BLACK-OUT PREVENTION BY DYNAMIC SECURITY ASSESSMENT FOR LARGE ELECTRICAL POWER GRIDS

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Abstract

In the last 10 years the number of severe fault situations and black outs world wide is increasing. The classical static security assessment is used to monitor the system situation after contingencies, but is not able to take into account the complex dynamic behaviour of an electrical system together with the control of generators and grid equipment like switched capacitors or FACTS together with the protection reaction in unforeseeable situations after severe system faults. The paper describes a modern dynamic security assessment (DSA) system which allows handling predefined dynamic contingencies in real-time and intelligent proceeding and evaluation. The base of the system is the system simulation tool PSS™NETOMAC, which can simulate the dynamic behaviour of large electrical systems including control and protection. A contingency builder allows the user to define the interesting contingency scenarios. The events can be calculated in real time which means, that about 100 cases can be handled in about 5 minutes, depending on the system size. The DSA-system analyses the events using an intelligent and flexible criteria editor which gives the opportunity to select criteria for critical system time behaviour. The information about severe cases is available in a protocol for easy recalculation of critical cases in details with more parameters checked and monitored. The results can be used to monitor the overall situation of a system periodically. The paper will show the main structure of the DSA-system and the capability of handling real time contingency calculations in a large electrical system.

Keywords: Black-Outs, System Dynamics, Dynamic Security Assessment

Presenting Author's biography

Olaf Ruhle received his Dipl.-Ing. and his Ph. D. degree in electrical engineering from the Technical University of Berlin in 1990 and 1994 respectively. Since 1993 he is a member of Power Transmission and Distribution Group and the system planning department at Siemens in Erlangen, Germany. He is working as a Senior Consultant / Senior Product Manager on power system stability, dynamics of multimachine systems, control, optimization and identification problems in electrical power systems. He is responsible for the program system PSS™NETOMAC support, sale and training worldwide. He is visiting professor at several universities.

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1 Introduction

All over the world electrical systems are growing or will be interconnected to allow new economic objectives for operation. With open access to deregulated markets the power transfers are forcing the transmission systems to its limits. To achieve higher economic objectives the systems are again operated closer to their limits. As a result unexpected events, weak interconnections, high loading of lines and corridors or hidden protection failures may cause the systems to loose stability – possibly leading to catastrophic failures or black-outs. In the last years the numbers of black-outs and the negative consequences have been grown. Analyzing these catastrophes show that for years operating guidelines have been used based on off-line stability studies, which tend to be conservative for normal conditions and inaccurate for unexpected unusual events. Oscillations and dynamics can compromise grid reliability and poorly understood dynamic constraints can unnecessarily narrow system limits. The complexity of large electrical systems with different primary and secondary control mechanisms, operation with economic objectives, use of extremely fast acting FACTS devices and fast change of load flow and last but not least complex protection philosophies can not be represented using static security assessment. In addition electrical markets are changing from vertically integrated structures with centralized competence to competitive deregulated structures, where electrical market is economics driven and needs higher automatic security assessment (fig. 1).

In many cases a static security assessment can not achieve the necessary security under changing grid and generation conditions. The need of real time assessment of dynamic stability (DSA) was high-lighted by the black-outs 2003 in USA and Italy: The Italy black-out started with 6545 MW import to Italy. In less than 3 minutes cascading phenomena isolated the Italian system from Europe: loss of generation in Italy and insufficient load shedding drove the system to be black (fig. 2). The phenomena occurred in less than 3 minutes, but it has been proceeded by about 15 minutes within which the problem has evolved from a normal situation to an alert and then to an emergency state with a restoration time of abnormally 19 hours. A list of evolving factors has been collected from which the improved power system monitoring and preventive actions are the most important items.

Other factors which affect system security are significant changes in generation in deregulated markets. Combined cycle power plants and distributed generation reduce the controllability; wind farms located not related to load centers affect the system security through the changing wind availability.

