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Analysis Causal of Collapses of the Networks of Energy: Application to the Arab Networks

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Abstract: The energy networks' performance depends on the architecture of the network as well as on the energetic transfer command. From the fact of the complexity of this architecture which involves the energy network from many diverse resources of different natures (production units, transformation stations, transport lines, consumption modes…), the auxiliary network (communication network, protection plan, signalisation and observation network,…) and the human network (including all the levels contributes going from dispatching down to un-keep and maintenance), it's necessary to proceed to the situation's global analysis by adopting a causal process including the different steps that could proceed any disturbance. It's also necessary to analyse the incident's dynamics, by exploiting the systematic method of Interventions' Planning Per Objectives (PIPO), this causal analysis allows us to put into evidence the tree of problems illustrating the causes of high voltage electrical systems' collapses. This tree constitutes a precious tool able to stop the intervention strategy in order to either avoid the black out or at least to reduce it on a given exploitation horizon. In the case of the back out occur and in seen to control the refeeding of the customers, a restoration's plan of the network must be established beforehand.

Key words: Collapse, preventive action, curative action, causal analysis, defense plan

INTRODUCTION

The electrical network supply of energy is classified among the most complex systems particularly its management in disturbed mode. Complexity comes from its architecture and the significant number of users. The electric system High Voltage (HV) is made up mainly of three sub-systems:

- Sub-system of power which includes primarily power stations of production, stations of transform ation, lines of transport and the noe uds of consumption.
- Sub-system of control which is made of the communication network, the network of observation and indication and the system of control and operation.
- Human sub-system which implies various levels of users going from the dispatcher to the operator of maintenance.

The effective control of such a system is subordinated to the coordination and the harmonization of these 3 sub-systems. The difficulty in leading the network resides in the requirements of the material and the severe and inevitable constraints: nonstorable electric power and the randomness of the load. There are other difficulties such as the decision-making, the availability of the means to carry out an action and the justification of the action. These are reduced by the procedures and the operating instructions. However, these difficulties remains always subjects of discussion in disturbed situation.

When, the normal situation is reinstalled and several events will take place successively (avalanche of information), it is difficult to obtain and analyze information to act quickly. In these disturbed situations, the information and communication network as well as the procedures and work instructions will be modified compared to the normal mode.

The management of the network in disturbed mode is based on the urgency of the situation and the degree of weakening of the system in the event of major incident. Indeed, these indices justify the setting of radical actions, at the expense of a certain deterioration of the quality of service for a number of limited customers. The adopted philosophy rests on the voluntary separation of certain loads to save priority customers like the hospitals or the zones of high monitoring. The control of the cuts supports the speed of later restoration of the normal conditions of supply to the whole mass of the customers.

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Table 1: The three stages of Oriented Object Planing Project (OOPP)

Problems analyze	Objectives analysis	Planning of the activities
To define the entity		
To choose the groups concerned		
To analyze the existing negative states: problems	To convert the negative states into positive states reached: objectives	
To establish the cause-effect relations between the problems	To establish relations means-ends between the objectives	
To build the tree of the problems	To build the tree of the objectives	To distinguish sets of objectives
		To compare these sets on the basis of criterion of given selection
		To choose a unit and a specific objective

One can distinguish two levels of counter-measurements, acting on different scales of time.

- A first level regoups the manual and automatic preventive actions are intended to counter the incidents. Thise incidents are manifested by phenomena whose dynamics is still compatible with a deadline for manual reply:
  - Cascade moderate releases caused by overload.
  - Collapses of voltage in their initial phases.
- Another level of measurements is intended to counter the incidents related to the fastest phenomena: the collapses of frequency and the ruptures of synchronism are quoted. In this case the speed, of appearance and the evolution of the phenomena exclude any possibility of human intervention. Only automatic devices can effectively ensure the curative action necessary. This action makes the defense plan which constitutes true protection to the electric system as a whole.

The whole of devices of prevention and defense is supplemented by measurements supporting a controlled and fast reconstitution of the zones not under voltage:

- Automatic isolation of the block of the groups of production with their auxiliaries: When the limit voltage incompatible with the reliable operation of the materials is reached.
- The plan of reconstitution predicts the refeeding of the system starting from the close zones still under voltage or the isolated groups or self-starting (black start).

