-phase tripping and reclosing for both sigle phase and 3-phase faults is an usual practice in Brazil. Most of the equipment support only this operation mode (the circuit breakers are fitted with a common command for the 3 poles). But power system security could probably be enhanced with single phase tripping/reclosing. In the perspective of the development of transmission system and renewing of present equipment, it could be interesting to **assess the cost/benefits ratio of the installation of single pole commands** (Mr. Osvaldo Shiraishi - CESP - mentioned costs of around 200 k US $ per line bay). This would give a possibility to progressively adopt single phase cycles on the network (and hence to limit the consequences of more than 80 % of the short circuits).

Furthermore, the measure consisting in **enlarging the angular tolerance for line reclosing** could also be studied (it would decrease the risk of reclosing refusals after multiple line trippings). For example in France, we accept the reclosing of long transmission lines at phase angles up to 60°).

12. Approach "by the risks" in operation

The adoption of the N-1 security rule gives guaranties against some types of disturbances (simple contingencies), but not against others (multiple contingencies). The later are rare, but their consequences can be disastrous. One way some companies have followed to progress in this field is to consider the risk of outage as the product of the probability of the event and the magnitude of the consequences (expressed in unserved power or energy for example), and to base their security rule on the risk rather than on the pure probability of events.

This leads for example to consider N-2 contingencies and busbar faults (and sometimes even more rare events), and assess if their consequences are limited or not (with a threshold to be defined). If not, the preventive actions taken to bring back the consequences under the threshold constitute the price to pay for the support of power system security towards these risks.

Some reflections could be usefully engaged on this topic. For example **special operating measures could be especially undertaken during very bad weather conditions**, when the probability of multiple contingencies increases significantly.

13. Use of differential protection on busbars

We were told that most substations will be equipped with differential busbar protection. EDF has had a good experience of such equipment for about 10 years, and is **recommending its use**.

14. Relay testing

Relay misoperation could be reduced by **better relay testing**. Mr Fromen (Electropaulo) reported experience in WAPA of a test of 8000 faults rapidly. Efficient tools exist now for this purpose, e.g. the Relay Digital Simulator of A&M-Texas (see document [23] in appendix), and ARENE-EDF (see documents [24], [25], [26] in appendix).

15. Reliability of substations

Some methodologies are now available to study the **reliability level of a substation**, depending on its structure and equipment. For example EDF uses a tool called TOPAZE, which is used in the design stage to calculate impacts of substation layouts and protection plans on potential consequences of short circuits and device failure (risks assessed in terms of severity, and probability). See document [27] in appendix.

16. Tap changer blocking

The rapidity of collapse occurred on 11th March 1999 was such that on-load-tap-changers have had no effect on the process. But in other circumstances, these devices can present a detrimental influence, which can be counteracted in implementing a blocking of the tap changers. EDF has a good practice of such measures, and has been introducing its automatic triggering since its last major disturbance of 1987. **The interest of this action on the Brazilian system could be analyzed**.

17. Enlarge the investigation on power system security to the frequency aspects

Spinning reserve in Brazil seems to be very narrow, particularly in peak hours, due to lack of capacity. The **present investigation could be extended to this problem**, as Brazil becomes now a wider power system. EDF could bring its experience of what is done in Europe in this field.

18. Power System Stabilizers

Problems of low damping occurred several years ago in the South-Eastern part of Brazil, but things seem to have been solved (particularly in using accelerating power signals in the PSS). Nevertheless the development and larger interconnection of the Brazilian power system **could lead to increase the risk of new oscillation modes** (interarea modes, in addition to the local modes). EDF has an extended experience in designing and adjusting generator controllers and power system stabilizers in large systems. Last developed methods and tools are described in the document [28] of the appendix.

19. Angra

The presence of the nuclear plant of Angra can lead to specific questions which could require adapted responses. We noted during the discussions interrogations linked to the equipment of generator controller with **PSS**, the capability of the **auxiliaries** to face disturbed situations without tripping the unit, and the particular needs of the plant during **restoration** phases.

20. Dispatching training simulator

EDF has developed a **Dispatching Training Simulator**, which now exists in a "light" version called SIDERAL (see document [18] in appendix). Training of operators, starting from existing situations, building critical scenarios, could improve system security.

An interesting practice is also the exercices of "**team training**" the Swiss companies organize regularly for all their operators during "restoration days". During these exercices, normal operators simulate restoration procedure application, while the normal operation is insured by back-up operators. This example is interesting because the Swiss organization of the electricity sector looks like the one in Brazil (number of actors, responsibilities assured).