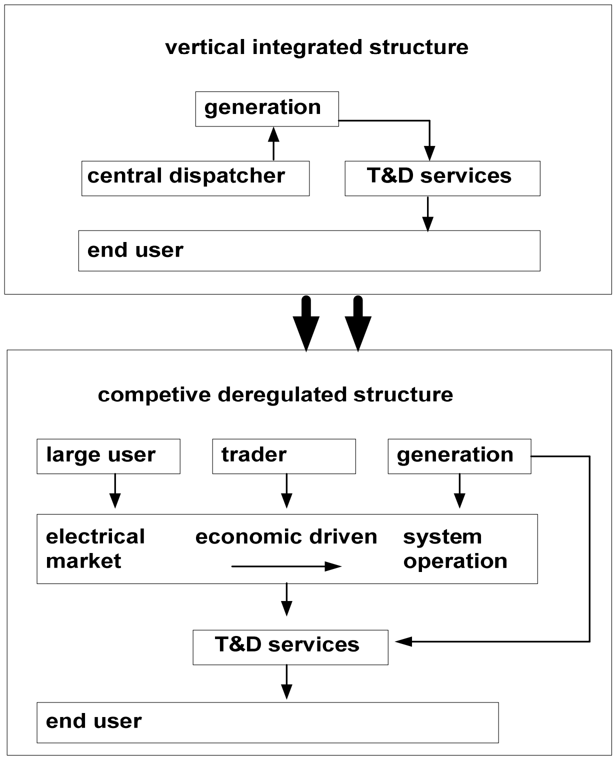

Fig. 1. Change of system structure in deregulated electric markets

Fig. 2. Black-out Sept. 28, 2003 in Italy

2 Security assessment and operations planning

At the planning stage systems are generally designed to meet or exceed previously specified criteria for voltage, frequency, stability or other adequate criteria. The target of system planning is to guarantee a secure transmission capacity subject to the established criteria by a suitable system design.

The objective of security assessment is to design and operate networks which will survive after unforeseen events. Several definitions for system security are in use, which provide reliability and security guidelines as "prevention of cascading outages when the bulk power supply is subjected to severe disturbances". The CIGRE definition is "power system security is the ability of the system to cope with incidents without the operator being compelled to suffer uncontrolled loss of load".

For security to be assured during operation it follows that operation must be consistent with network design philosophy and criteria. The original design criteria must apply to the main degraded topologies of the complete system. Inherent to this is the concept that the network topology changes in time due to unforeseen events and due to planned system changes like scheduled maintenance. The operation planning problem differs fundamentally from the system planning where the degraded topologies and criteria are known at any time and transmission capacity is the only remaining freedom in the system. The security limits provided to the system operator are power flow values which guarantee that a given topology is secure for every one of a list of contingencies. Individual transfer limits and the most restrictive limit, whether from steady state-, voltage-, or transient-stability consideration are the security limits.

There are various methodologies to define dynamic security limits like system stability calculations, sensitivity studies or security margin calculations, which optimize security limits in terms of various network parameters. Dynamic security has to be guaranteed in order to maintain the reliability and quality of service provided to the customer mainly consisting of continuity and constancy of voltage and frequency. Dangerous events such as short circuits, loss of equipment, loss of generation or sudden system change produce electromechanical transients. Control reaction and excitation of protection devices has to be considered. To take all these phenomena into account fast time domain simulation of the most severe contingencies is of essential importance. Fig. 3 shows the different operational states of a system. DSA task is to prove realistic contingencies during system operation not to drive the system from normal, secure operation to an emergency situation.

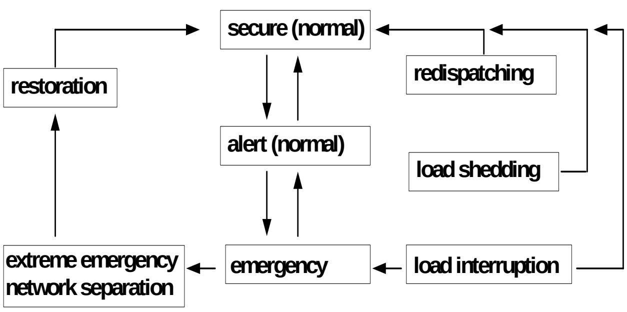

Fig. 3. Operating states of an electrical system and means to rebuild normal secure operation

The requirements for the system the DSA has to prove are different and depending on the system topology, generation (mix) and interconnection to other systems. However for practical purpose the requirements can be classified to be