SYSTEMATIC ANALYSIS OF LATEST NETWORK COLLAPSES IN THE WORLD

In the objective to release the principal causes and consequences of collapse of the networks (rules and operating instructions, policy of management, electrotechnical phenomenon, disfonctioning of the automatisms, climatic conditions…), we carried out a systemic analysis of the collapse of the networks which emerged these last years. We adopted in this systemic step method Oriented Object Planing Project (OOPP) also called Planning of the Interventions by Objectives (PIPO).

Presentation of the method of analysis: The OOPP method is made up of three stages:

- A stage of problems analysis.
- A stage of objectives analysis.
- A stage of activities planning.

Here, we will, restrict ourselves to the presentation of the stage of problems analysis.

The following Table 1 shows the three stages of OOPP (AGCD, 1991).

It's quite frequent that the conception as well as the starting of a project responding to a problematic situation motivating the investigation, thus the analysis of this situation must be led in accordance with a structured methodology based on a causal logic identifying the effects and their causes.

Problems formulation is described by a negative state (non-efficient management system). The stages of analysis of a problem whatever its nature might be, are:

- Identifying the Central Problem (CP).
- Identifying its Direct Causes (DC).
- Applying the same logic for every direct cause by considering it a problem whose proper direct causes have good grounds to be identified, then these causes become Sub-Causes (S.C) of the central problem.
- Continue the ysis which must be made hierarchical up to a level judged sufficient enough to understand the totality of the problems and their causes.

A problem's stage of analysis can be described by the tree of problems represented in the following Fig 1.

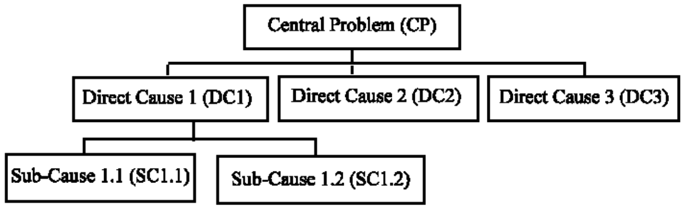

Fig. 1: Tree of the problems

Study of the black out occurred in Tunisia, Algeria and Italy into 2002/2003

Tree of the problems of the black out: The analysis of black out occurred in Tunisia (June 2002), Algeria (February 2003) and Italy (September 2003) made it possible to constitute a tree of the problems which regroup the various possible causes of collapses of the networks. Thus, the system of production and transport of the electric power consists of a network ensuring the transfer of the electric energy of the centers of production towards the centers of consumption. Often these centers are distant from each other. The correct operation of the system is subjected to the imperative satisfaction of the two types of constraints: the dynamic stresses of load which instantly represent balance between the production and the consumption and the static stresses of operation expressing the physical limitations of the equipment (transport capacity of the lines and the transformers, level of acceptable overpressure compatible with the dielectric behaviour of the insolation…).

The appearance of the static stresses of operation is caused mainly by:

- The management of the electric system nonefficient (unavailability of programme of decision-making, operation in limit of capacity, nonefficient topology and unclear management policy…).
- Reduction in the size of the system (release of work of production or transport).
- Appearance of an engine of incident (cascades and release by overload of the works, collapse of voltage).

The dynamic stresses which represent balance consumption-production are very short in time and are very violent for the material. They appear in general following the one of the following causes:

- Uninsured dynamic stability (the majority of the Control system are not provided with a function integrating dynamic safety).
- Dimension of the system decreased (releases of work of production or strategic connection which can cause a phenomenon of instability or a loss of synchronism inter area, appearance of an isolated network…).
- Appearance of a dynamic engine of incident (collapse of frequency, loss of synchronism).

After having established a tree of the problems of collapses of the electrical supply networks, we will structure the causes in order to identify the various possible strategies of intervention to eliminate or minimize within the limit of possibility the black out.

Presentation of the causes and associated strategies of intervention: The causes constituting the tree of the problems of the black out are classified in 3 types: those which are linked to the initial conditions of the electric system before the disturbance, those which are at the origin of the incidents which constitute the fortuitous events and those which are regarded as worsening factors and like engines of great incidents.

This classification enabled us to release three strategies of interventions in the objective of eliminating or minimizing the black out.

- Strategy of policy of management which touches the initial conditions in order to put the network in a state of security.
- Strategy of maintenance and investment to minimize the unforeseeable occurrences and their direct consequences.
- Strategy of defense in order to control the incident and its propagation.

