

DEVELOPMENT OF ELECTRIC POWER SYSTEM EMERGENCY CONTROL IN A MARKET ENVIRONMENT

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ABSTRACT

Emergency control is an inherent part of operating control of electric power systems. High speed of processes proceeding under emergency conditions makes necessary a maximal automation of emergency control. The paper describes different principles and generalized structure of emergency control organization in electric power systems. There are some global tendencies in development of electric power industry. Their influence on the dynamic behavior of electric power systems is very important in terms of control system effectiveness. The negative and positive effects of the global tendencies should be taken into account to understand possible constraints in development of electric power systems and requirements to their control systems.

Keywords: Global Tendencies in Electric Power Industry, Electric Power Systems Dynamics, Emergency Control Systems.

1. INTRODUCTION

The main tendencies in development of electric power

systems (EPS) at the end of the 20th - the beginning of the 21st centuries seem to be of principal importance in the context of the EPS dynamic behavior and are associated with the processes of globalization, liberalization, diversification, decentralization and modernization in electric power industry [1]. *Globalization* in electric power industry is characterized by strengthening of EPS integration in such aspects as: economic (electricity markets, investments), technological (expansion of the territory of the centralized electricity supply), interstate and intercontinental (interstate and intercontinental interconnections). *Liberalization* results in the rise in deregulation and competition, development of regional, interregional and interstate electricity markets. *Diversification* implies an increasing variety of fuels, sources of fuel and electricity supply, types of energy units. *Decentralization* is associated with refusal from constructing large power plants and commissioning of small power units. Transmission and distribution networks still play an important role as an infrastructure that provides efficiency, reliability and quality of power supply. This brought to existence the notion of distributed generation. *Modernization* is associated with enhancement of traditional technologies and units and creation of new highly

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efficient ones.

Structural and functional changes in expanding interconnections predetermine an important role of control systems of EPS operating conditions that should also develop. This corresponds to a known principle of necessary (or sufficient) complexity, based on which the complexity of a control system should correspond to the complexity of a controlled system and processes taking place in it [2]. A dialectical contradiction in EPS development consists in non-coincidence between changing structural properties of the system in the process of its complication and development (as well as varying external conditions) that determine the changes in

conditions of its operation and dynamic properties, on the one hand, and retained principles and means of EPS control, on the other hand. The dynamic properties of EPS here imply the properties that determine in aggregate the character of system behavior in emergency operating conditions. Growth of the indicated contradictions leads to the "bottlenecks" in the system, deterioration of its controllability, decrease in reliability and efficiency, etc. Elimination of the contradictions requires improvement of principles and systems of EPS control. An important role in controlling the EPS operation is played by the emergency control systems that provide the required dynamic properties of the system [3, 4].

Table 1. Two approaches to emergency control

	<i>Approach A</i> (most pronounced in Russia and France)	<i>Approach B</i> (typical of some EPSs in the USA and Canada)
<i>Main priority</i>	Maintenance of the main grid in operation	Maintenance of power supply to consumers
<i>Technical features of EPS</i>	• Relatively low level of reserving the generation and grid, and therefore substantial tension of load-flow conditions with maximal use of transmission capability of the main grid. • High level of emergency control systems.	• Substantial level of reserving the generation and transmission capability of the main grid, and therefore high level of structural stability of EPS which makes the stability loss improbable even under the heaviest emergency disturbances. • Insufficient development of emergency control systems intended for preventing the initial stability loss.
<i>Legal availability to disconnect consumers</i>	EPS may perform any disconnections practically free.	Forced automatic disconnection of consumers is applied only in rather rare and obvious cases (when an emergency expands with danger for survivability of the whole EPS).
<i>Consequences of using the approach</i>	• Frequent disconnections of EPS elements and short-term limitations of consumer supply. • Effective overcoming of emergency processes leading to heaviest consequences.	• Low probability of limited system emergencies with short-term and small-size limitations of consumers. • Relatively high probability of rare but very heavy emergencies.

2. DEFENSE PLANS

The systems of emergency control measures and devices applied to prevent cascading emergencies in most countries of the world are called "Defense Plans". The defense plans relate to automatic control, i.e. they are to act against the emergency processes in EPSs, the high rate of which makes impossible human control.

Defense Plans differ for different countries in both philosophy (from maintenance of EPS integrity at any cost to practically absolute prohibition of consumer disconnection) and structure of the control system (from the totally uncoordinated operation of separate devices to a maximum centralized hierarchical structure). Those are objective differences, since EC was developing in conformity with grid topology, capacity structure and taking into account home policy

of each specific country. Several examples of defense plans are presented below.