- margins to thermal limits
- margins to loading limits
- stability
- margins to instability
- damping

These requirements can be expressed in concrete criteria like

- critical fault clearing time (generator stability)
- oscillation time (damping)
- out of step of generators, machine load angle (instability)

and

- loading of lines
- critical under/over voltages
- critical under/over frequencies
- angle differences between system parts

3 Structure of a DSA system

The structure of a DSA system allows to select different load flow (LF) situations and to build individual contingencies to be calculated in an automatic process. The contingencies are checked using user defined criteria. The process has the following structure shown in fig. 4:

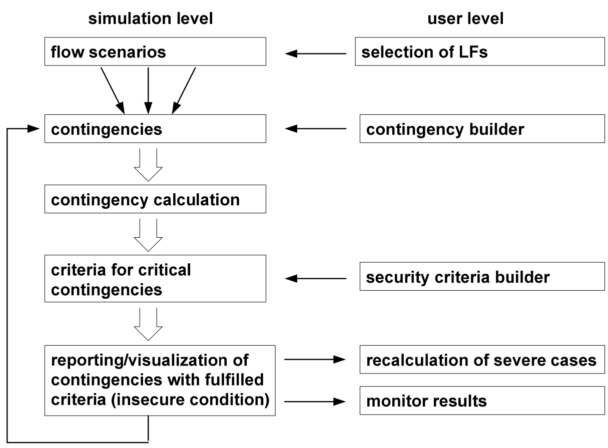

Fig. 4. Functional structure of the DSA system

On the simulation level load flow scenarios are available which the user can select. With a contingency builder the most sever contingencies can be selected to be calculated. The program checks the security criteria (stability, under-/over voltage,

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damping etc.) which have been defined by the user with the help of the security criteria builder. These criteria can be combined individually to define a suitable set of criteria which describe the limits of the system.

The DSA reports and documents the contingencies when the system limits are exceeded (generator instability, voltage below 80 %, angle between node 1 and node 2 larger 40°, etc.).

These cases can be recalculated very easily and all typical characteristics can be visualized to get a deeper view for the specialist. In parallel the critical contingencies can be monitored for the operator.

4 Dynamic security assessment using a modern simulation tool

Because of the individual character of an electrical system DSA has to be flexible to simulate all important system components representing the passive grid equipment (lines, cables, transformers, etc.) and the active switching or control elements (capacitor banks, FATS devices etc.) together with their control schemes. For cascading faults important protection devices have be activated in the simulation. All important contingencies have to be simulated using a simple contingencies building process. The decision criteria have to be flexible, users defined and are adapted to describe critical limits of the system. The DSA presented here was built based on a general simulation packages for electromechanical time simulations with a module to calculate small signal stability (Eigenvalue analysis), too.

The PSS™NETOMAC simulation system was selected to be the calculation base of the DSA [1, 2].

The time domain simulation allows the most accurate description of the system from transient stability to voltage collapse. The DSA provides the analysis of dozens of contingencies per minutes, based on the actual state of the system, and potential system failures. A typical demand per computer system is 10 load flow cases with about 20 main contingencies checked and reported in 10 minutes.

The program system used for the DSA allows this computation speed as the example in chapter V proves. In addition the use of Eigenvalue analysis allows to have a specific view on system interarea oscillation and damping, too [3, 4].

Fig. 5 depicts how the simulation tool is structured to be used as a DSA system importing data from the EMS and using user defined contingency and security criteria builder. The figure shows that preventive measure design and test can be incorporated in the DSA to support the operator finding countermeasures in case of critical system situations.

Fig. 6 shows the typical user interface to create the contingencies which shall be investigated. The contingency builder allows selecting grid elements, equipment and events and combination of them to write a scenario file. The security criteria builder defines the criteria and combination which the user has defined to be representative for the system security.