Table 2 presents the various causes and the corresponding strategies.

The systemic analysis of incidents confirms indeed that the collapse of the inter-connected wide-area networks results from the initial conditions, of the origin of the incident, the driving engine to support the diffusion of the disturbance in the system and the worsening factors.

Table 2: Presentation of the various causes and strategies of intervention

No	Code	Problem and causes	Strategies
1	PC	black out realised	
2	CD1	Appeared constraints of operation	
3	CD1.1	Management of the nonefficient system	Initial condition: Strategy of policy of management
4	CD1.1.1	Reserve into reactive insufficient	
5	CD1.1.2	Increase in non controlled consumption	
6	CD1.1.2.1	Nonefficient forecast	
7	CD1.1.2.2	Charges rulers not blocked	
8	CD1.1.2.3	Increased loss in network	
9	CD1.1.3	Nonefficient topology	
10	CD1.1.4	Security N-1 non insured	
11	CD1.2	Dimension of the system decreases	Event original of the incident: Strategy of maintenance and investment
12	CD1.2.1	Release of work of transport	
13	CD1.2.2	Release of means of production	
14	CD1.3	Appeared engines of incident	Worsening factors: Strategy of defense
15	CD1.3.1	Overload of work occurred	
16	CD1.3.2	Fall of voltage appeared	
17	CD2	Dynamics of the electric system violated	
18	CD2.1	Dynamic security not ensured	Initial condition: Strategy of policy of management
19	CD2.1.1	Primary reserve into active insufficient	
20	CD2.1.2	Park of production badly placed	
21	CD2.1.3	Prolonged short-circuit	
22	CD2.1.4	Time limit for elimination of the defect not respected	
23	CD2.1.5	Coupling separated network not controlled	
24	CD2.2	Dimension of the system decreases	Event original of the incident: Strategy of maintenance and investment
25	CD2.2.1	Release of means of production	
26	CD2.2.2	Lost strategic connections	
27	CD2.2.2.1	Loss of external interconnection	
28	CD2.2.2.2	Started internal connection	
29	CD2.2.3	Appeared separate network	
30	CD2.3	Dynamic engines of incident appeared	Worsening factors: strategy of defense
31	CD1.3.1	Collapse of frequency expressed	
32	CD1.3.2	Synchronism regime not occurred	

CIRCUMSTANCE OF DEVELOPMENT OF THE THREE TYPES OF IDENTIFIED CAUSES AND RECOMMENDED ACTIONS

Initials conditions: With regard to the topology of the system, the outlying areas are more sensitive to the major incidents. The longitudinal networks are particularly exposed to the risk of collapse of voltage (Duguan *et al*., 2003). The analysis of incidents indicates that massive transport on parallel lines and the situations of strong load constitute a factor of risk. The examination of the profile of voltage in the system plays the role of indicator. A plan of abnormally low or high voltage is a sign which must encourage more attention.

It is implicitly recognized that the quality of the policies of adjustment must not only be clearly established but also be plantable in the most total possible way than. It is often admitted, wrongly, that the secondary adjustment of voltage can be carried out without major disadvantages by manual action of the dispatcher. The development of a major incident is sometimes favoured when the normal situation is established.

Auxiliary functions of adjustment are established to maintain works in their acceptable operating range and to avoid release by "unit" protection. Thus, on the synchronous machines, the limiting devices of excitation or of under excitation maintain the point of operation longest possible inside the curve of capacity, with the detriment of the effective participation of the group in the adjustment of the voltage, in order to avoid a release by overload or instability.

The manager of the network must make so that any moment has, the system remains viable after a risk on the normal situation leading to the disfonctioning of the installed equipment. With respect to this type of risks, this manager can nevertheless tolerate a certain risk according to a compromise cost-security.

Event origin of the incidents: At the origin of any major incident there is an unforeseeable enent. This latter can affect the system locally, such as the release of an equipment of transport or production. They are often traditional defects of insolation or simply of inopportune cuts. This type of disturbance can cause a change of state in the system. Other more total events affect the state directly without a local cause being able to be identified as a starting factor. A mong these events, the increase in load exceeding the forecasts is undoubtedly the most often.