GENERAL COMMENTS

21. Future of GCOI

GCOI has presently a task of coordination of the Brazilian actors, particularly towards **power system security**. We think that this function is fundamental and must be preserved in the future. How will this be managed in the new organization ? One of the concrete objectives of this entity in the coming period could be to develop among the participating companies a common culture of power system security and reliability. Another could be to make the transmission system progressively converge towards a standardization of voltage levels.

22. Manage carefully the implementation phase of the remedies

Risks of misoperation increases during works in substations. Hence **particular precautions** are highly recommended when implementing Security Schemes or other remedies, in order to avoid endangering the system, which would be particularly inopportune in such a context.

3. COMPLEMENTS

3.1. Summary of the activities of the joint work groups ELETROBRAS/CEPEL/ONS (extract from ELETROBRAS documents)

Work group #1

Identification of the system's critical point (substations), where simple defects lead to multiple contingencies. The studies will take into account possible alternative bus lay-out and associated protection, defining groups and priorities.

Work group #2

From the results of Group #1, proceed with the analysis of the listed substations, regarding protection scheme, local control and lay-out (e.g. changing the bus bays, the protection philosophy, the bus lay-out, etc.), in order to identify actions of performance optimization.

Work group #3

Description of the state-of-the-art in special Protection Schemes to prevent widespread blackouts in the United States, Canada and France. Examples of previous disturbances : causes, required time to analyze, restoration time and actions taken following the disturbances.

Work group #4

Revision and recommendations to modernize the national supervising and controlling systems : synchronization of the Remote Terminal Units, national network of digital oscillography, high-level management information system, operator training center, real time network analysis program, specification of generic Programmable Logic Controllers.

Work group #5

Analyze the interaction among the actions taken by the existing Special Protection Schemes, when there are multiple contingencies.

Work group #6

Proposition for new Special Protection Schemes in order to minimize the consequences of multiple contingencies.

Work group #7

Identification of new reinforcements in the interconnected power system in order to minimize the effects of some probable multiple contingencies.

3.2. Brazilian experts met during the EDF mission in Rio from 3rd to 7th May 1999

Mr Xisto Viera (ONS/CEPEL)
Mr Eurico Salgado Sobrinho (CEPEL)
Mr Nelson Matins (CEPEL)
Mr Paulo Gomes (ONS)
Mr Marcelos Groetaers Dos Santos (ONS)
Mr Johann Michael Steinberger (ELETROBRAS)
Mr Antonio Ricardo Cavalcanti Dias de Carvalho (CEPEL)
Mr Luiz Alberto da Silva Pilotto (CEPEL)
Mr Joao Carlos de Oliveira Mello (CEPEL)
Mr Raul Balbi Sollero (CEPEL)
Mr Herminio José Da Cunha Pereira Pinto (CEPEL)
Mr Antonio Carlos Barbosa Martins (FURNAS)
Mr Paulo Cesar Alves Fernandez (FURNAS)
Mr Sergio Espiriti Santo (FURNAS)
Mr Nilo (FURNAS)
Mr Osvaldo Takeshi Shiraishi (CESP)
Mr Erasmo Fontana (CESP)
Mrs Silvia Regina F. O. Delollo (ELETROPAULO)
Mr Charles Fromen (ELETROPAULO)
Mr Anselmo Ribeiro Nascimento (LIGHT)

3.3. List of documents provided in appendix

[1] : Analysis of a Voltage Collapse Incident and Proposal for a Time-Based Hierarchical Containment Scheme, Y. Harmand, M. Trotignon, JF. Lesigne, JM. Tesseron, C. Lemaître, F. Bourgin, CIGRE Paris August 1990, 38/39-02

[2] : Defense Plans Against Major Disturbances, UNIPEDE Large Systems and International Interconnections Study Committee, Birmingham June 1994

[3] : Defence Plan Against Major Disturbances on the French EHV Power System : Present Realization and Prospect of Evolution, M. Trotignon, C. Counan, F. Maury, JF. Lesigne, F. Bourgin, JM. Tesseron, J. Boisseau, CIGRE Paris August 1992, 39/306

[4] : Major Incidents on the French Electric System : Potentiality and Curative Measure Studies, C. Counan, M. Trotignon, E. Corradi, G. Bortoni, M. Stubbe, J. Deuse, IEEE Trans. On Power Systems, August 1993, p 879

[5] : Contingency System Against Losses of Synchronism Based on Phase Angle Measurements, M. Bidet, EDF report March 1993, 93NR00009