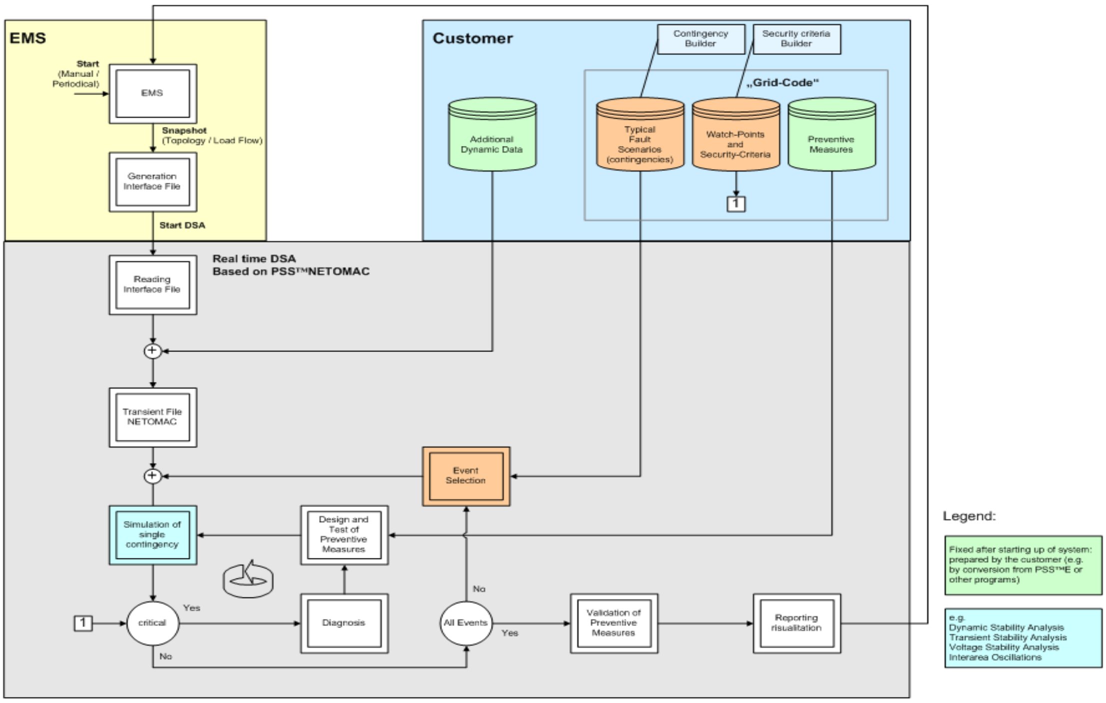

Fig. 5. Structure and data exchange of the PSS™NETOMAC based on DSA

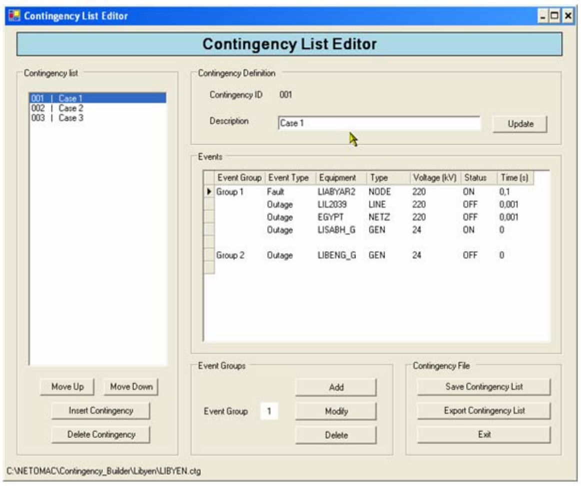

Fig. 6. Snapshot of the contingency builder

5 Example: the European interconnected system

The European UCTE system was used to demonstrate the performance of the DSA. The system today has an installed capacity of about 530 000 MW (2004) with a maximum load demand of about 386 000 MW (2004). A model of the system was built with 610 generators, 4400 nodes, 12000 grid branches, 1050 controllers. The system model was tested using measurements of the installed WAMS [5]. Fig. 7 shows the installed WAMS system (fig. 7a), the measured interarea oscillation after trip of a 300 MW power station (fig. 7b) and the simulation of the event for 15 seconds (fig. 7c). The results demonstrate that the model represents the overall electromechanical system behavior.

Fig. 8 shows the time behavior of the UCTE system and the extension of the system to the so called Mediterranean Ring which couples the systems between North Africa and Turkey to the UCTE system. Time steps of 10 ms are the limit to run the system under real time conditions. For the electromechanical behavior the accuracy with time steps of 20 – 50 ms is suitable (fig. 9).