The realization of a system satisfying an objective of security requires identifying and taking into account the possible causes of defects and their origins.

Thus, the risks of the electric system are classified in four families:

Risks of consumption: The nonstorable character of the electric power, it is necessary to ensure the adaptation of the production consumption. The electric system is thus controlled by the consumption which reflects the economic and social activity in the country. Consumption presents an overall foreseeable character but with a notable random margin.

Climatic risks: The electric system, very wide geographically, is in strong relationship with the environment (variation of consumption due to the climatic variations, climatic effects on the electric equipment, sources of cooling of the power stations…).

External breakdowns and aggressions: The components of the electric system are always subjected to failures of internal origin (construction) or external origin (accidents, electromagnetic interference, vibration…).

Dysfunctions related to the personal element: The level of performance of the components depends on the personal element which intervenes on all levels, from the design of the equipment to their exploitation such as the errors of designs, the use of the material an environment for which it was not conceived, the error of a human operator in the use of the equipment or at the time of a maintenance action.

Worsening factors: When an incident affects an element of network, the elementary system of protection starts without returning to a stable operation if the network was in N-1 security. So that an initially banal incident is transformed into major incident, a series of disfunctions is needed such as a bad adjustment of protection, a refusal of opening a circuit breaker or that the point of initial operation does not guarantee a sufficient trading margin…

The extension of the incident can also occur by various mechanisms being able to have the following impacts:

- Change of the state of the network.
- Appearance of static instabilities, generating an imbalance between production and consumption resulting from a parcelling out of the network.
- Instability of voltage resulting from the absence of reserves or automatic operation of the rulers in load of the distribution transformers.
- Inadequate unballasting of load.
- Reaction speed of the operators unsuited to the dynamics of the incident.

Under these conditions the plan of defense constitutes the only possible solution.

ANALYSES OF THE BLACK OUTS OCCURRING IN THE ARAB ELECTRICAL SYSTEM

Within the framework of the committee of the interconnections of the Arab networks, a working group was formed of which the objective to analyze the major incidents which have occurred in the world Arab these last years (Anonymous, 2000). The incidents considered are those which caused a cut of the customers having more than 20% of the overall consumption (Fig. 2).

Identification and analyse of the incidents: Collected information relates to mainly eleven incidents distributed on the various countries are summarized in Table 3.

Among the incidents, two are black outs. The time of restoration for supplying the customers varies between 28 min and 10 h.

In a critical stage of analysis, the causes of the incidents were classified in 2 categories:

- The human causes related to the policy of management.
- The causes linked to the performance of the equipment being part of the worsening factors. These causes include the disfunction and the bad adjustment of protections.

This causal analysis of the incidents, permits us to obtain the following points:

- All the incidents considered are in the beginning completely or partially, of a factor of performance of the equipment.
- Twenty seven percent of the incidents are personal elements.

Table 4 summarizes the causes of the major incidents considered.

Retained conclusions: This work also drew the following conclusions (Anonymous, 2000):

- Good coordinations between the various entities which manage the network at the time of the black out (regional control system, center of control, producer…).