[6] : Power System Control Based on Phase Angle Measurements, O. Faucon, Y. Therme, EDF report June 1994, 95NR00019

[7] : Coordinated Defence Plan - An Integrated Protection System, O. Faucon, L. Dousset, J. Boisseau, Y. Harmans, M. Trotignon, CIGRE Helsinki Symposium 1995, 200-07

[8] : Coordinated Defense Plan Protects Against Transient Instabilities, O. Faucon, L. Dousset, IEEE Computer Applications in Power, July 1997, p 22

[9] : Risk of Major Disturbance Spreading Among Interconnected Power Systems and Efficiency of Remedial Action Schemes - Experinece Feedback on Mutual Co-operation Between Utilities, J. Auriault, M. Trotignon, Y. Harmand, P. Scarpellini, R. Marconato, R. Lusvarghi, UNIPEDE Budapest November 1996, 2.06

[10] : Development of Transient Stability Control System (TSC System) Based on On-Line Stability Calculation, H. Ota, Y. Kitayama, H. Ito, N. Fukushima, K. Omata, K. Morita, Y. Kokai, Chubu Electric Power Co., IEEE PES 1995 SM

[11] : Development of Transient Stability Control System (TSC System) Based on On-Line Calculation, Y. Sudou, Y. Kitamura, Chubu Electric Power Co. 1997

[12] : New Stabilizing Protection Systems With an Adaptive Control Approach, M. Tsukada, I. Kouda, I. Mitani, H. Hayashi, H. Kokai, Chubu Electric Power Co.

[13] : Stabilizing Control System Preventing Loss of Synchronism From Extension and its Actual Operating Experience, K. Matsuzawa, K. Yanagihashi, J. Tsukita; M. Sako, T. Nakamura, A. Takeuchi, Tokyo Electric Power Co., IEEE 95WM188-3PWRS

[14] : Strategy of 400 kV Regional Frameworks to Restore the French Network After a Blackout, P. Selosse, G. Testud, J. Nicolas, M. Martin, CIGRE Paris August 1998, 39-104

[15] : Restoring Electrical Power System With Hydro Units After a Blackout - How to Avoid Unacceptable Overvoltages on Long Transmission Lines ? J. Nicolas, B. Caillault, Small Hydro Conference Water Power and Dam Construction, New Delhi, November 1992

[16] : Co-ordination of Service Restoration, UNIPEDE Large Systems and International Interconnections Study Committee, January 1997

[17] : Training Simulator Within the EDF, J. Macrez, M. Navarro, P. Selosse, EDF report February 1994, 94NR00025

[18] : SIDERAL - Dispatching Training Simulator, EDF brochure

[19] : Experimentation of a New Voltage Stability Analysis Tool in French National Control Center, Y. Jacquemart, A. Giard, V. Sermanson, G. Nérin, CIGRE London Symposium, June 1999

[20] : A Statistical Analysis of the Impact on Security of a Protection Scheme on the French Power System, C. Lebrevelec, P. Cholley, JF. Quenet, L. Wehenkel, Powercon'98, August 1998, Beijing

[21] : Power System Security Analysis - New Approaches Used at EDF, S. Henry, Y. Schlumberger, C. Lebrevelec, M. Bulot, JM. Tesseron, CIGRE London Symposium, June 1999

[22] : Power System Security Control : a Probabilistic Approach, EDF brochure

[23] : Automated Analysis of Protective Relay Operation, M. Kezunovic, I. Rikalo, ISAP'99, April 1999, Rio de Janeiro

[24] : ARENE : a New Simulator Reduces the Cost of Equipment Tests, O. Devaux, P. Lemerle, O. Delsol, S. Martino, CIRED 1999, Nice (France)

[25] : A Simulator With Batch-Testing Facility for Relay Testing, O. Delsol, LG. Andersson, LG. Nimmersjo, International Conference on Digital Simulation, May 1999, Vasteras (Sweden)

[26] : ARENE - the Digital Transient Network Analyser, EDF brochure

[27] : Substation Design Improvement With a Probabilistic Reliability Approach Using the TOPASE Program, M. Bulot, G. Heroin, JL. Bergerot, M. Le Du, EDF report, May 1997, 97NR00049

[28] : Robust Coordinated AVR+PSS for Damping Large Scale Power Systems, H. Quinot, H. Bourlès, T. Margotin, IEEE PE-455-PWRS-0-12-1998

RECOMMENDATIONS FOR THE IMPROVEMENT OF THE BRAZILIAN POWER SYSTEM SECURITY FOLLOWING THE 11TH MARCH 1999 OUTAGE
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