Using the Eigenvalue mode of the system the interarea oscillations of the system can be easily monitored and the system shows how and which generators are involved in the oscillation (Fig. 10).

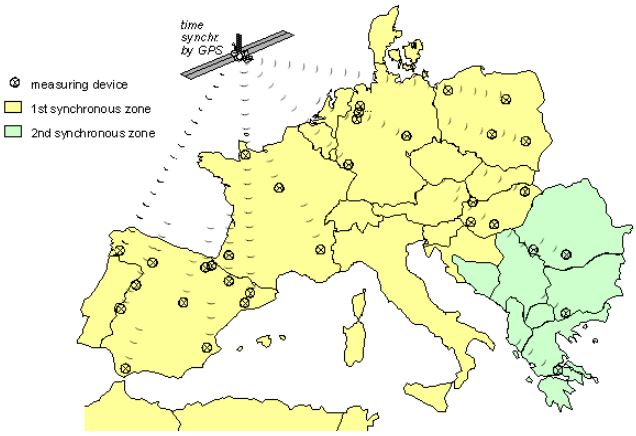

Fig. 7a. Installed WAMS

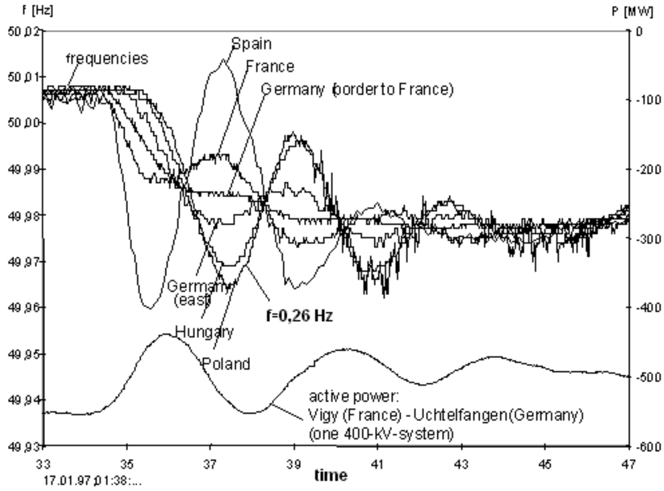

Fig. 7b. Measurement of a power oscillation after 300 MW trip

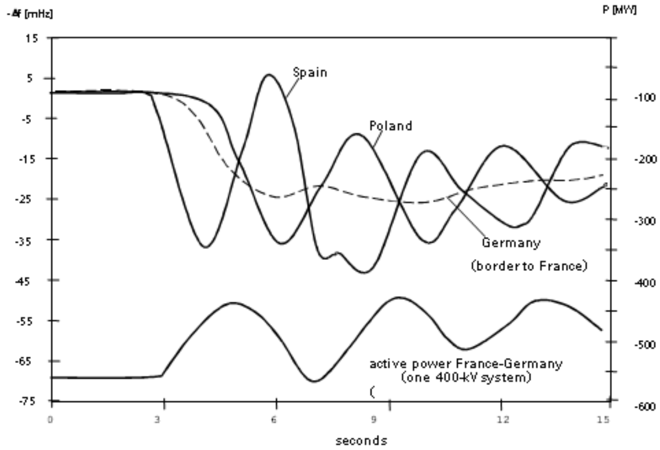

Fig. 7c. Simulation of a 300 MW trip

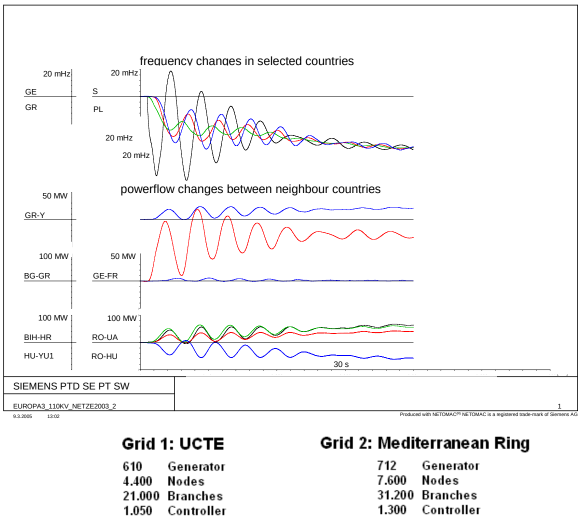

Fig. 8. Simulation of power oscillation after outage of 1000 MW generation in Spain in the UCTE system interconnected with the Mediterranean Ring