2.1 Defense Plan of French EPS

The defense plan in EPS of France performs the following functions [5]:

- Separation of subsystems, where asynchronous mode was detected, from the remaining part of EPS. On the basis of previous repeated stability calculations, the French EPS is divided into twenty subsystems, between which the asynchronous run is most probable under heavy disturbances.
- If necessary, load tripping in separated subsystems to prevent disconnection of generators due to frequency fall.

2.2 Defense Plan of Hydro-Quebec EPS

Due to specific features of this EPS (such as its practical isolation from other EPSs, length of the main grid and very long distance between generation and consumption centers) the EPS disintegration is equivalent to its blackout (there were three severe system emergencies in the 1980s in this EPS). Therefore (in contrast to most other North American EPSs) the main purpose of the Hydro-Quebec defense plan is not to detect an asynchronous run with fast splitting of the system, but to preserve integrity of the main grid in all conditions [6]. The defense plan includes conventional emergency control devices installed at substations for:

- Generation and load tripping (for grid unloading),
- Connecting/disconnecting the 735kV shunt reactors,
- Load tripping at fall of the frequency and voltage (the latter has not been realized yet).

The principle of organizing the Hydro-Quebec defense plan is the priority of efficiency over selectivity. That is why it includes the volumes of disconnections calculated for the heaviest possible disturbances, which were calculated and ranged in advance. One more feature of the Hydro-Quebec defense plan is the absence of mutual coordination in operation of emergency control devices.

2.3 Defense Plan of Brazilian EPS

After the system emergency in March 1999

Brazil started to revise the emergency control system and create a centralized defense plan. This currently developed plan comprises the following [7]:

- Ranging the substations by the probability of heavy disturbances and the degree of their effect on EPS operation. On this basis the priorities for modernization of bus arrangement and equipment and for implementation of advanced emergency control devices are identified.
- Dividing the EPS into “security zones” (mainly by administrative affiliation).
- System of measurement transmission and centralized remote control (mainly for generation/load tripping).

At present three trial operated PLCs (Programmed Logical Controllers) are intended for identification of the disturbance reason and location by the measurements and for information transmission to the central PLC. The central PLC in turn is to form a proper control signal for disconnecting the generation and/or load.

2.4 Defense Plans of Russian EPSs

Centralized emergency control complexes are installed in several EPSs in Russia (EPSs of Ural, Middle Volga, Taymyr and Norilsk, West Siberia, and Krasnoyarsk-Bratsk-Ust'-Ilimsk power pool) and intended for taking the coordinated control actions aimed at prevention of the system emergency development, maintenance of the steady-state and transient stability and keeping the main grid in operation [8]. On the level of an individual EPS the following functions are performed on-line:

- Tracking the EPS topology (from remote signals),
- Determination of load-flow conditions (from remote measurements),
- Assessment of EPS stability and detection of emergency contingencies, when the system is unstable,
- Determination of necessary control actions for detected cases,
- Formation of signals (in terms of disturbance parameters) for adjustment of local devices.

In general one can mark two polar approaches to the Defense Plans organization, which are based on historically formed priorities of managing and controlling a concrete EPS

(Table 1).

3. ECHELONS OF EMERGENCY CONTROL SYSTEM

Composition and character of primary disturbances, that lead to the emergency operating conditions in EPS are objectively predetermined regardless of the way the system expands and operates. They are caused mainly by short circuits in transmission lines and transformers as well as by the other sudden failures of primary and secondary elements of EPS. Emergency conditions may result also from unexpected manifestations of bottlenecks in EPS or from such specific situations as subsynchronous resonance, etc.

Three main echelons can be distinguished in the emergency control systems of EPS. The task of the first one is localization and elimination of primary emergency disturbance to avoid undesirable development of the emergency situation. This problem can be solved by relay protection and those types of emergency control devices and systems of continuous control (for instance, those of excitation of synchronous machines) that are intended to maintain EPS stability.

However in bulk EPS the first echelon of emergency control system can not very often cope with its task and emergency process grows taking a cascade form and brings about severe consequences for EPS and consumers. The reasons of a typical contingency development into a cascade system emergency can be divided into three main groups: complex primary disturbances (multiple short circuits, natural phenomena, etc.), failures, wrong or insufficient actions of dispatching or operating personnel. Prevention of the cascade development of emergencies is a function of the second echelon of the emergency control system that comprises automatic termination of asynchronous run, automatic frequency load shedding, automatic limitation of increase and decrease of frequency and voltage.

Restoration of EPS plays an important role in minimizing the impacts of system emergency. In severe system emergencies of a cascade character the process of EPS restoration is not trivial [3, 9]. EPS restoration after a system emergency requires operation of some automatic devices (for synchronization, reclosing, etc.), but a key role is played by dispatcher. The means used in the EPS restoration can be called the third echelon of emergency control system.