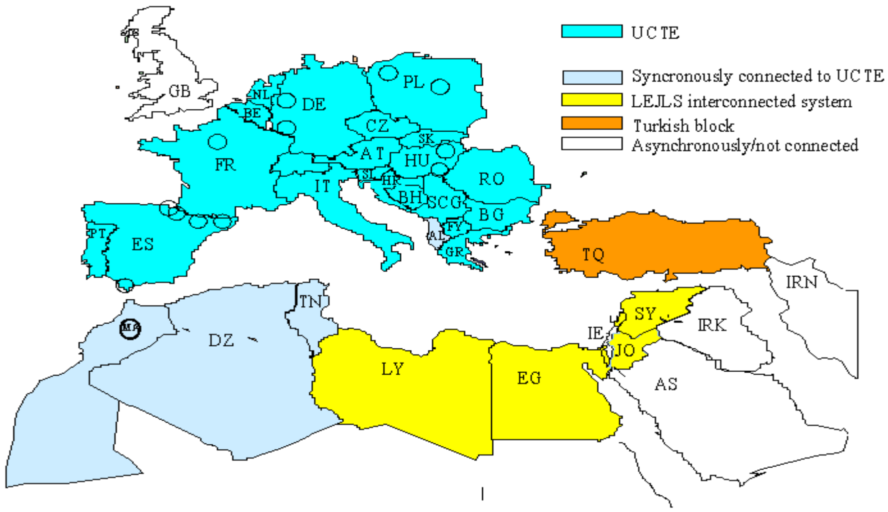

Fig. 2: Diagram of the studied countries

Table 3: Summary of the incidents in the various Arab countries

Country	Numbers of incident	Date of the incident
Morocco	1	03/07/2000
Jordan	2	22/11/2003, 09/08/2004
Egypt	1	24/04/1990
Bahrayn	2	30/06/2004, 23/08/2004
Saudi Arabia	2	03/08/2003, 08/08/2003
Yemen	1	17/11/2000
Tunisia	2	30/06/2002, 24/02/2004
Syria	No major incident	

Table 4: Causes of the major incidents

Country	Disfonctioning	Bad adjustment	Human performance
Morocco	X		X
Jordan (1)		X	
Jordan (2)		X	
Egypt		X	
Bahrayn (1)	X		
Bahrayn (2)	X		
Saudi (1)	X		
Saudi (2)	X		
Yemen	X	X	X
Tunisia (1)		X	X
Tunisia (2)	X		

- Use of the technical tools at disposal in the national control system at the time of the black out. For the rare cases, these tools are not available, because of nonintegration of certain post offices high voltage postes in the information processing system Scada which ensures the control and the command of the system or the blocking of this “Scada” system because of technical performance (old technology).
- The system of telecommunication contributes, at the time of major incidents especially, to the level of the availability of information to the control system.

Advantages and disandvantages of the electrical system restauration: With regard to the restoration of networks, several strong points and weak points were elucidated:

- Absence of the restoration documents and reconstitution strategy before the incidents considered.
- There was much difficulty for the control of the frequency especially during the first phase of reconstitution.
- Without taking account of some problem with certain producers, there was a good coordination between the various entities during the phase of restoration.
- Some informations (origin of the incident) came in time and which contributed enormously to the speed of reconstitution of the network
- No problem of control of the voltage
- During restoration- operations.

Actions to undertake: The recommendations after these major incidents comprise primarily short-term actions and others medium and long term actions, among which we mention:

Action of management policy: These actions regroup the following activities:

- Revision and update of the plan of protection.
- Update of the Scada system (control system and dated acquisition) in the national control systems for a better detection of the abnormal situations and decision-making in time.
- Preparation of the documents of restoration and drive on the reconstitution of the networks.

Action of strategy of maintenance and investment: It regroups the following operations:

- Introduction of a structure of experience feedback in order to take account of the lessons drawn from the great incidents and performances of the equipment.
- Reinforcement of the networks in order to satisfy the request under good security conditions.
- Improvement of the preventive maintenance while benefitting from the hours of hollow-charge for work not under voltage and of the peak hours of consumption for work under voltage.

Action of strategy of defense: It concerns:

- Update of the plans of defence.
- Use of the modern tools for the establishment of the plans of defenses.

THE EXAMINATION OF SOME CURVES OF RESUMPTION OF SERVICE AFTER THE MAJOR INCIDENTS

The examination of some curves of resumption of service after incidents of great width which have occurred in various countries makes it possible to note that durations of cuts higher than 4 hours are relatively current (Fig. 3).

It is advisable to have studied and have prepared longest possible in advance the reconstitution and to update periodically the associated plans to take account of the evolutions in the structure of the network. These actions are regrouped in a plan called "plan of reconstitution of network ". The plan of reconstitution of network resulted in setting up a certain number of installations to the level of the materials of network and production in order to improve their operation at the time of a generalized incident or to automate certain sequences (to accelerate the operations). Also a certain number of procedures must be defined in order to study, test and form to save time (CUTE, 2003).