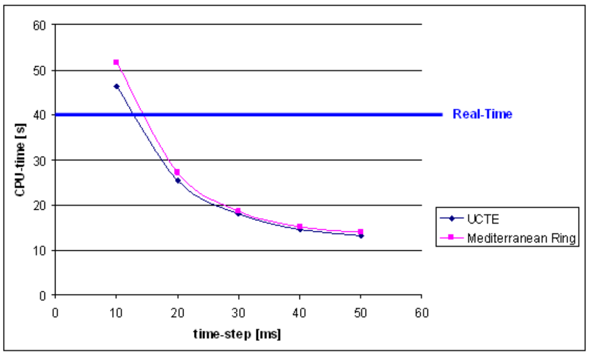

Fig. 9. Simulation results and computation time

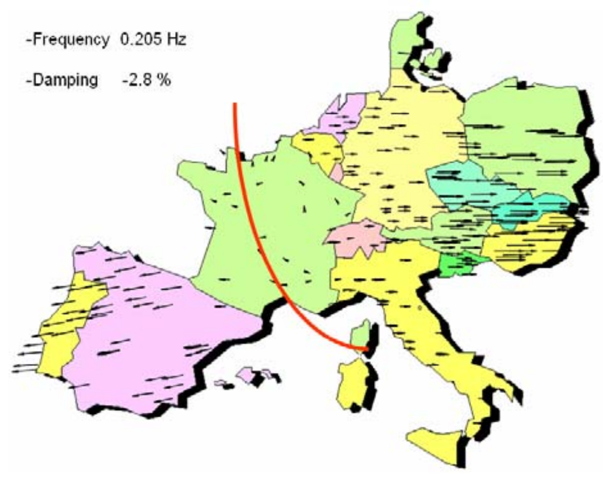

Fig. 10. Monitoring of geographical mode shape of an interarea oscillation in the UCTE system (Spain oscillates against Central Europe and the CENTREL Counties)

Because of the flexible change from time domain to frequency domain calculation remedial actions and preventive measures as defined in fig. 5 can be checked very fast. Fig. 11 depicts countermeasures at different generators to increase damping in the system, here shown in the time domain, but analyzed in the frequency domain by system eigenvectors and residues.

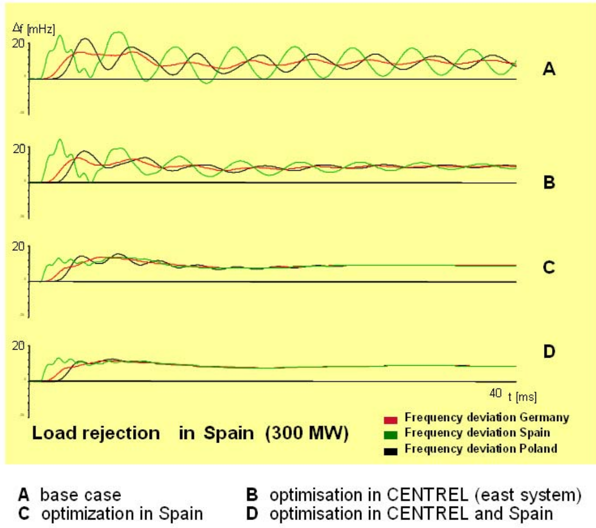

Fig. 11. Countermeasures to improve system stability and reduce interarea oscillation, checked by frequency deviation monitoring in different countries

6 Conclusion

The evolving nature of the power industry under changing conditions to economic driven deregulated markets has made on-line security assessment a critical function-essential component in ensuring reliability. The paper shows how a powerful simulation system can be used to built a system and user oriented DSA which includes contingency building, security criteria selection, computation and reporting/ visualization to support the operators to understand the complex structure of electrical system. The use of the contingency builder, a flexible criteria creator to identify critical contingencies and a flexible reporting allow the user to customize the DSA for the system where it will be used. The example of a very large electrical system proves the real time opportunities of the system.

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