4. GLOBAL TENDENCIES AND THEIR IMPACT ON DYNAMIC PROPERTIES OF THE SYSTEM

In connection with structural and functional changes in EPSs that are determined by the global tendencies in electric power industry it is necessary to analyze if (and which way) these changes will affect the emergency control system.

4.1 Globalization

Globalization of EPS (its integration into a powerful territorially expanded interconnected power system) leads to the following effects:

- Growing scale of EPS potentially raises the probability of system emergencies, including those particularly severe due to increasing variety of operating conditions, additional bottlenecks at the first stages of integration and potential lagging of emergency control system development, etc.; further expansion of the interconnection, decrease of non-homogeneity and strengthening of its electric network smoothes out the above negative factors;
- Natural damping in EPS strongly affects the character of transient processes and their intensity. At the same time in the extended interconnections there are cases of weakly damped low frequency electromechanical oscillations, generator swings in the peripheral sections of interconnection, etc. These situations are explained mainly by disadvantages of automatic voltage regulators of generators (non-adequate regulation, poor adjustment, etc.) and can be eliminated with time.

Thus, strengthening of the EPS integration may cause temporary problems with dynamic properties of systems that can later be eliminated with the development of the control system. At the same time a factor of potential increase in probability of system emergencies persists.

4.2 Liberalization

Influence of liberalization on dynamic properties of EPS is tied up to the following factors:

- A large number of subjects of relations results in different control criteria for the system as a whole and for its individual parts. This fact complicates the emergency control system; in the case of delay in development of this system it can react non-adequately to the emergency situation. It is interesting to note that the factor of different control criteria in liberalized EPS (but in wider understanding than emergency control only) is considered the primary reason of the system emergency in India's interconnection in January 2001 [10].
- There arises a contradiction between the commercial interests of energy companies and the need to provide EPS reliability, which can result in the system operation with lower stability margins.
- Operation of spot electricity market causes considerable changes in electric modes which lead to lower margins in ties and unexpected operating conditions. This can make the emergency control system operate inadequately.

Hence, liberalization complicates essentially the EPS emergency control system which increases the probability of its non-adequate operation due to its possible obsolescence, complicated adjustment and coordination, increase of probability of failures of individual elements, etc. Besides, operating conditions, in which emergencies may occur and emergency control system should operate, get more loaded and complicated. Finally, the emergency control principles change and also get complicated.

Liberalization, together with globalization, practically inevitably violates a principle of centralized emergency control. Namely, the problem of cascade development of emergency does not become a problem of the whole interconnection. Quite the reverse, the EPS with the cascade emergency should eliminate it on its own trying to rule out the negative impact on the other EPSs of the interconnection (to the point of emergency EPS isolation from the interconnection). Such principles of emergency control are realized, for example, in the west-European interconnection UCTE [11].

All these factors lead to a growing danger of EPS stability violations and undesirable cascade development of emergency processes

with heavy consequences for EPS and consumers.

4.3 Diversification

Diversification of energy units affects the dynamic properties of EPS by complicating the system control. However this factor is not critical and its impact can be smoothed out by development of emergency control system.

4.4 Decentralization

Distributed generation which is associated with increasing decentralization of power supply changes essentially the structural and functional characteristics of EPS in the following aspects:

- Location of distributed generation in the distribution network leads to unloading of the main grid; at the same time generation nears the consumers and hence the distance of electricity transmissions decreases; both these factors affect positively the dynamic properties of EPS.
- At the same time distributed generation is new elements of EPS with new dynamic characteristics and control capabilities. The problem of the impact of distributed generation on dynamic properties of EPS is at the initial stage of study and more or less definite conclusions and recommendations are premature so far.
- Distributed generation complicates the EPS emergency control system by sharing some of its functions with the distribution network. The complication itself may have negative sides, however this aspect of the problem has not been studied at all.

Thus, decentralization of electric power supply may have both positive and negative impacts on dynamic properties of EPS, capabilities and principles of emergency control, which requires special studies.

4.5 Modernization

Modernization (enhancement of efficiency of traditional energy technologies and creation of new highly efficient ones) in electricity generation does not change much the EPS dynamic properties. An exception exists only for the above problems, associated with distributed generation and updating control systems for modernized energy units.