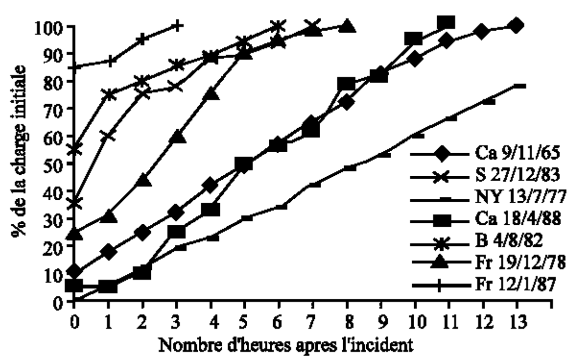

Fig. 3: Some curves of resumption of service after the major incidents

STANDARDS PLAN OF RSTAURATION NETWORK

Definition of the reconstitution steps according to the experience feedback: The plan of reconstitution of the network is a complement essential to the preventive actions and corrective. It reduce the possibilities of propagation of the major incidents. The plan of reconstitution of the network summarizes the instructions, the procedures and the necessary actions relating to an Incident Generalized or Major in order to carry out the reconstitution after setting not under voltage of a part or the majority of the network. This plan is a tool essential to the reconstitution scen as a support of exploitation.

The frameworks of the network must be defined and established in a clear way and off line. The sources of voltage of the frameworks and the files of references constitute dynamic information which influences the choice of the strategy of reconstitution must also be prepared and tested beforehand.

Alarms of incident generalized or major following the appearance of one or several indicators preestablished must be emitted on all levels of the owners of the network in order to launch the procedures, the instructions and the actions to be undertaken for the good course of the reconstitution: from the appearance of the incident and the beginning of diagnosis until the securisation of the network after the supply of the majority of the customers.

Mechanism of the standard reconstitution plan: The essenrial blocs of general diagram used to the power system restauration plan is given by Fig. 4.

Proposal of a guide and a tool of assistance to the restauration: The stages of an available reconstitution of the network could be defined as follows:

Stage A: Diagnosis: It comprises the network diagnosis and the production diagnosis. This stage allows the identification of the real physical states of the works high voltage (lines, cables, transformers, switchgear, groups of production…) and of the auxiliary equipments (protections, transformers of carrent, transformers of voltage, auxiliaries central…). The operation of protections of isolation (principal protection differential or complementary) makes it possible to identify the equipment non available. A diagram of routing of information makes it possible to identify the circuit of communication clearly to be respected.

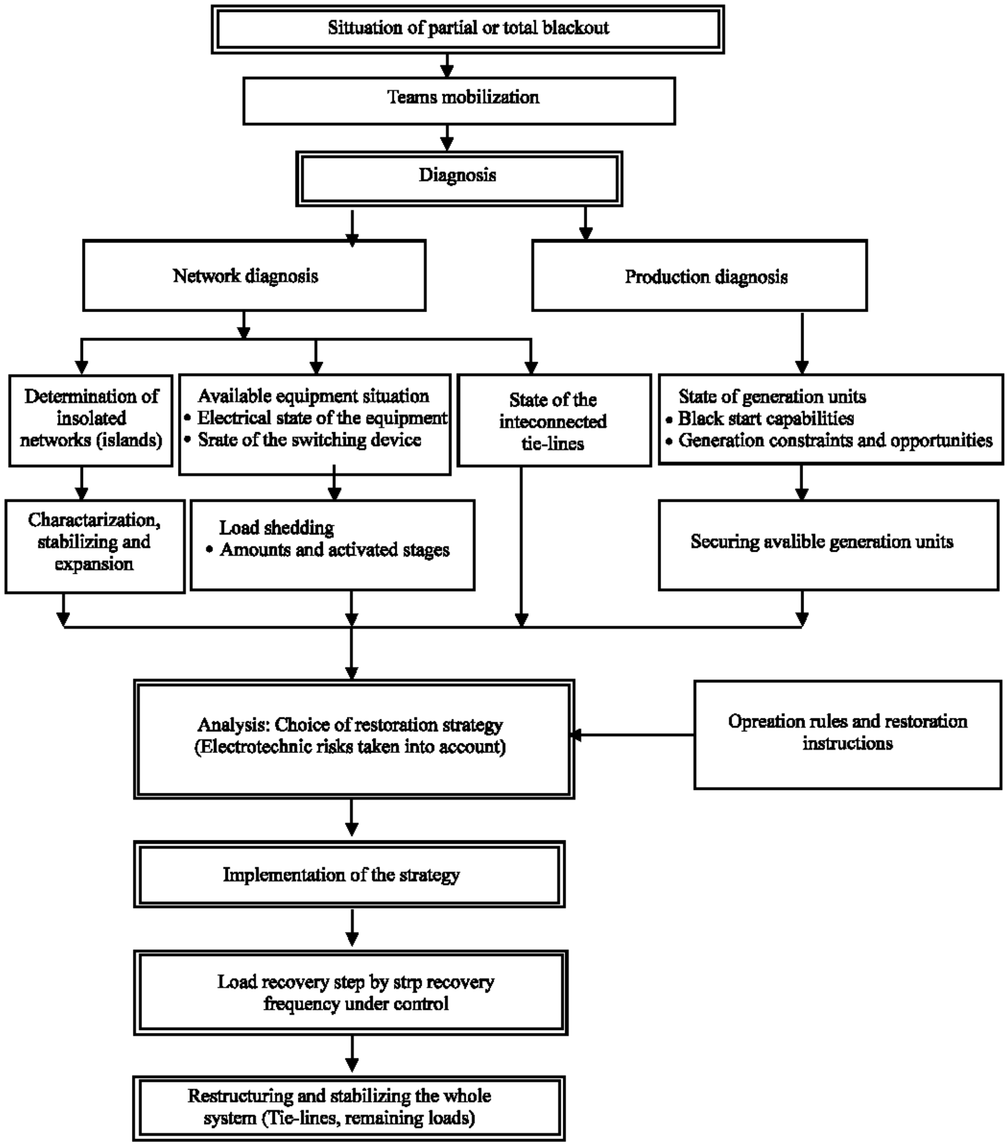

Fig. 4: General diagram of the Power System Restoration Plan (Heydt *et al*., 2001; Tesseron *et al*., 2002)

Stage B: Development of the separate networks and securisation of the groups available: This stage can be done before the end of the preceding stage, at the appearance and the identification of this situation case.

Stage C: Analyze and choice of the strategy: There is standard strategy applicable to all the types of incidents. However, the thorough analysis of the incident (starting from the diagnosis network and diagnosis production) makes it possible to list all the possible solutions in order to choose and decide options taken by considering the opportunities and the constraints.

Stage D: Implementation of the restoration strategy: The distribution and the organization of the teams is a paramount activity for the setting implementation of the solution taken in the preceding stage. The supplying of the frameworks, the coupling of the separate networks and the mutualisation of the production are the principal activities in this stage.

Stage E: Load recovery: The significant zones and the priority zones constitute the critical loads to supplying. The supply of the frameworks, the volume of resumption of load, the level between two recoveries, the management of the transits as well as the control of other parameters must be well defined and clearly defined in this stage. The experience feedback, suggests to the managers of the networks for the resumption of load a series of actions to undertake to conclude operation of resumption of load.

In the first phase of reconstitution, it is necessary not to supply the load more than 30% of power available (high risk of starting point of means of production and high risk of irreversible collapse of the frequency).

- As the situation is stabilized, the volume of resumption of the load must be lower than 5% power available (imposed by the thermal stresses of the turbines on vapor).
- To evaluate the variation with the awaited rise of consumption.
- The volume of recovery must be limited and spread out in time.
- The interval between 2 levels of recovery must take account of the reconstitution of the vapor reserve of the group (in general between 5 to 10 minutes for the thermal groups).
- To manage the transit on the possible line of interconnection (with the close countries and inter areas).
- To supervise the parameters of voltage and frequency.

Stage F: Securisation of the network: This stage includes mainly the extension of the framework towards secondary sites of production, the looping of the network, the control of the transits and the definition of the new programs of the groups of production.

CONCLUSION

This study describes some points having been the subject of investigations, by means of systemic analysis and experience feedback of the most remarkable incidents which have occurred in the world. The systemic analysis of incidents showed that the collapse of the inter-connected wide-area networks results from the existence of 3 principal factors which relate to three possible strategies of intervention:

- Unfavourable factors concerning the state of the system before the incident: it is the strategy of policy of management.
- The nature of incident affecting the system: it is the strategy of maintenance and investment.
- Engines likely to support the diffusion of the disturbance in the system: it is the strategy of defense.

However, for technico-economic considerations, these strategies of intervention are not sometimes completely respected. Indeed, for combinations of particularly severe risks but far from probable, we tolerate degradations of the operation of the system leading to significant effects on the customers. The priority is then to preserve the control of the evolution of the incidents in order to limit their final size. In more serious cases, we possibly agree to sacrifice a reduced part of the system. Thus a plan of restoration of the network must be established and tested beforehand.

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