An essentially more important aspect of modernization in the framework of the above is improvement of traditional controlled elements in electrical network and creation of new ones that radically increase controllability of the system as a whole. These elements include:

- Flexible AC Transmission Systems (FACTS) are the devices with regulated reactance that may practically immediately (under the influence of the quick-response thyristor control system) change in a wide range from capacitance to inductance. FACTS can be connected both in parallel and in series and allow fast change of the load flow and voltage levels in the network, increasing the margins of static and dynamic stability and level of oscillation damping. For the time being FACTS are quite expensive, but judging by the progress in the development of high-current thyristors they will hopefully become cheaper in the future. The FACTS technology is supposed to be used also for creation of transformers and switching equipment.
- Energy storage systems of different types - from storage batteries to super-conducting magnetic energy storage systems with a thyristor converter for connection with EPS and effective fast-response control system.
- DC-transmission lines and back-to-back stations. These rather conventional elements have been lately essentially updated which has resulted in radical improvement of their reliability and cost efficiency. With fast control systems of thyristor converters they noticeably increase stability and controllability of EPS.

5. CONCLUSION

The present-day energy tendencies require to adjust principles and methods of emergency control arrangement. The heaviest demands are placed by liberalization and globalization. The former causes plurality of control priorities (to take into account requirements of energy market participants), the latter necessitates coordination of Defense Plans of power interconnection partners. The growing size and complexity of power interconnections complicate their control. At the same time the risk of occurrence and

avalanche-like development of emergencies also increases.

Moreover, the above tendencies intensify purely technical problems, namely liberalization provokes great tension of load-flow conditions (with loading of lines at their transmission capability limit) and globalization causes creation of long-distance electric grids with relatively little-studied characteristics. Besides, development of distributed generation (as a great number of small power sources) favors appearance of scores of load-flow conditions differing in power flow directions, which considerably complicates adjustment of emergency control devices.

That is why emergency control plays more and more important part in prevention of emergencies, termination of their development and restoration of normal operation of EPS. Structural and functional changes in EPS in the context of global tendencies in electric power industry will result in change in the dynamic properties of the future EPS which will necessitate development of principles and systems of emergency control.

Using the conception of three functional levels (echelons) of emergency control as a basis, one can assess the trends) of their development as follows.

5.1 The first echelon

The principle tasks of the first echelon (devices aimed at localization and elimination of the primary disturbance and thus at prevention of emergency expansion) of the emergency control system in terms of structural and functional changes in EPS remain the same. The changes concern new element base and constructions with the use of digital systems and advanced information technologies. Complication of the network structure of EPS leads to development of the hierarchical centralized emergency control systems in which the low level represents the conventional automatic systems and the upper level plays a coordinating role and uses fast-operating models of EPS in different situations [4].

Nevertheless, the problem of efficient and reliable operation of systems of the first

echelon of the emergency control system remains urgent. It does require comprehensive studies that will probably lead to the problem of changes in emergency control principles of this level.

5.2 The second echelon

Despite potential essential structure and functional changes in the future EPS the main objective of the second echelon (complexes providing termination of cascading emergency processes and transition of EPS into stable post-emergency mode) of the emergency control systems will remain unchanged. However the principles of this subsystem operation may change considerably – primarily due to the effect of liberalization in EPS. It is noteworthy that all the existing coordinated defense plans relate to one independent EPS. It is unclear if the centralized emergency control subsystem of the second echelon can be combined with the interaction principles of many independent EPSs in the interconnection. Even less clear are the principles of such a subsystem effect in case of vertical disintegration of EPS on the generating (competing generating companies), network (natural monopoly) and market constituents. All this requires further studies.

In any case a new element base and modern information technologies are likely to be introduced into the second echelon to improve its adaptivity, reliability and efficiency of operation.

5.3 The third echelon

Structural and functional changes in EPS will not apparently change principally the structure and functions of the third echelon (principles and tools of EPS post-emergency restoration) of the emergency control system. Here we can expect further development of the most important elements of such a subsystem – advisors of dispatcher on EPS restoration that will be based on the advanced information technologies. In the most developed world countries this process is very intensive, however in Russia, unfortunately, very little attention is paid to development of advisors of dispatcher on EPS restoration.

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SOMMAIRE

Contrôle d'urgence est une partie integrante du contrôle d'operation des systèmes d'énergie électrique. La haute vitesse des processus évoluant dans les circonstances d'urgence exige l'automation maximale du contrôle d'urgence. Cet article-ci a pour sujet differents principes et la structure generalisée de l'organisation du contrôle d'urgence des systèmes d'énergie électrique. Il y a quelques tendances globales dans le developpement de l'industrie d'énergie électrique. Leur influence sur la conduite dynamique des systèmes d'énergie électrique est très importante du point de vue de l'efficacité du système du contrôle. Il faudrait prendre en consideration les effets positifs et negatifs de cetttes tendances globales pour comprendre les contraintes du developpement des systèmes d'énergie électrique et les exigences à